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The User Innovation Paradigm: Impacts on Markets and Welfare

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Abstract. Innovation has traditionally been seen as the province of producers. However, theoretical and empirical research now shows that individual users—consumers—are also a major and increasingly important source of new product and service designs. In this paper, we build a microeconomic model of a market that incorporates demand-side innovation and competition. We explain the conditions under which firms find it beneficial to invest in supporting and harvesting users' innovations, and we show that social welfare rises when firms utilize this source of innovation. Our modeling also indicates reasons for policy interventions with respect to a mixed user and producer innovation economy. From the social welfare perspective, as the share of innovating users in a market increases, profit-maximizing firms tend to switch "too late" from a focus on internal research and development to a strategy of also supporting and harvesting user innovations. Underlying this inefficiency are externalities that the producer cannot capture. Overall, our results explain when and how the proliferation of innovating users leads to a superior division of innovative labor involving complementary investments by users and producers, both benefitting producers and increasing social welfare.

History: Accepted by Lee Fleming, entrepreneurship and innovation.

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Keywords: user innovation paradigm • user–producer interactions • social welfare • complementarities • division of innovative labor • externalities

1. Introduction and Overview

Innovation has traditionally been seen as the province of *producers* who invest in product and service development to sell their innovations. However, extensive theoretical and empirical research has now led to an understanding that *users* are also a major source of innovation development, where users are defined as entities that develop novel products and services for use rather than sale.

Over the last three decades, user innovation by individual citizens has moved from being considered an anomaly to being recognized as an activity conducted by many millions of users that results in the creation of many individually and commercially important new products and services (von Hippel 2005, Bogers et al. 2009, von Hippel et al. 2012). Further, it is now understood that the range of innovation opportunities viable for innovation by users, acting both individually and collaboratively, is increasing over time (Baldwin and von Hippel 2011).

Despite increased understanding of the importance of the phenomenon, innovation by users and particularly by end users—consumers—has not yet been incorporated into standard microeconomic thinking and modeling of markets for innovative products and services (Syam and Pazgal 2013). Our objective in this paper is to begin this major task. We first describe processes that occur within what we term the user and producer innovation "paradigms," and then we describe the four types of interactions between them. With this description in hand, we next analyze the impact of paradigm interactions in an analytical model of a market where both producers and users innovate, and we then develop and discuss theoretical, policy, and managerial implications.

In overview, we explain that consumer innovators have two linked attributes from the point of view of producers, one positive and one negative. On the positive side, they can develop new product designs of potential commercial value. On the negative side, their ability to self-provision can reduce the producer's market. Examples are legion: users develop and self-provision video game and software "mods" to commercial products they use, with some of these later being commercialized by vendors (Jeppesen and Frederiksen 2006). Users also develop and self-provision hardware products, such as "customized" cars and motorcycles, with producers later commercializing some of the features they develop (Harley-Davidson 2016).

In our model, we explore the interplay of two key variables. The first is the share of user innovators in a producer marketplace; i.e., users who can innovate, self-provide, and/or buy as they prefer. The second describes producers' choice between two archetypal modes of organizing for innovation: The first is the traditional mode in which producers invest in research and development (R&D) without paying much attention to user innovation. They view their R&D as "exhaustive" in the sense that it covers all the facets—from design to technology—that need to be addressed to serve the market. Thus, their R&D *substitutes* for any potential contributions from the user domain because even if the users innovate, firms have developed competing solutions internally. The second archetypal mode for producers to organize innovation involves a more "open" approach whereby they design their R&D to be *complementary* with user innovation activities. In this mode, firms take into account that users can innovate and seek to conduct in-house R&D activities that are complementary to user innovation.

Our major findings are three. First, we explore the optimal producer strategies—traditional versus open—and welfare effects associated with a rise in the proportion of innovating users in a market from near-zero to a higher fraction. We find that when the proportion of innovating users in a producer market is very low, profits are maximized by producers choosing the traditional, producer-centric mode of innovation, substituting for any innovative contributions the few user innovators could make and not investing in supporting them in any way. The added number of commercially valuable innovations users could produce is too low to justify the producer investments and the risk of information spillovers to additional users who could then also potentially choose to self-provision.

When the proportion of innovating users in a marketplace increases from low to moderate levels, it becomes increasingly attractive for producers to switch to the user-augmented mode of innovation that is based on user–producer complementarity, and to invest in providing innovating users with tools to support their efforts. At a tipping point identified via the model, the benefit in commercially valuable innovations spilled over from innovating users to producers makes this second strategy more profitable than an exclusive focus on commercially performed R&D. This is so even though a side effect of these investments is loss of potential market via increased self-provisioning capabilities and activities among innovating users.

As our second major finding, we show that as the proportion of innovating users in a market grows, firms generally switch "too late" to investing in supporting user innovation from the social welfare perspective. That is, social welfare would be better served if firms switched when the share of user innovators in the market is smaller than profit maximization would dictate. Underlying this inefficiency are externalities that the producer cannot capture, e.g., what we will describe as a "tinkering surplus" that accrues to users.

Third, we find that any government policies that have the effect of raising the productivity of innovating users encourage firms to switch to the user-augmented mode and do not reduce welfare. By contrast, government policies such as intellectual property rights and R&D subsidies that specifically support producer R&D increase the proclivity of producers to switch to an open innovation mode too late, or even encourage firms to switch back to the traditional producer-innovation mode and thereby may reduce welfare.

In net, the contributions of our paper are among the first to integrate the user and producer paradigms and their interactions in one modeling framework. In our microeconomic model, what is traditionally viewed as the demand side of the market becomes a source of innovative designs and products. We show how the interactions between the user and producer paradigms affect the creation and distribution of value in a market relative to the standard model of producer innovation only. The model leverages standard welfare economics with externalities to analytically capture and analyze the paradigm shift toward innovation by individual users. This approach produces results, such as the policy theorem (the third finding described just above), that are not straightforward based on standard welfare economics. It also yields novel testable predictions, e.g., about the level of producer investment in support of user innovation and about the relationship between the share of innovating users and producer profits. Finally, we identify tinkering surplus as a third component of social welfare in addition to profits and consumer surplus in markets with user innovation and self-provisioning.

Overall, our paper advances the concept of a division of labor in innovation between users and producers. We find that more labor shifted to users than producers would find optimal maximizes value creation in markets for innovation. If users' capabilities to innovate are expanding in many industries, as has been argued (Baldwin and von Hippel 2011), innovation tasks can and should increasingly be shifted to the demand side. To stay competitive, companies should carefully observe market trends, especially the share of potential user innovators, and be prepared to shift to the user-augmented mode of innovation.

The remainder of the paper is structured as follows: In Section 2 we describe what we term the user and producer innovation "paradigms" and the evidence for each. In Section 3 we describe four types of interactions between the user and producer paradigms and the evidence for these. In Section 4 we present a model to theorize the impact of user innovation on producer profits and social welfare. In Section 5 we discuss our findings and suggest implications for research, policy, and practice.

2. User and Producer Innovation Paradigms

In this section, we first provide some key definitions integral to the user and producer innovation paradigms. Then we describe and contrast the functioning of these two paradigms.

2.1. Key Definitions

A *single user innovator* is a single firm or individual that creates an innovation in order to use it. Examples are a single firm creating a process machine in order to use it, a surgeon creating a new medical device in order to use it, and an individual consumer creating a new piece of sporting equipment in order to use it (von Hippel 2005). In this paper, as was mentioned previously, we focus on user innovations by individuals only.

A *producer innovator* is a single firm or individual anticipating profiting from their designs by selling design information or products based on that "recipe" to others: by definition, they obtain no direct use-value from them. Examples of producer innovators are a firm or individual that patents an invention and licenses it to others and a firm that develops a new product or service to sell to its customers (von Hippel 2005, Baldwin and von Hippel 2011).

A *design* is a set of instructions that specify how to produce a novel product or service. These instructions can be thought of as a recipe for accomplishing the functional requirements of the design (Baldwin and Clark 2006, Baldwin and von Hippel 2011). In the case of products or services that themselves consist of information such as software, a design for an innovation can be virtually identical to the usable product itself. In the case of a physical product, the design recipe must be converted into a physical form before it can be used.

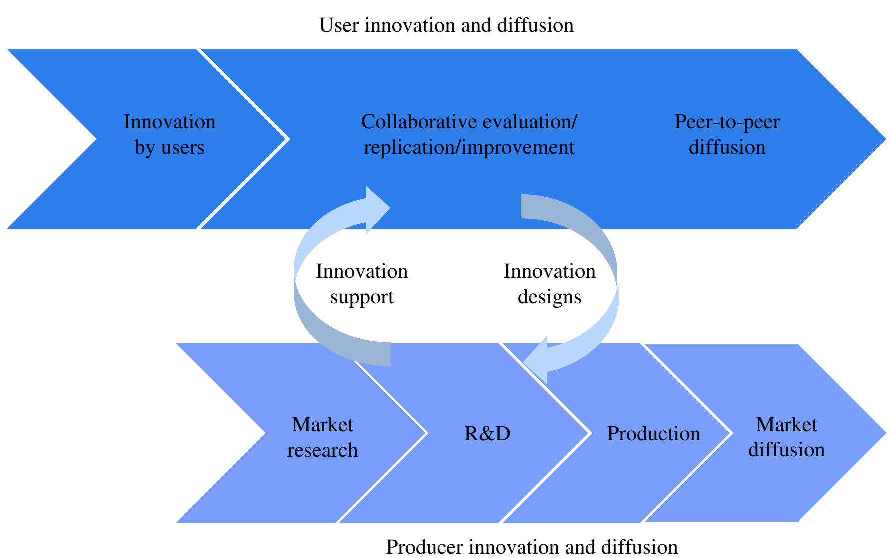
Free revealing occurs when an innovator gives up exclusive intellectual property rights to an innovation design, and all interested parties are given access to it—the information becomes a public good (Harhoff et al. 2003).

Self-provisioning occurs when a user makes a copy of a product or service for him- or herself independent of producers. Innovating users self-provision when they build a working copy of their innovation for their own use. Adopting users self-provision when they build a copy of a user innovation—or a producer product—for their own use.

2.2. The User Innovation Paradigm

The sequence of activities carried out by individual innovating users within the user innovation paradigm is represented by the broad arrow shown in the top half of Figure 1. It is important to emphasize that from left to right, it involves *user* activities only; no producers are involved. At the left side of the arrow, we see users developing new products and services to serve their own in-house needs. In any given innovation category, they often begin to innovate before producers do, as

Figure 1. (Color online) The User and Producer Innovation and Diffusion Paradigms



shown by the leftward positioning of the arrow. This is the case especially in instances where innovations offer functional novelty relative to existing products, because users are then in a better position to perceive an innovation opportunity before producers do. This is because of the sticky information they possess regarding their needs and context of use (von Hippel 2005). Users then may elect to freely reveal their innovation designs to any and all without compensation. As shown at the center of the arrow, when users in addition to the innovator have an interest in the innovation, this can trigger an open collaborative user innovation process (Baldwin and von Hippel 2011). Such processes involve contributors who share the work of developing a new product or service and who also reveal the outputs from their individual and collective design efforts openly for anyone to use. Free diffusion of innovation-related information to *non*-innovators via peer-to-peer transfer also occurs and is shown at the right end of the user innovation paradigm arrow.

The necessary condition underlying both user improvement activities and straight adoption activities by users peer to peer is that adopters have the capability to produce copies of a user-created innovative design for themselves. This capability is increasingly extant among individual users with respect to both software (where the "recipe" is the product) and hardware designs. With the proliferation of digital products and services and also the rise of three-dimensional printing and other modes of decentralized production, increasing numbers of innovating and noninnovating users will be able to self-provision without producer intermediation (Baldwin and von Hippel 2011).

Studies of national representative samples of individual citizens in five developed countries document the scale of the sequence of innovation activities described in the user innovation paradigm (see Table 1). These studies find that from 3.7% to 6.1% of citizens report having engaged in developing or modifying consumer products to better serve their own needs. This involves millions of citizens collectively investing billions of dollars annually in product development. With respect to scope, individual innovating users have been found to be active developers in all consumer product fields inquired about to date, ranging from sports, to clothing, to vehicles, to dwellings. Whereas innovations by consumers are developed for their own use, typically without consideration of their possible value to others, individuals' needs are often similar. For this reason, many of their innovations are, in fact, of value to others as well (de Jong et al. 2015).

It has been shown that about half of consumer innovators are willing to share their designs with others free of charge (de Jong et al. 2015, de Jong 2016). As shown in Table 1, only a small fraction of innovating consumers protect their designs by acquiring intellectual property. As can be seen in Table 2, empirical research on representative samples of user innovators finds that 44% of innovating individual users in Finland and 66% in Canada are willing to freely reveal their innovations to any and all without compensation. A further 40% in Finland and 22% in Canada are willing to reveal without charge but selectively (de Jong et al. 2015, de Jong 2016). Research on users participating in communities with a shared innovation interest, such as the design of sporting equipment or software, have found essentially 100% of those communities are willing to freely reveal their innovations (Franke and Shah 2003, Harhoff and Mayrhofer 2010).

2.3. The Producer Innovation Paradigm

The bottom broad arrow in Figure 1 is a schematic representation of the "linear" producer innovation paradigm. By our earlier definition, *producer innovators* invest in creating a new design to profit by selling instantiations of it; they obtain no direct use-value from it. In the sequence of activities shown in the producer innovation paradigm, producers begin their innovation process by studying user needs, and then they perform R&D as required to develop and produce novel products and services. On the right-hand side of the broad arrow, we see that they then diffuse what they have created via sales in the marketplace. Because producers would lose profits if other producers adopted their innovations without payment,

Table 1. National Survey Data on the Scale of Product Development by Users

	United Kingdom ($n = 1{,}173$)	United States ($n = 1{,}992$)	Japan ($n = 2{,}000$)
% consumer innovators in the population aged ≥ 18	6.1	5.2	3.7
Number of consumer innovators aged ≥ 18 (million)	2.9	16.0	4.7
Annual expenditures by average consumer innovator ($)	1,801	1,725	1,479
Estimated total expenditures[a] by consumer innovators on consumer products per year (billion)	$5.2	$20.2	$5.8
Estimated consumer product R&D expenditures funded by companies per year (billion)	$3.6	$62.0	$43.4
% consumer innovations protected by IP	2	9	0
% consumer innovations that diffuse to commercializers and/or peers	17	6.1	5

Note. Data sources include von Hippel et al. (2012) and Ogawa and Pongtanalert (2013, Table 4).
[a]Total expenditures include out-of-pocket expenditures and time investment evaluated at average wage rate for each nation.

Table 2. Innovators' Willingness to Freely Reveal Their Innovations

	Finland *Finland* ($n = 176$)	Canada *Canada* ($n = 539$)
Willingness to share "for free"		
Yes, with everyone	44%	66%
Yes, selectively (e.g., friends, relatives, business contacts, people in my network)	40%	22%
No	16%	12%

Note. Sources of data are de Jong et al. (2015) and de Jong (2016).

innovating producers generally do *not* freely reveal their innovation designs. Indeed, they often try to prevent design information spillovers via such means as secrecy and intellectual property rights.

The "producer innovation paradigm" is today deeply embedded in research, public policy, and governmental statistics. With respect to research, almost all academic work on innovation is based on improving our understanding of and management of producer innovation (Schumpeter 1943/2003, Bush 1945, Godin 2006, Aghion et al. 2013). With respect to public policy, the producer innovation mode is the central theoretical pillar that justifies public policies granting subsidies or intellectual property rights to producers (Penrose 1951, Teece 1986, Gallini and Scotchmer 2002).

3. Interactions Between User and Producer Innovation Modes

Drawing on academic literature, this section distinguishes four pure types of interaction between the user and producer innovation modes: As indicated by the transparent arrows in Figure 1, (1) producers may supply information, tools, and platforms that make user innovation and modification easier. (2) Via free or selectively free or compensated revealing, users may transfer innovative designs to incumbent or start-up producers. Further, innovative outputs diffusing peer to peer in the user paradigm, and via the marketplace in the producer paradigm, both (3) compete with and (4) complement each other. All four pure types of interaction will be explicated in Sections 3.1–3.4, and hybrids will be considered in Section 3.5.

3.1. Producer Support for User Innovation

When users innovate, or when producers wish them to do so, producers may want to invest to support them to increase their levels of activity and also to direct them toward design activities of potential commercial value to the producers. The empirical literature describes a plethora of such producer investments: producers may sponsor a user innovation community (West and Lakhani 2008, Bayus 2013) or a design contest (Füller 2010, Boudreau et al. 2011). They may also "open up" their product designs to make them easier for users to modify (MacCormack et al. 2006, Balka and Raasch 2014), or they may provide users with kits of tools to enable them to make their own designs more easily (von Hippel and Katz 2002, Franke and Piller 2004). Moreover, firms often engage in boundary spanning activities and invest the working time of employees in supporting innovating users (Henkel 2008, Colombo et al. 2013).

3.2. User Innovation Spillovers to Producers

In this case, the interaction between user and producer is the transfer of user-created innovative designs to the producer. Transfer is typically for free, but sometimes it may also involve a market transaction of buying or licensing a user design (Antorini et al. 2012, de Jong et al. 2015). Designs that producers find of commercial value are then supplied to the market at large. Evidence from a Finnish nationally representative survey of consumer innovators shows that 6% of innovation designs developed by consumers for their own use are adopted and commercialized by existing producers, and an additional 2% are commercialized by user-formed start-up ventures (de Jong et al. 2015).

The literature shows that user innovation spillovers can be exceedingly valuable to producer firms (Lilien et al. 2002, Smith and Shah 2013). In studies from several industries, the best user-generated solutions and product concepts have been found to be more novel and to offer higher customer benefit than the best producer-generated ones (Poetz and Schreier 2012), which translates into higher sales revenues and gross margins (Lilien et al. 2002, Nishikawa et al. 2013) and longer product life cycles (Nishikawa et al. 2013).

3.3. User-Complemented Markets

From Figure 1 we can see that the user and producer innovation and diffusion channels can operate independently, creating and diffusing innovative designs. In some cases, an innovation diffused for free by users *complements* one or more innovations diffused by producers, creating what we term a *user-complemented market*. The key characteristic of a user-complemented market is that one or more users self-provision complements to a product offered on the market by a producer. The distinction that matters here is self-supply and not the source of the innovative design being produced. A user may have invented the design himself, or adopted it from another user, with or without further modification, or even from a producer in the market for complements.

User-complemented markets can involve products that are separate from but complementary to producer products and/or can involve modifications or other complements built onto or into producer products or platforms. In either case, they are user-created complements that are diffused peer to peer. With respect to the former, consider that techniques for using products are useful or even essential complements to producer products, and they are often developed by users (Hyysalo 2009, Morlacchi and Nelson 2011, Hinsch et al. 2013). For example, whitewater kayakers develop and noncommercially diffuse novel kayaking techniques that are essential complements to whitewater kayaking equipment (Hienerth 2016). With respect to complements built into or onto producer products, consider software modifications and additions that complement the value of basic commercial software products in fields ranging from music software to computer gaming software (Jeppesen and Frederiksen 2006, Prügl and Schreier 2006, Boudreau and Jeppesen 2015).

The evidence for the widespread presence of user-complemented markets runs counter to the conventional assumption that only producers provide complements, although users may select and assemble them (Sanchez and Mahoney 1996, Schilling 2000, Jacobides 2005, Adner and Kapoor 2010, Baldwin 2010).

3.4. User-Contested Markets

Again referring to Figure 1, we can see that the user and producer innovation and diffusion channels can operate independently, creating and diffusing innovative designs. In some cases, an innovation diffused for free by users *substitutes for* one or more products diffused by producers, creating what we term a *user-contested market*. The key characteristic of a user-contested market is that one or more users via self-provisioning build for themselves substitutes to a product offered on the market by a producer. Recall that the factor that matters is user self-supply of a full or partial substitute for a commercial offering and not the source of the innovative design being self-provisioned. As illustration, the market for recreational sailboats is a user-contested one. Some sailors can and do build their own innovative or noninnovative boats rather than purchasing a boat supplied by a producer (Raasch et al. 2008).

Some dynamics underlying user-contested markets have been explored in the context of innovation and competition among "open source" and "closed source" software suppliers (Casadesus-Masanell and Ghemawat 2006, Sen 2007). According to this literature, "open source projects" supply their code for free; they do not behave strategically in competition with commercial substitutes. Users can choose to contribute to the supply of open source software code, to free ride on the effort of others, or to buy the producer software. Their choices are determined by heterogeneity in users' willingness to pay, development capabilities, adoption costs, and impatience for a solution meeting their needs. Conclusions of this literature are that open source projects can establish themselves as competitors to closed software producers; producers lose profit because of this competition; and consumers benefit from the existence of an open source alternative, unless it forces proprietary firms to exit the market (Kuan 2001, Baldwin and Clark 2006, Casadesus-Masanell and Ghemawat 2006, Lin 2008).

3.5. Hybrids

Note that to this point we have distinguished and explained four pure types of user–producer interactions. However, real-world interactions may well be hybrids of these. For instance, a pure case of user innovation spillovers occurs when a user creates a design and transfers it to a producer for commercialization without making a copy for in-house use (Füller 2010). A hybrid case of spillovers plus user-contested market would involve a user(s) making a copy(s) and also transferring innovation design information to a producer (e.g., de Jong and von Hippel 2009).

The very fact that real-world user–producer interactions are often hybrids is a source of complexity, requiring strategic decision making by producer firms with respect to balancing off multiple effects. For example, producer firms making decisions with respect to investing in user innovation support versus their own R&D must consider effects both with respect to user likelihood of developing complementary and with respect to substitute innovations. To improve our understanding of producer decision making and its consequences for user innovators, noninnovating users, and society at large, we next proceed to formalize these considerations in an analytical model.

4. Model Setup and Findings

In this section, we provide both needed model contextual "setup" information and related findings in combination.

4.1. User Types and Tinkering Surplus

We divide a producer's potential market into two types of users: innovating users and noninnovating users. *Innovating users* find it viable to develop and self-provision innovative designs related to the producer product, e.g., improvements, customizations, and complements. They can also viably self-provision home-made copies of the producer product itself and so can choose whether to buy the product from a firm or to make it themselves. *Noninnovating users* do not have a viable option of innovating. Their costs may be too high, for example, because they lack needed skills or access to tools, or because they have a high opportunity cost for their time. However, it is viable for noninnovating users to make copies and self-provision products based on designs developed by user innovators at some level of quality ranging from equal to innovating users down to zero.

The share of innovating users is σ, and we regard this share as exogenous and static; users cannot change their type. For simplicity, we normalize the size of the market to 1, so that σ and $1-\sigma$ are also the number of users of each respective type.

With respect to the utility users derive from innovating, we note that empirical research finds that innovating users derive utility *both* from using the innovation they have created and from innovation "process benefits" they gain from engaging in the innovation process itself, such as fun and learning (Lakhani and Wolf 2005, Franke et al. 2010, Raasch and von Hippel 2013). Users seek to maximize their utility from innovating, which we call h, by determining the optimal amount of resources, such as time, t, to devote to innovation projects:

$$\max_t h \equiv \chi + (\phi^{1-\alpha}/\alpha)x^{1-\alpha}t^{\alpha} + 1 - t. \tag{1}$$

In Equation (1), the parameter χ represents a user innovator's utility, net of all innovation-related costs, from go-it-alone innovation projects, i.e., when producers do nothing to support him. The second term of (1) represents the user innovator's additional utility when a firm conducts x projects to support his endeavors. Examples of such support are the development of design tools for users and gamification to make product design activities more enjoyable to users. The parameter $\alpha \in (0,1)$ captures whether innovating users' utility is mostly determined by the time they invest (high α) or by the extent of firm support (low α). The parameter $\phi > 0$ captures the productivity of this process. The last term, $1-t$, captures the value of the user innovator's remaining time that he can spend on other matters, when the total time he has available is normalized to 1 and he has decided to spend t on innovation projects.

We derive from (1) that the user's utility-maximizing time investment in innovation is $t = \phi x$, which yields utility $h = \chi + ((1-\alpha)/\alpha)\phi x + 1$. We call this expression capturing users' net benefit from innovating the *tinkering surplus* (TS), where TS is the aggregate net benefit that all users gain from innovating and self-provisioning. It consists of benefits from the use of the self-provisioned innovation, plus innovation process benefits, as mentioned above, minus costs. When the investment of firms in user innovation support is zero, innovating users still get their go-it-alone tinkering surplus; $h = \chi + 1 > 0$. If firms do invest ($x > 0$), TS increases as a function of the level of that investment.

4.2. Shared vs. Producer-Only Innovation

We decompose the value that all buyers derive from the producer product into two parts: value v that they derive from features and components that only the producer firm will develop and produce and value b that buyers derive from features and components that can be developed and produced by firms *and* users, jointly or in isolation.

Features that only producers will find viable to develop include those that offer limited value to many individual users. No individual user would find it viable to develop such a feature, but producers can aggregate demand across buyers and thereby recoup their investment (Baldwin and von Hippel 2011). Features in this category may include, e.g., product engineering for greater durability and ease of use, a more elaborate design, a manual to accompany the product, etc. By contrast, features b that both individual users (typically "lead users") and producers can viably develop require smaller investments, compensated for by larger benefits to individual user innovators. They provide high functional novelty and solve important, hitherto unmet user needs (von Hippel 2005). As the needs of lead users foreshadow demand in the market at large (cf. definition of lead user), noninnovating users, too, will predictably benefit from solutions to these problems with the passage of time.

We assume that all users tend to have more similar assessments of the features we call b that innovative users may get involved in developing than of the features v that the producer has to develop on its own. Capturing this idea of less heterogeneity with regard to b but simplifying our analysis, we assume that users differ only in their valuations of v ($v \sim \mathrm{U}[0,1]$), whereas they all like b to the same degree. In our model of innovation and production by users and producers, we focus on innovations of type b, following our assumption that producers are the only ones to invest in v. Innovations with regard to b are assumed to depend on two activities.

First, the volume of innovations of type b depends on the aggregate effort T exerted by all innovating users, to the extent that it is useful to the firm (e.g., net of redundancy). To streamline our analysis, we assume that the aggregate usable effort is simply proportional to the total efforts t of the σ innovating users; that is, $T = \gamma'\sigma t$, $\gamma' > 0$. (We could use more complex aggregations, allowing for increasing or diminishing returns to the number of innovating users, but our results would remain materially unchanged.) Assuming identical innovating users, and employing the optimal expression for t, $t = \phi x$, we obtain aggregate user effort

$$T = \gamma\sigma x,$$

where $\gamma = \gamma'\phi$ comprises any factor that raises the ability of the firms to take advantage of the productivity of the innovating users' efforts to improve b. As explained earlier, the firm can influence aggregate user effort T through x projects to develop tools and platforms that support and leverage innovating users. The projects affect the time t users want to spend on innovation projects, which then affects the value of the innovative product b via aggregate effort T.

Second, innovations of type b are a function of some commitment of resources Y carried out by the firm. To fix ideas, Y can be commercial R&D projects or any other product creation or development activity. We define

$$Y = \xi(1-s)y, \quad \xi \geq 0,$$

where y is the total number of innovation projects of the firm. The firm allocates a share s to projects that support innovating users (that is, $x = sy$), and the remainder, $(1-s)y$, goes to traditional commercial R&D projects (either in-house or external). Projects that support innovating users are of little commercial value, per se, but indirectly produce value by attracting more user innovation activities. The parameter ξ measures the productivity of the firm's commercial R&D.

Taking into account these two drivers of innovation—aggregate user effort T and producer R&D activity Y—let the value of the innovative product to users be

$$b = (T^{\beta} + Y^{\beta})^{1/\beta}, \quad \beta > 0,$$

which we can rewrite as

$$b = [\tau^{\beta} s^{\beta} + \xi^{\beta}(1-s)^{\beta}]^{1/\beta} y = \tilde{b} y,$$

where $\tau \equiv \gamma\sigma$ and $\tilde{b} \equiv [\tau^{\beta} s^{\beta} + \xi^{\beta}(1-s)^{\beta}]^{1/\beta}$ is the productivity of all the firm's y projects taken together.

4.3. User and Producer Innovation Activity as Substitutes or Complements

The parameter β plays an important role in our analysis. It captures two options that firms can choose from, each of which involves a distinct form of organizing tasks and resources for innovation. The first option is such that the efforts of innovating users, T, and those of the producer, Y, are substitutes. Take, for instance, the writing of new software code. Suppose that both the producer and users can work on each of two tasks: (1) novel functionality or (2) the creation of convenience-enhancing features such as "user-friendly" installation scripts. The more effort the producer spends on each of these tasks, the *lower* the innovation impact that users can make, and vice versa. *One effort tends to substitute for the other*. In our model, this situation is captured by $\beta > 1$, which implies that the marginal impact of T on b decreases as Y increases, and vice versa.

The second option, by contrast, structures R&D for complementarity between user and producer innovation activities. In our example, suppose that users write novel code and producers develop "convenience features." The more effort users put into coding, the *higher* the impact that producers can make, and vice versa. In our model, this situation is described by $0 < \beta < 1$, which implies that the marginal impact of T on b increases as Y increases, and vice versa. Research has shown that user innovators tend to focus on developing innovations providing novel functionality, and producers on developing innovations that increase product reliability and user convenience (Riggs and von Hippel 1994, Ogawa 1998). A good example in the software field is RedHat. That firm's commercial offerings are based on open source software code such as Linux and Apache software, developed by users, to which RedHat adds convenience features such as "easy installation" software scripts.

To streamline our analysis, we assume that each firm can pick its preferred innovation option but not the specific level of β. A fully endogenous β would add complexity without substantial new insight. In practice, its value will depend on the industry in question, the technologies available to the firm, and best practices for integrating innovating users in R&D.

4.4. Individual Market Demands of Innovating Users and Noninnovating Users

Next, we need to understand the demand for the producer product from noninnovating users and from innovating users given user contestability, user-created complements, and spillovers, i.e., the different types of interactions that we developed in Section 3.

Starting with innovating users, we expect that they will buy the product from a firm only if their consumer surplus is positive and exceeds their surplus from self-provisioning, i.e., if

$$v + b - p + h \geq \lambda b + h, \quad v \sim \mathrm{U}[0,1], 0 \leq \lambda \leq 1. \tag{2}$$

The term $v + b - p$ is the consumer surplus, where $v + b$ is our value decomposition of the producer product (cf. Section 4.2) and p is its price. In case of self-provisioning, a user innovator will not get utility v, which is provided by the firm only. Of utility b that all innovating users cocreate with the firm, he will get only the "walk-away value" λb that he can realize by learning from this cocreation process and trying to build features akin to b on his own. The quality $0 \leq \lambda \leq 1$ of his self-provisioned version of b will depend on several factors, such as the extent and format of information spillovers from the firm to the user innovator, his "absorptive capacity" for the spillovers, and his skills to build the information into a usable artifact. In the case of software programming, for instance, where the producer opens up his source code for users to codevelop, λ will be close to 1, if and as the essential design information required to replicate functionality b is fully revealed. In this example, if the producer shares only part of his source code, λ is depressed accordingly.

Finally, recall the user innovator's surplus h from her own innovation activities, including those extensions and customizations that the firm is not interested in. The user innovator is assumed to get this surplus h—the tinkering surplus—regardless of whether or not she buys the producer product.

Turning to noninnovating users, recall that they do not innovate; they simply buy a producer-provisioned product via the market or, to the extent that they are able, can elect to replicate a design developed and then shared peer to peer by a user innovator. Building on what we said earlier about v, b, and p as constituents of demand, we expect that noninnovating users will buy on the market if

$$v + b - p + \mu' h \geq \mu b + \mu' h, \quad 0 \leq \mu,\ \mu' \leq 1 \tag{3}$$

and self-provision otherwise.

The parameters μ and μ' in (3) capture the noninnovating users' ability to obtain knowledge of the innovating users' designs (which will depend on the innovating users' propensity to diffuse design information), to replicate them, and to benefit from them. Whereas μ' refers to a noninnovating user's ability to benefit from an individual user innovator whose design they adopt, μ captures their trickle-down benefits from what the user innovator has learned from the producer as well as other innovating users during the cocreation process of b. Of course, when the noninnovating users buy from the firms they enjoy b incorporated in the firms' product, whereas they enjoy μb when they obtain the product from the innovating users through peer-to-peer diffusion. We expect noninnovating users to have imperfect knowledge of the innovating users' designs, to be less skilled at self-provisioning them, and to benefit less from using them ($\mu \leq \lambda$ and $\mu' \leq 1$). With respect to imperfect knowledge and higher costs of self-provisioning, consider that innovating users may well regard careful design documentation for the benefit of potential adopters to be an unprofitable chore in the case of freely revealed designs (de Jong et al. 2015, von Hippel et al. 2014). With respect to lower levels of benefit, consider that the designs were developed to precisely suit the innovating users' individual tastes.

Finally, it is crucial to note the trade-off that our model implies for the producer: Firms benefit from learning from innovating users about how to make a better product b for both innovating and noninnovating customers; to that end they want to invest in x to involve users more extensively. At the same time, this comes at the cost of facilitating self-provisioning by both innovating and noninnovating users. As the producer invests in tools and tool kits, modularizes the product, or reveals design knowledge such as source code to facilitate user innovation, he also makes it easier for both innovating and noninnovating users to self-provision rather than buy. Our model assumes that the producer cannot entirely avoid this side effect of enhanced user contestability, even while choosing a mode of supporting user innovation that best serves his goals.

4.5. Profit Maximization by Firms

The aggregate demanded quantity of $1-\sigma$ noninnovating users and σ innovating users is

$$\begin{aligned} q &= (1-\sigma)(1-p+(1-\mu)b) + \sigma(1-p+(1-\lambda)b) \\ &= 1-p+\eta b, \quad \text{with } \eta \equiv (1-\mu)(1-\sigma)+(1-\lambda)\sigma. \end{aligned} \tag{4}$$

Solving for p, inverse demand is

$$p = 1 + \eta b - q. \tag{5}$$

With N symmetric firms in the market, aggregate demand is $q = \sum_{j=1}^{N} q_j$, and q/N is the demand faced by one firm. Firm profits Π_i are given by the number of units sold by firm i, q_i, times the profit margin, given by price p minus marginal cost of production φ, and minus the cost of y innovation projects:

$$\Pi_i = (p-\varphi) q_i - \kappa y^2, \quad \kappa > 0, \tag{6}$$

where we assume diminishing returns to running y projects.

To maximize profits, firms make several interrelated decisions in the following sequence: First, they decide on the organization of their R&D. Specifically, they pick one of two options available to them: the organization of R&D such that user and producer inputs, T and Y, are substitutes ($\beta > 1$) or the organization for complementarity ($0 < \beta < 1$). It will take firms longer to change their organizational structure and capabilities in R&D than to change the number of projects, which is why we model this as the first choice. Next, the firms pick their total number of R&D-related projects (y). Then they decide on the share of projects ($1-s$) to allocate to traditional producer R&D. The remainder of the projects, share s, will be devoted to user-innovation support and thus indirectly increase the flow of new product ideas available to the firm. Finally, firms decide on the quantity to produce and sell on the market (q_i).

We use backward induction to derive the producers' optimal decisions. In this section, we look at the optimal choices of q_i, s, and y, in this order. In Section 4.7, we will study the choice of innovation mode (β).

4.5.1. Choice of q_i. We take the derivative of (6) with regard to output quantity (q_i) and obtain the first-order condition (*foc*): $1 + \eta b - \varphi - \sum_{j=1}^{N} q_j - q_i = 0$. In symmetric equilibrium, this produces profit-maximizing quantity, price, and profits, respectively:

$$q_i = (1+\eta b - \varphi)/(N+1), \tag{7a}$$

$$p = (1+\eta b - \varphi)/(N+1) + \varphi, \tag{7b}$$

$$\Pi_i = (p-\varphi)^2 - \kappa y^2 = [(1+\eta b-\varphi)/(N+1)]^2 - \kappa y^2. \tag{7c}$$

4.5.2. Choice of s. To determine the share of the firms' projects aimed at supporting user innovation, s, we maximize $\tilde{b}$ yielding *foc* $\tau^\beta \beta s^{\beta-1} - \beta\xi^\beta(1-s)^{\beta-1} = 0$. To determine the optimal s, a case distinction is required. In the case of complementarity between user efforts and producer R&D, i.e., if $0 < \beta < 1$, the second-order condition (*soc*) is negative, which implies that there is an intermediate project allocation $0 < s < 1$ to user support that maximizes innovation output $\tilde{b}$ (specifically, $s = \tau^\theta/(\xi^\theta + \tau^\theta)$, with $\theta \equiv \beta/(1-\beta)$). As can be seen from the expression for τ, this optimal project share allocated to user innovation support increases in the share of innovating users in the market and their productivity in terms of commercially valuable ideas ($s_\sigma, s_\gamma > 0$, where from now on we use subscripts to denote derivatives), and decreases with the productivity of producer R&D ($s_\xi < 0$). In the case of substitution between user and producer innovation efforts, i.e., if $\beta > 1$, the *soc* is positive, which implies that the optimal allocation to user support, s, is either 0 or 1, depending on whether the productivity of the user contribution in $\tilde{b}$, that is τ, is greater or smaller than the productivity of the firm contribution, ξ.

4.5.3. Choice of y. The *foc* of (7c) with respect to y is $2(1 + \eta b - \varphi)\eta\tilde{b}/(N+1)^2 - 2\kappa y = 0$, which yields $y = (1-\varphi)z/[\kappa(N+1)^2 - z^2]$, where $z \equiv \eta\tilde{b}$. Note that the *soc* implies $\kappa(N+1)^2 - z^2 > 0$ such that the profit-maximizing investment y is always positive. It is also easy to see that y increases with z.

4.6. The Producer vs. User-Augmented Innovation Modes

From our findings from the previous section relating to the distribution of innovation projects by the firm (s), we see that there are two modes of innovating and that firms will want to choose between them. The first mode is characterized by $\beta > 1$ and $s = 0$. That is, in this mode firms choose to organize their R&D such that user and producer efforts are substitute inputs and then allocate their entire budget to their own commercial R&D efforts, not supporting user innovation activities in any way. We call this the *producer* (P) *innovation mode*. In this mode, firms ignore the innovating users and organize the creation of b solely around closed commercial R&D.

As a consequence of being closed, firms need not fear information spillovers to innovating users ($\lambda = 0$) and on to noninnovating users ($\mu = 0$). In the producer mode, therefore, the demands of the noninnovating users and the innovating users simplify to

$$v - p + b + \mu' h \geq \mu' h \tag{8}$$

and

$$v - p + b + h \geq h, \tag{8'}$$

respectively. At the same time, aggregate demand is (4), with $\eta = 1$ rather than $(1-\mu)(1-\sigma) + (1-\lambda)\sigma$.

The second innovation mode is characterized by the firm organizing its R&D for complementarity with user innovators ($0 < \beta < 1$) and then making a positive investment in user innovation support (optimal $s = \tau^\theta/(\xi^\theta + \tau^\theta) > 0$). We call this the *user-augmented* (U) *mode*. In this mode, firms actively leverage user-created spillovers for innovation and organize their R&D to exploit the complementarity between the two sources of innovation. Users contribute to raising the use value b of the product, which enhances the demand of both the noninnovating users and the innovating users. At the same time, firms' support of innovating users creates user contestability with regard to features b ($\lambda, \mu \geq 0$).

To summarize, the trade-off between the U versus P modes pivots on producers investing to facilitate user innovation and reap spillovers but, by this action, simultaneously and unavoidably boosting user self-provisioning to a degree that may be small or large.

4.7. Choice of Innovation Mode (β)

Continuing our earlier process of backward induction to understand outcomes in markets with innovating users, we now consider the very first producer decision, the choice of innovation mode. Our goal is to understand under what conditions a producer will prefer the producer mode over the user-augmented mode, or vice versa. Additionally, and importantly, we examine under what conditions the increasing prevalence of innovating users that we observe in many markets (cf. Baldwin and von Hippel 2011) renders user integration the profit-maximizing innovation strategy for producers.

Our first theorem below explains the choice of innovation mode by a producer firm. It establishes that, subject to two conditions, firms in markets with an increasing share of innovating users will find it in their own best interest to switch to the user-augmented mode. In switching, firms are aware that they are strengthening user contestability, but they also realize that, overall, this is more profitable than a closed innovation approach.

To find the profit-maximizing mode of innovation, it is convenient to rewrite expression (7c) for the profits of the firms as

$$\Pi = [(1 + zy - \varphi)/(N+1)]^2 - \kappa y^2. \tag{9}$$

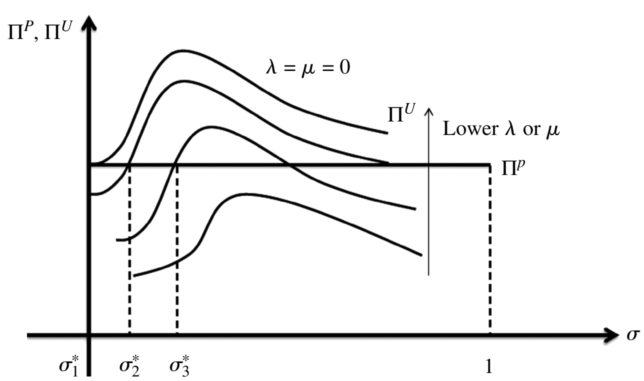
This expression captures profits in both the P and U modes, which differ only in z. (In particular, in the P mode, $z^P = \eta^P \tilde{b}^P$, with $\eta^P = 1$ and $\tilde{b}^P = \xi$; in the U mode, $z^U = \eta^U \tilde{b}^U$, with $\eta^U = (1-\mu)(1-\sigma) + (1-\lambda)\sigma$ and $\tilde{b} = (\xi^\theta + \tau^\theta)^{1/\theta}$.) Given the optimal choices of s and y, as derived in Section 4.5, this implies that $\Pi^P \geq \Pi^U$ if and only if $z^P \geq z^U$. In other words, we can check whether profits are higher in the P or U mode simply by checking whether z is higher in one or the other.

We find that when there are very few innovating users (σ close to zero), profits in the P mode are always higher than profits in the U mode ($\Pi^P > \Pi^U$). Thus, when there are very few innovating users, firms choose the P mode. The intuition is that from the firms' perspective, the user innovation spillovers that they can harvest, the upside of conducting projects x to support user innovation, are low. At the same time, the downside is considerable, as the information and tools that the firms supplies to the few innovating users can enable innovating users to develop a competing design and share it peer to peer, knocking off a good part of the producer's demand. The magnitude of this loss, and thus the downside of switching to the U mode, will depend on λ and μ, users' ability to self-provision b.

As the share of innovating users increases, profits stay the same in the P mode but increase in the U mode. (This is true under two conditions that we will explain below.) Firms will switch from the P to the U mode when the share of innovating users is larger than a threshold σ^*, beyond which $\Pi^U > \Pi^P$. This is illustrated in Figure 2.

The first condition relates to λ and μ. When user contestability is very weak (as indicated by the uppermost curve for which $\lambda = \mu = 0$), the producer can switch to the user-augmented mode free of risk. On this curve, when the share of innovating users is $\sigma = 0$, profits are equal for both modes of innovating. Then, as σ increases, the U mode outpaces the P mode in terms of firm profits. Intuitively, in this case firms benefit from the contribution of innovating users without risking the rise of self-provisioning and concomitant reduction of demand for the firms' product. When user contestability is more pronounced (as illustrated by the second and third curves), we see that the threshold σ^* at which the switch to the U mode can occur shifts to the right; that is, a higher share of innovating users in the market is needed for the producer to prefer the U mode. If spillovers λ or μ are very large, as illustrated by the bottom curve, a switch to the U mode will never be attractive to firms.

Figure 2. Firms' Profits Under the U and P Modes



The second necessary condition for the switch to occur is that the complementarity between user and producer efforts T and Y must be strong enough. Specifically, $\theta < 1$ (i.e., $0 < \beta < \frac{1}{2}$) must hold.[1] In other words, the contribution of the innovating users must be strong enough to trigger a significant increase in b that outweighs the negative impact on profits from intensified user contestability; otherwise, firms will prefer to stay in the producer mode.

Theorem (Choice of Mode). *If the innovative contribution of the innovating users is sizable* ($0 < \beta < \frac{1}{2}$) *and user contestability* (λ *and* μ) *is not too high, a critical mass of innovating users* ($\sigma > \sigma^*$) *makes profit-maximizing firms prefer the user-augmented mode of innovating to the producer mode.*

Proof. See Appendix A.

It should be noted that whereas firms may find it profitable to switch to the U mode at threshold σ^*, they may switch back again to the P mode at a high σ. (As illustrated in Figure 2, Π^U reaches a maximum and then declines, potentially even falling below the Π^P line.) This is particularly likely at higher levels of λ and μ (cf. Figure 2). The reason is the following: by our assumption of $\lambda \geq \mu$, innovating users are more capable than noninnovating users of self-provisioning; i.e., they exhibit a superior outside option and thus lower demand for the product of the firm. When the share of innovating users σ gets quite large, this not only means extensive user innovation spillovers to firms but also implies that the share of noninnovating users—those who benefit the most from these spillovers by getting to buy a superior product—is small. Having many innovating users implies having low demand, particularly if λ is large. This detracts from the attractiveness of the U mode and may make firms prefer to switch back to the P mode where they can better capture demand. We will leave this issue for future research to investigate in more detail, since our core objective is to understand the initial switch from the producer mode to the user-augmented mode when the prevalence of innovating users increases.

4.8. Welfare and Policy

In this final section, we consider the welfare implications of firms choosing either to "go it alone" in the producer mode of innovating or to integrate user inputs in the user-augmented mode. We need to understand whether firms' choice of mode is efficient from a societal perspective and, if not, whether policy is likely to improve economic outcomes.

Calculations of social welfare that include user innovation are different from the standard mode of calculating welfare. Conventionally, social welfare is calculated as profits (PS) plus consumer surplus (CS). When innovating users develop and build a new product for their own use, welfare calculations must be modified to include their full costs and benefits. In particular, we need to take into account their tinkering surplus TS, which is the aggregate net benefit that all users gain from self-provisioning, if they choose to do so. To give an example, if a user self-provisions a newly designed product at a cost of 10 dollars and receives a monetized use value of 30 dollars, her tinkering surplus equals 20 dollars. Recall that benefits to tinkering can also accrue in the form of process value (Franke and Schreier 2010, Raasch and von Hippel 2013), e.g., enjoyment of or learning from the innovation process itself, or social status in the user community. Our model is agnostic to the composition of these benefits. It only presumes them not to be profit based, in line with the definition of a user innovator. We will consider generalizations of this aspect in the Discussion section.

Incorporating these considerations, then, welfare in markets containing both user and producer innovators should be computed as

$$W = PS + CS + TS, \tag{10}$$

where PS and CS are the standard producer, and consumer surplus and TS are the tinkering surplus. How significant is the omission of the tinkering surplus in conventional analyses? The answer depends on the extent of user self-provisioning in a market. If many users self-provision (as is common across an increasing range of markets, especially markets for digital products; cf. Baldwin and von Hippel 2011), the omission can be substantial. In some cases, it may dwarf traditional components of welfare.

In our model, the tinkering surplus for a user innovator equals h, whereas for noninnovating users, it is $\mu' h$, which stems from their ability to tap into peer-to-peer diffusion from the innovating users. Computing the components of welfare as they accrue to producers (aggregate profits, PS), noninnovating users (consumer surplus, CS^{nui} plus tinkering surplus TS^{nui}), and innovating users (CS^{ui} plus tinkering surplus, TS^{ui}), we have

$$PS = N\Pi,$$
$$CS^{nui} + TS^{nui} = (1-\sigma)[(1-p+(1-\mu)b)^2/2 + \mu b + \mu' h],$$
$$CS^{ui} + TS^{ui} = \sigma[(1-p+(1-\lambda)b)^2/2 + \lambda b + h].$$

The first term is the aggregate profit of all the producers. The second term is the aggregate surplus of all noninnovating users, calculated from

$$(1-\sigma)\left[\int_{p-(1-\mu)b}^{1} (v-p+b+\mu' h)\,dv + \int_{0}^{p-(1-\mu)b} (\mu b + \mu' h)\,dv\right].$$

The third term derives from

$$\sigma\left[\int_{p-(1-\lambda)b}^{1} [v-p+b+h]\,dv + \int_{0}^{p-(1-\lambda)b} (\lambda b + h)\,dv\right].$$

These expressions will differ, depending on whether the U mode or the P mode is being chosen by firms.

Our analysis of welfare produces two main results that we summarize in two theorems. The first theorem states that, given our condition $0 < \beta < \frac{1}{2}$, higher firm profits in the U mode imply higher welfare in the U mode, but the reverse is not true. That is, whenever firms' profits are higher in the U mode, welfare is aligned; by contrast, when firms' profits are higher in the P mode, welfare may not be aligned. Specifically, there are levels of σ, the share of innovating users in a market, such that profits are higher in the P mode but welfare is higher in the U mode. As a result, to the extent that the decision to switch belongs to the producers, as we modeled it, producers will remain in the P mode even though the share of innovating users is substantial and social welfare would be better served in the U mode. The reason is that firms do not internalize the key externalities of our model—that is, the increase in tinkering surplus (h) accruing to users because of firms' investment in user support (x) and also facilitation of self-provisioning that firms bestow on innovating users (λb) and, subsequently, noninnovating users (μb) even if they do not buy the product.

Theorem (Welfare)**.** *Under the conditions of the choice-of-mode theorem, if firms' profits are higher in the user-augmented mode, so is welfare, but the reverse is not true.*

Proof. See Appendix B.

Our second result regards policy. We show that policies that increase the productivity of innovating users *can never reduce welfare*, provided that the costs of such policies do not outweigh their benefits. By contrast, policies that increase the productivity of R&D within firms *may reduce welfare*.

Examples of policies that raise the productivity of innovating users, γ, are subsidized access to design tools and maker-spaces. If innovating users become more productive, both profits and welfare rise under the U mode but not under the P mode, which, after all, does not leverage users' productivity. As firms' profits in the U mode increase, they may come to exceed profits in the P mode. We know from the previous theorem that if profits are higher in the U mode, welfare is also higher.

Policies that increase the productivity of producer R&D, ξ, include R&D subsidies and tax exemptions as well as publicly funded applied R&D. Increases in firms' research productivity ξ raise profits in both the P and the U modes. We show that, unless complementarity between user and producer efforts is high, increases in ξ induce a larger increase in profits in the P mode than in the U mode.[2] This means that policies that support traditional producer R&D may induce a switch back to the P mode. Since welfare is sometimes lower in the P mode even while firms prefer it, increases in ξ may render the P mode more attractive to the firms in spite of the fact that welfare is higher in the U mode. In other words, such increases may induce a switch to the P mode even though welfare is higher in the U mode, or they may prevent a welfare-increasing switch to the U mode.

To summarize, policies that support producer innovation productivity ξ may reduce welfare. The mechanism is that such policies encourage firms to adopt a closed producer innovation mode, whereas welfare may be higher in an open user-augmented mode. By contrast, policies that support the productivity of the innovating users can never reduce welfare. This is because they can only encourage a switch to the U mode, and this is never welfare reducing because whenever firms prefer the U mode welfare is higher in this mode.

Theorem (Policy). *Under the conditions of the choice-of-mode theorem, policies that raise the productivity of innovating users, γ, encourage firms to adopt the user-augmented mode and can never reduce welfare. By contrast, if the complementarity between user and producer innovation activities, T and Y, is weak ($\beta > \beta^*$, with $\beta^* < 1/2$), policies that raise firms' research productivity, ξ, encourage firms to adopt the producer innovation mode, which may reduce welfare.*

Proof. See Appendix C.

5. Discussion

In this paper we analyzed the effects of user innovation by consumers on standard outcomes in markets for innovation. Our special focus was on understanding the implications of the increasing prevalence of innovating users (σ increasing from a low level), as found in many markets.

Our principal findings were three. First, as the share of innovating users in a market increases beyond a certain threshold, firms' profit-maximizing strategy is to switch from the traditional producer-only innovation approach to an innovation mode that harnesses user innovators. Subject to two intuitive conditions relating to the innovative and competitive impact of user activities, welfare is higher in this user-augmented mode than in traditional producer-only innovation mode. All of the constituencies—producers, innovating users, and noninnovating users—benefit.

Second, any firm that elects to switch to integrating innovating users definitely augments social welfare, but firms generally switch too late. Thus, markets containing both user and producer innovators tend to fall short of their theoretical optimum in terms of value creation because producers are too slow, from a social welfare perspective, to embrace user innovation. Thus, producers' optimal R&D strategies yield a suboptimal division of innovative labor between users and producers at the societal level. Underlying this inefficiency are externalities that the producer cannot capture, e.g., the tinkering surplus that accrues to users, a novel component of social welfare.

Third, policies that raise the productivity of innovating users encourage firms to switch to the user-augmented mode and can never reduce welfare. By contrast, policies that raise firms' research productivity encourage firms to switch back to the traditional producer-innovation mode and thereby may reduce welfare.

5.1. Assumptions, Robustness, and Generalizability of Findings

Our model rests on several assumptions that can be usefully investigated via further research.

First, as we mentioned at the start of the paper, innovating users are defined as individuals or firms developing innovations to use rather than sell. In this paper, we have focused on individual consumer innovators only. We have done this to highlight the contestable nature of their demand and to emphasize that contestability can occur in markets for consumer goods. However, follow-on research could develop a similar model focused on or including user firms creating, for example, process innovations for their own use rather than for sale.

Second, we note that there are fields and markets in which some types of innovations originate only from innovating users—a situation with $s = 1$ in terms of our model. This is often the case, for example, with respect to the development of specialized techniques. Producers often find it impossible to profitably develop and market unprotectable techniques, and they tend to leave that vital arena entirely or almost entirely to users (Hienerth 2016). In this paper we explored the importance of user innovation in markets that include producer innovation as well. However, further work could explore the nature of markets characterized by user innovation only.

Third, for simplicity, our model assumed that all innovating users will be able to benefit from a producer's investment in user innovation support and that the producer will be able to observe the efforts of all innovating users and be able to reap any valuable spillovers. This is clearly not the case in practice—users will be differentially affected, and producers will not be able to observe or capture all spillovers generated by users. However, the same modeling logic and the same findings apply if our assumptions are true only for a subset of users.

Fourth, we assume that producers can choose the level of investment in support of innovating users that will maximize their profits. In the real world, users are independent actors who often have power to "push back" against producer plans and actions. They also can initiate user innovation activities in ways that producers do not expect. An example of investment in supporting user innovation not going according to producers' profit-maximizing plans is the case of Xara, a proprietary software company. In 2006, Xara invested in opening a large percentage of the source code of Xara Xtreme, a vector graphics package, as a way to invite user innovation. However, Xara did *not* open a small, commercially critical part of the source code. This omission caused a boycott among user programmers, and in the end, Xara yielded and opened more of the code than it would have preferred absent pressure from innovating users (Willis 2007).

It would be valuable and interesting for follow-on research to address situations such as the above. Whereas in this paper we assumed that producers decide unilaterally to what extent they want to support and complement user innovation activities, we could think of a game in which innovating users can possess the power to determine the extent of user support, s, and potentially even the degree of complementarity, β. We expect that, in such a game, when the power to make both decisions lies with innovating users, they will pick higher levels of *user support* and *complementarity* than producers would. Unless users pick very high levels of s, this should lower producer profit but increase welfare overall. Future research could further explore this and also consider situations in which the decision power with regard to s and β is distributed between innovating users and producers.

Fifth, it is noteworthy that user innovators in our model receive no remuneration from producer firms. In the real world, successful user innovators sometimes receive payments for valuable contributions (such is the case with Lego and many app stores). Still, as a nationally representative survey in Finland shows, innovating users typically do freely reveal their innovations; our assumption of no payment is based on that situation (de Jong et al. 2015). In a different model, our variable x could be seen as the cost of user royalties to the firm, and implications for market outcomes could be explored.

Sixth, we have modeled producer support of user innovation as *increasing* the amount of time (or resources more generally) that users wish to spend on activities that benefit producers. Gamification of contributions and the setting up of a user community were examples in point. It is also conceivable, however, that producer support, e.g., in the form of better tools, will enable users to *save time* while innovating. Such kinds of producer support could attract additional users to contribute, i.e., those who were previously noninnovators. This would endogenize the share of user innovators, σ, in a market, which we have taken to be exogenous in our model. It would be interesting for future research to explore the outcomes of this extended model, especially with regard to the optimal choice of producer strategy β.

Finally, our model treated all producers symmetrically, having all of them choose either a user-substituting or a user-complementing innovation strategy. Future research can usefully generalize from this limiting assumption. In the real world, we observe the coexistence of producers of both types. A key reason, we think, is that reorganizing and restructuring R&D to exploit user-created innovation spillovers can be quite costly. Established firms with a legacy of producer-centric innovation will, therefore, be hesitant to switch, whereas new entrants without a commitment to the traditional model will likely find it economically more viable to choose the user-augmented innovation mode. Such constraints and switching costs could usefully be analyzed regarding their effects on strategic heterogeneity and firm- and market-level outcomes. For instance, in markets with a growing share of user innovators, we should observe that new entrants and incumbents that are more flexible in organizing their R&D are more profitable.

5.2. Implications for Theory

It has been argued, on the basis of theoretical and empirical literature on user innovation, that we are in the middle of a paradigm shift. User innovation has moved from being considered an anomaly to being recognized as a new paradigm that challenges and extends our traditional view of innovation (von Hippel 2005, Baldwin and von Hippel 2011). Both theory building and empirical research are needed to marry the two paradigms and build a new and consistent structure. Our general objective in this paper has been to contribute to this major task. More specifically, this paper contributes to theory building in several important ways.

Our paper leverages standard welfare economics with externalities to analytically capture and analyze the paradigm shift in innovation toward user and open innovation. We explore the nature of these externalities and find they have strategic implications: companies can raise profits by producing more externalities, even though they cannot capture them in full. Our model also produces results, such as the policy theorem, which are not straightforward based on standard welfare economics. It yields novel testable predictions, e.g., about the level of producer investment in support of user innovation and about the relationship between the share of innovating users and producer profits. Future research should assess these predictions empirically and identify additional contingency factors.

While deriving these insights, we found that conventional concepts were not sufficient for the analysis of markets containing innovating users. Conventional microeconomics does not conceive of individual consumers as a source of innovation and production. Our distinction of four pure types of user–producer interactions in innovation translates central aspects of the richness of real-world user–producer phenomena into a language that supports strategic analysis. We developed new concepts such as user-contested demand and tinkering surplus. In markets with user innovation and self-provisioning, tinkering surplus constitutes a third component of social welfare, next to profits and consumer surplus. Future studies can adopt and further develop these concepts to analyze firm strategizing and outcomes in markets where users are a major source of innovation and atomistic demand-side production.

Overall, our paper advances the concept of a division of labor in innovation between users and producers. We find that more labor shifted to users than producers would find optimal maximizes value creation in markets for innovation. If users' capabilities to innovate are expanding in many industries, as has been argued (Baldwin and von Hippel 2011), innovation tasks can and should increasingly be shifted to the demand side. Our findings also elucidate the boundaries for producers to invest in such a division of innovative labor with users. Its viability from the producer's perspective is partly exogenous, determined by technological conditions as well as the characteristics of innovating users in the market, and partly endogenous to the producer's own decision making. Through their own investment in specialization and complementarity with users, producers can, and may, find it in their own best interest to partly outsource innovation to users.

5.3. Implications for Policy

It is increasingly clear that the world significantly contains user innovation as well as producer innovation. We have shown that, in such a world, synergies with users yield a superior outcome from a welfare point of view. This now becomes a clear opportunity compared to the traditional producer-centric innovation world. There is reason, we argue, to review existing policies that assume producer innovation only and to develop new innovation policies that incorporate an understanding of both user and producer innovation.

Our model tells us that five aspects particularly require new policy measures. First, we have found that producers choose R&D strategies that are too conservative, from a welfare point of view, with insufficient specialization and complementarity with innovating users (choice of β in our model). The reason is that part of the value generated by their investment slips to users in the form of tinkering surplus and higher consumer surplus (two externalities). New policy measures can be designed to address these failures. We showed that such policy measures could never reduce welfare (provided they are effective) and would often increase it.

Second, policy measures supporting firm investment should be designed to distinguish carefully between investments that complement and substitute for user innovation activities. They should favor a division of labor between users and producers and seek to support users and producers each in what they do best. Our model shows that public incentives for corporate R&D can *reduce* welfare if they cause firms to be less open to innovating users. Such policies can crowd out firm support of user innovation and keep firms in the producer-only innovation mode.

Third, for historical reasons, producers are likely to mostly possess R&D capabilities and beliefs (β in our model) that support go-it-alone innovation programs rather than programs designed to complement user innovation such as user tool kits and employment of personnel who know how to effectively interact with innovating users. This raises the question whether firms would quickly switch to complementary technologies as innovating users start populating their markets or could be stuck in a substitution equilibrium. Our model shows that the share of innovating users in a market and their productivity from the producers perspective have to be significant for producers to change their R&D strategy and begin to collaborate with innovative users. If firms are stuck in an inferior equilibrium, temporary policy measures to reduce producers' switching costs to the welfare-superior strategy of complementing user innovation could be valuable.

Fourth, our findings suggest that policy measures directed at elevating the share of innovating users (σ in our model) will increase welfare even further. This is true until the welfare-maximizing share of innovating users in the market is reached (which, as we show, is clearly greater than 0): if a market has too few or too many, either it does not have enough production of valuable spillovers or does not have enough noninnovating users that benefit from them, and thus welfare is not optimized. In essence, in a world with synergistic investments of firms and users, you need both innovating users and noninnovating users who benefit from their efforts to maximize welfare. Although everyone, including producers, would gain from measures that turn noninnovating users into innovating users up to the levels described above, producers may nonetheless not undertake such measures on their own. The types of investments required often have the character of investment in a public good, which typically results in private underinvestment. They involve education, easy access to cheap design creation, sharing and production technologies, and the promotion of a "maker culture" (Baldwin and von Hippel 2011).

Finally, our findings emphasize that the impact of users on market outcomes hinge on users having access to innovation design and self-production technologies that are economically viable from their perspective. This brings rapidly improving user production capabilities into the limelight of future research and policy. Whereas the extant literature investigates the antecedents of user design creation in some detail, user self-provisioning has received much less attention (cf. Kleer and Piller 2013). Our analysis highlights that the creation of innovative designs is not sufficient for the existence of user-contested and user-complemented markets; self-provisioning is also required.

5.4. Implications for Producer Firms

As noted earlier, the range of innovation opportunities where single and collaborative user innovation is viable is steadily increasing (Baldwin and von Hippel 2011). This means that the user contestability of many markets will increase, as will users' ability to create design spillovers and complements to producer products.

Our findings imply that, because of these technological and societal shifts, producers should carefully observe market trends to understand if or when their markets will reach the tipping point beyond which the user-augmented innovation mode is their profit-maximizing strategy. Recall that our findings show that when the share of user innovators in a market reaches a certain threshold, producers increase their profits by leveraging user innovators, as long as the share of users contesting the producer market does not get very high and the contestability, λ in our model, does not get too strong. The switch from a producer-centric, user-substituting R&D strategy to user-complementing R&D involves a major reorganization of R&D functions and the development of new capabilities that will derive benefits from valuable user-created spillovers and reduce losses from user self-provisioning of the firm's product. Producers are well advised to choose their approach carefully at any given time and to prepare to adjust early on to remain competitive.

To illustrate how this can be done, consider how Harley-Davidson Motorcycles invested to capture more profit from the widespread activity of motorcycle customization by consumers. It created websites to enable users to share their designs and learn from each other—and to make the user designs visible to Harley. The user design spillovers are evaluated for commercial potential. To reduce loss from self-provisioning, Harley offers custom production of new bikes according to users' designs and also offers postproduction parts that can be installed by the user who is customizing a bike he already owns. This enables Harley to capture increased profits from this type of complementary user self-provisioning as well (Harley-Davidson 2016).

As a second illustration, consider that Lego sponsors many events where fans are invited to meet and engage in joint design activities. It also supports fan websites where fans can post their novel constructions made of Lego bricks (Antorini et al. 2012). The Lego-sponsored website allows Lego to directly observe the popularity of user-created designs in terms of download counts. If a design appears to be very popular, Lego can benefit from the information spillover, build it into a kit product, and sell it to consumers.

In both these cases, consumers were innovating, creating complements, and modifying products without company involvement or approval prior to official company responses. The goal of producer investments was then to enhance the benefits the producer obtained from these activities. If firms learn how to "direct" users better toward the type of innovation activity that is valuable to firms, value capture by producers increases.

To conclude, we began with the observation that theoretical and empirical research now shows that individual users—consumers—are a major and increasing source of new products and services. To develop the implications, we built a microeconomic model of a market that incorporates innovation by both users and producers. We think this initial work has shown and analyzed important interactions between the user and producer paradigms. We suggest that further explorations of this topic can provide major new insights into the nature and functioning of markets for innovative products and services.

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Appendix A. Proof of the Choice-of-Mode Theorem

As noted, $z^U \leq z^P \rightarrow \Pi^P \geq \Pi^U$, and vice versa. Moreover, σ affects Π only through z, and therefore, we can study the impact of σ on Π by studying the impact of σ on z. We first show that at $\sigma = 0$, $z^U \leq z^P$, which establishes that at $\sigma = 0$, firms choose the P mode. We then show that and if $0 < \beta < \frac{1}{2}$, $z_\sigma^U \geq z_\sigma^P$, $\forall \sigma < \sigma_0$, with $\sigma_0 < 1$. For the first point, compare $\eta^U \tilde{b}^U$ with $\eta^P \tilde{b}^P = \xi$. At $\sigma = 0$, $\eta^U \leq \eta^P$ and $\tilde{b}^U = \tilde{b}^P = \xi$. As a result, $\sigma = 0$ implies $z^U \leq z^P$. For the second point, it is not difficult to see that $z_\sigma^P = 0$, and $z_\sigma^U = \tilde{b}^U(\eta_\sigma^U + \eta^U \tilde{b}_\sigma^U / \tilde{b}^U)$. Recall that $\eta_\sigma^U \leq 0$, and it is easy to see that $\tilde{b}_\sigma^U / \tilde{b}^U = \tau^\theta / [\sigma(\xi^\theta + \tau^\theta)]$. This expression is positive, and if $\theta < 1$ or $0 < \beta < \frac{1}{2}$, it is very high when $\sigma \rightarrow 0$. Moreover, it declines as σ increases, and, given $\lambda \geq \mu$, η^U declines. All this implies that when σ is close to zero, $z_\sigma^U > 0$, because the positive value of $\eta^U \tilde{b}_\sigma^U / \tilde{b}^U$ outweighs the negative η_σ^U. As σ increases, z_σ^U declines; that is, $z_{\sigma\sigma}^U < 0$. This is because $z_{\sigma\sigma}^U = \tilde{b}_\sigma^U(\eta_\sigma^U + \eta^U \tilde{b}_\sigma^U / \tilde{b}^U) + \tilde{b}^U \partial(\eta_\sigma^U + \eta^U \tilde{b}_\sigma^U / \tilde{b}^U) / \partial\sigma$, where based on what we have just said, the last derivative is negative. Then, when $\eta_\sigma^U + \eta^U \tilde{b}_\sigma^U / \tilde{b}^U = 0$—that is, $z_\sigma^U = 0$—$z_{\sigma\sigma}^U < 0$, which in turn means that z^U reaches a maximum when $z^U_\sigma = 0$, and it then starts declining. This explains the shape of our curves in Figure 2. We have discussed in Section 4.7, and it is easy to see that when $\sigma = \lambda = \mu = 0$, then $\Pi^U = \Pi^P$. Then, as Π^U increases faster than Π^P as σ increases, a higher σ, with $\lambda = \mu = 0$, implies $\Pi^U > \Pi^P$. This establishes that a switch can take place if λ or μ is sufficiently small. Finally, differentiate $z^U - z^P$ with respect to λ or μ at $\sigma = \sigma^*$. We know that $z^U_\sigma - z^P_\sigma > 0$, and therefore, the sign of σ^*_λ or σ^*_μ is the opposite of the sign of $z^U_\lambda - z^P_\lambda$ or $z^U_\mu - z^P_\mu$, which are both negative because λ and μ affect these expressions only through η^U. As a result, σ^* increases with λ or μ, and if λ or μ is too high, the switch does not take place. Q.E.D.

Appendix B. Proof of the Welfare Theorem

The strategy to prove this theorem is to show, first, that σ^*, $W^U - W^P \geq 0$ and then that $W^U_\sigma - W^P_\sigma \geq 0$. Under the conditions of the choice-of-mode theorem, $\Pi^U_\sigma \geq \Pi^P_\sigma$. This means that at σ^*, when the firms switch from the P to the U mode, welfare is higher in the U mode, and for larger σ, welfare does not switch back to the P mode.

To show that $W^U - W^P \geq 0$, evaluate

$$\begin{aligned}
&W^U - W^P \\
&= N(\Pi^U - \Pi^P) + (1-\sigma)\big[\tfrac{1}{2}(1-p^U+(1-\mu)b^U)^2 + \mu b^U + \mu' h^U \\
&\qquad - \tfrac{1}{2}(1-p^P+b^P)^2 - \mu' h^P\big] \\
&\quad + \sigma\big[\tfrac{1}{2}(1-p^U+(1-\lambda)b^U)^2 + \lambda b^U + h^U - \tfrac{1}{2}(1-p^P+b^P)^2 - h^P\big]
\end{aligned}$$

at σ^*, where $\Pi^U - \Pi^P = 0$ and $z^U y^U = z^P y^P$, which implies $p^U = p^P$ and $z^U = z^P$. The latter equality implies $y^U = y^P$, and therefore $\eta^U b^U = b^P$. We can rewrite $W^U - W^P$ at σ^* using all this information, suppressing for simplicity the superscript U, and rearranging terms,

$$\begin{aligned}
&W^U - W^P \\
&= (1-\sigma)\tfrac{1}{2}\big[(1-p+(1-\mu)b)(1-p+b) + \mu b(p-(1-\mu)b)\big] \\
&\quad + \sigma\tfrac{1}{2}\big[(1-p+(1-\lambda)b)(1-p+b) + \lambda b(p-(1-\lambda)b)\big] \\
&\quad + \tfrac{1}{2}(1-\eta)b - \tfrac{1}{2}(1-p+\eta b)^2 + \big[(1-\sigma)\mu' + \sigma\big](h^U - h^P).
\end{aligned}$$

The terms in the first two square brackets are the number of users who buy times their surplus plus the number of users who do not buy times their surplus. This also explains why $0 \leq p - (1-\mu)b \leq 1$ and $0 \leq p - (1-\lambda)b \leq 1$. Beyond these boundaries, the surplus of the noninnovating user is $\frac{1}{2} + \mu' b$ or $(\mu + \mu')b$ and $\frac{1}{2} + h$ or $\lambda b + h$ for the innovating users. As a result, $\mu b(p-(1-\mu)b)$, $\lambda b(p-(1-\lambda)b) \geq 0$, and it is easy to see that $h^U - h^P \geq 0$. Sum the first terms in the first two square brackets, weighed, respectively, by $(1-\sigma)$ and σ, and subtract $\frac{1}{2}(1-p+\eta b)^2$. This yields

$$\tfrac{1}{2}\big[(1-p+b)(1-p+\eta b) - (1-p+\eta b)(1-p+\eta b)\big] \geq 0$$

because $\eta \leq 1$ and $1 - p + \eta b \geq 0$ because η is a weighted average between $(1-\mu)$ and $(1-\lambda)$, and $(p-(1-\mu)b) \geq 0$. Since all the other terms in the expression for W^U˘W^P are nonnegative, this establishes that at σ^*, $W^U \geq W^P$.

The next step is to show that $W^U_\sigma \geq W^P_\sigma$. The expression for W^P is (10) using the specific expressions for PS, CS^{nui}, and CS^{ui}, with $\lambda = \mu = 0$ and p, b, and h computed for the P mode, which means that $x = 0$, and η, $\tilde{b}$, and y are obtained from the problem of the firm under the P mode. It is easy to see that in this case, σ does not affect η, $\tilde{b}$, and y, and therefore $W^P_\sigma = (1-\mu')h^P$. For the U mode,

$$\begin{aligned}
W^U_\sigma &= N\Pi^U_\sigma + (1-\sigma)\big[(1-p+(1-\mu)b)(-p_\sigma + (1-\mu)b_\sigma) \\
&\qquad + \mu b_\sigma + \mu' h^U_\sigma\big] \\
&\quad + \sigma\big[(1-p+(1-\lambda)b)(-p_\sigma + (1-\lambda)b_\sigma) + \lambda b_\sigma + h^U_\sigma\big] \\
&\quad + \big[(1-p+(1-\lambda)b)^2 - (1-p+(1-\mu)b)^2\big]/2 \\
&\qquad + (\lambda-\mu)b + (1-\mu')h^U\big],
\end{aligned}$$

where apart from Π^U_σ and h^U, we suppressed all the superscripts U. If $0 < \beta < \frac{1}{2}$ and σ is close to zero, $\Pi^U_\sigma \geq 0$. Moreover, $h^U - h^P \geq 0$. Thus, to establish the sign of $W^U_\sigma - W^P_\sigma$, we need to show that all the other terms of the expression for W^U_σ are nonnegative. Start with the last term. Rewrite the difference of squares as the product of the sum and difference of the two terms, and collect $(\lambda - \mu)b$. We obtain $(\lambda-\mu)b(p-(1-(\lambda+\mu)/2)b) \geq 0$, because $\lambda \geq \mu$ and $(p-(1-(\lambda+\mu)/2)b) = \frac{1}{2}(p-(1-\lambda)b + p - (1-\mu)b)$, and we already established that $(p-(1-\mu)b)$, $\lambda b(p-(1-\lambda)b) \geq 0$. Finally, $(1-p+(1-\mu)b)(-p_\sigma + (1-\mu)b_\sigma) + \mu b_\sigma = (1-p+(1-\mu)b)(-p_\sigma + b_\sigma) + \mu b_\sigma(p-(1-\mu)b)$. We know that $(1-p+(1-\mu)b) \geq 0$, $(p-(1-\mu)b) \geq 0$, and $-p_\sigma + b_\sigma = -(\eta_\sigma b + \eta b_\sigma)/(N+1) + b_\sigma = -\eta_\sigma b/(N+1) + b_\sigma[1 - \eta/(N+1)] \geq 0$. This is because $\eta_\sigma \leq 0$, $b_\sigma = \tilde{b}_\sigma y + \tilde{b} y_\sigma \geq 0$, and $1 - \eta/(N+1) > 0$ because $\eta \leq 1$. We obtain a similar result for the analogous term in λ. This establishes that $W^U_\sigma \geq W^P_\sigma$. Q.E.D.

Appendix C. Proof of the Policy Theorem

Like in the previous theorem, the strategy to prove this theorem hinges on the fact that, as shown in the previous theorem, at σ^*, $W^U - W^P \geq 0$, and then we study how $\Pi^U - \Pi^P$ and $W^U - W^P$ vary as we change γ or ξ. The logic is to check whether, under the conditions of the choice-of-mode theorem, changes in $\Pi^U - \Pi^P$ and $W^U - W^P$ go in the same direction.

In $W^U - W^P$, changes in γ do not affect any of the variables in the P mode. They raise Π^U and h^U. The expression for W^U_γ is equivalent to W^U_σ in the proof of the previous theorem, without the last two terms and with subscripts γ instead of σ. Thus, to show that $W^U_\gamma - W^P_\gamma \geq 0$, we need to show that the second and third terms are nonnegative. Analogously to the proof of the previous theorem, the second term can be written as $(1-p+(1-\mu)b)(-p_\gamma + b_\gamma) + \mu b_\gamma(p-(1-\mu)b)$. We know that $(1-p+(1-\mu)b) \geq 0$, $(p-(1-\mu)b) \geq 0$, and $-p^U_\gamma + b^U_\gamma = b^U_\gamma(1 - \eta^U/(N+1)) \geq 0$. The same applies to the third term, which establishes that at σ^*, where $\Pi^U - \Pi^P = 0$ and $W^U - W^P \geq 0$, $W^U_\gamma - W^P_\gamma \geq 0$. This means that at σ^* increases in γ raise Π^U beyond Π^P, which induces firms to switch to the U mode. At the same time, welfare, which at σ^* is higher in the U mode, cannot turn to be smaller than in the P mode.

Consider now increases in ξ. We first show that if $\beta > \beta^*$ with $\beta^* < \frac{1}{2}$, then $\Pi^U_\xi - \Pi^P_\xi \leq 0$. To see this, $z^U_\xi - z^P_\xi = \eta^U \Psi - 1$, where $\Psi \equiv [1 + (\tau/\xi)^\theta]^{(1-\theta)/\theta}$. If $0 < \theta < 1$, or $0 < \beta < \frac{1}{2}$, then $\eta^U \leq 1$, but $\Psi \geq 1$. However, $\theta \to 0$ implies that Ψ becomes very large, and $\theta = 1$ implies that $\Psi = 1$. Moreover, Ψ declines monotonically with θ. Consider $\partial \log \Psi / \partial \theta = -\theta^{-2} \log \Psi' + [(1-\theta)/\theta][(\tau/\xi)^\theta / \Psi'] \log(\tau/\xi)$, where $\Psi' \equiv [1 + (\tau/\xi)^\theta]$. This expression is negative because we study cases in which $\tau/\xi < 1$. As a result, there is a threshold $\theta^* < 1$, or $\beta^* < \frac{1}{2}$, such that $\beta > \beta^* \to z_\xi^U - z_\xi^P < 0$, and vice versa. Thus, at $\sigma = \sigma^*$, increases in ξ induce a switch to the P mode.

To check for $W_\xi^U - W_\xi^P$, using the logic of the proof of the previous theorem, we can write

$$W_\xi^U = N\Pi_\xi + (1-\sigma)[1-p+(1-\mu)b)(-p_\xi + b_\xi) + \mu b_\xi(p+(1-\mu)b) + \mu' h_\xi] + \sigma\left[(1-p+(1-\lambda)b)\left(-p_\xi + b_\xi + \lambda b_\xi(p+(1-\lambda)b) + h_\xi\right],\right.$$

where for simplicity we suppressed the superscripts U. The expression for W_ξ^P is the same with $\lambda = \mu = h_\xi = 0$, and the variables are all evaluated at the P mode. Recall that, as noted in the proof of the previous theorem, at $\sigma = \sigma^*$, $p^U = p^P$ and $\eta^U b^U = b^P$. Then, in $W_\xi^U - W_\xi^P$, the difference between $(1-p+(1-\mu)b)(-p_\xi + b_\xi) + \mu b_\xi(p-(1-\mu)b)$ and the equivalent term in W_ξ^P, weighed by $(1-\sigma)$, and the difference between $(1-p+(1-\lambda)b)(-p_\xi + b_\xi + \lambda b_\xi(p-(1-\lambda)b)$ and the equivalent term in W_ξ^P, weighed by σ, yields, after some algebra, $[(1-\eta) + \sigma(1-\sigma)(\lambda-\mu)^2 b]b_\xi \geq 0$. In addition, while h^P does not change with ξ, h^U increases in ξ. We conclude that at $\sigma = \sigma^*$, where $W^U \geq W^P$, the sign of $W_\xi^U - W_\xi^P$ is ambiguous and can very well be positive. Since $\beta > \beta^*$ implies $\Pi_\xi^U - \Pi_\xi^P \leq 0$, it may be that a higher ξ induces firms to switch to the P mode, while welfare is still higher under the U mode. Q.E.D.

Endnotes

[1] The ratio of the marginal products of $b = (T^\beta + Y^\beta)^{1/\beta}$ with respect to T and Y is equal to $(Y/T)^{1-\beta}$. With σ small, T is small, and therefore Y/T is likely to be larger than 1. As a result, a lower β makes the impact of T on b higher relative to the impact of Y on b. Since a higher σ makes T higher and Y lower because the optimal s increases, the condition $0 < \beta < \frac{1}{2}$ says that the contribution of the higher T on b has to be strong enough to compensate by a sizable amount the negative effect on b because of a lower Y.

[2] The intuition is that increases in ξ have a direct positive impact on Y in both the P and U modes. In addition, in the U mode, increases in ξ reduce s, which raises Y and reduces T. However, a higher β generates a more pronounced drop in s relative to $(1-s)$ because when complementarity is strong, the increase in Y does not produce a strong decline in T as a result of the feedback produced by complementarity. As a result, when complementarity is weak, increases in ξ produce a stronger increase in b in the P than in the U mode.

References

Adner R, Kapoor R (2010) Value creation in innovation ecosystems: How the structure of technological interdependence affects firm performance in new technology generations. *Strategic Management J.* 31(3):306–333.

Aghion P, Akcigit U, Howitt P (2013) What do we learn from Schumpeterian growth theory? Aghion P, Durlauf SN, eds. *Handbook of Economic Growth*, Vol. 2 (Elsevier, Amsterdam), 515–563.

Antorini YM, Muñiz AMJ, Askildsen T (2012) Collaborating with customer communities: Lessons from the Lego group. *Sloan Management Rev.* 53(3):73–79.

Baldwin CY (2010) When open architecture beats closed: The entrepreneurial use of architectural knowledge. Working paper, Harvard Business School, Boston.

Baldwin CY, Clark KB (2006) The architecture of participation: Does code architecture mitigate free riding in the open source development model? *Management Sci.* 52(7):1116–1127.

Baldwin CY, von Hippel E (2011) Modeling a paradigm shift: From producer innovation to user and open collaborative innovation. *Organ. Sci.* 22(6):1399–1417.

Balka K, Raasch C (2014) The effect of selective openness on value creation in user innovation communities. *J. Product Innovation Management* 31(2):392–407.

Bayus BL (2013) Crowdsourcing new product ideas over time: An analysis of the Dell IdeaStorm community. *Management Sci.* 59(1):226–244.

Bogers M, Afuah A, Bastian B (2009) Users as innovators: A review, critique, and future research directions. *J. Management* 36(4): 857–875.

Boudreau KJ, Jeppesen LB (2015) Unpaid platform complementors and the network effect mirage. *Strategic Management J.* 36(12): 1761–1777.

Boudreau KJ, Lakhani KR, Lacetera N (2011) Incentives and problem uncertainty in innovation contests: An empirical analysis. *Management Sci.* 57(5):843–863.

Bush V (1945) Science the endless frontier: A report to the president. Report, United States Government Printing Office, Washington, DC. http://www.nsf.gov/about/history/vbush1945.htm.

Casadesus-Masanell R, Ghemawat P (2006) Dynamic mixed duopoly: A model motivated by Linux vs. Windows. *Management Sci.* 52(7):1072–1084.

Colombo MG, Piva E, Rossi-Lamastra C (2013) Authorizing employees to collaborate with communities during working hours: When is it valuable for firms? *Long Range Planning* 46(3): 236–257.

de Jong J (2016) The empirical scope of user innovation. Harhoff D, Lakhani K, eds. *Revolutionizing Innovation: Users, Communities, and Open Innovation*, Chap. 4 (MIT Press, Cambridge, MA).

de Jong J, von Hippel E (2009) Transfers of user process innovations to process equipment producers: A study of Dutch high-tech firms. *Res. Policy* 38(7):1181–1191.

de Jong J, von Hippel E, Gault F, Kuusisto J, Raasch C (2015) Underdiffusion of generally valuable consumer-developed innovations. *Res. Policy* 44(10):1856–1865.

Franke N, Piller F (2004) Value creation by toolkits for user innovation and design: The case of the watch market. *J. Production Innovation Management* 21(6):401–415.

Franke N, Schreier M (2010) Why customers value self-designed products: The importance of process effort and enjoyment. *J. Product Innovation Management* 27(7):1020–1031.

Franke N, Shah S (2003) How communities support innovative activities: An exploration of assistance and sharing among end-users. *Res. Policy* 32(1):157–178.

Franke N, Schreier M, Kaiser U (2010) The "I designed it myself" effect in mass customization. *Management Sci.* 56(1):125–140.

Füller J (2010) Refining virtual co-creation from a consumer perspective. *Calif. Management Rev.* 52(2):98–122.

Gallini N, Scotchmer S (2002) Intellectual property: What is the best incentive system? Jaffe A, Lerner J, Stern S, eds. *Innovation Policy and the Economy*, Vol. 2 (MIT Press, Cambridge, MA), 51–78.

Godin B (2006) The linear model of innovation: The historical construction of an analytical framework. *Sci., Tech. Human Values* 31(6):639–667.

Harhoff D, Mayrhofer P (2010) Managing user communities and hybrid innovation processes: Concepts and design implications. *Organ. Dynam.* 39(2):137–144.

Harhoff D, Henkel J, von Hippel E (2003) Profiting from voluntary information spillovers: How users benefit by freely revealing their innovations. *Res. Policy* 32(10):1753–1769.

Harley-Davidson (2016) Inspiration on demand. Accessed January 14, 2016, http://www.harley-davidson.com/content/h-d/en_US/home/hd1-customization/build-your-harley.html.

Henkel J (2008) Champions of revealing—The role of open source developers in commercial firms. *Indust. Corporate Change* 18(3): 435–471.

Hienerth C (2016) Technique innovation. Harhoff D, Lakhani K, eds. *Revolutionizing Innovation: Users, Communities, and Open Innovation*, Chap. 16 (MIT Press, Cambridge, MA).

Hinsch ME, Stockstrom C, Lüthje C (2013) User innovation in techniques—A case study analysis in the field of medical devices. *20th Internat. Product Development Management Conf. (IPDMC), Paris*.

Hyysalo S (2009) User innovation and everyday practices: Micro-innovation in sports industry development. *R&D Management* 39(3):247–258.

Jacobides MG (2005) Industry change through vertical disintegration: How and why markets emerged in mortgage banking. *Acad. Management J.* 48(3):465–498.

Jeppesen LB, Frederiksen L (2006) Why do users contribute to firm-hosted user communities? The case of computer-controlled music instruments. *Organ. Sci.* 17(1):45–63.

Kleer R, Piller F (2013) Welfare effects of a radical process innovation: Benefits of local production by users via 3D printing. Working paper, RWTH Aachen University, Aachen, Germany.

Kuan J (2001) Open source software as consumer integration into production. Working paper, Stanford Institute for Economic Policy Research, Stanford, CA. http://ssrn.com/abstract=259648.

Lakhani KR, Wolf B (2005) Why hackers do what they do: Understanding motivation and effort in free/open source software projects. Feller J, Fitzgerald B, Hissam SA, Lakhani KR, eds. *Perspectives on Free and Open Source Software* (MIT Press, Cambridge, MA), 3–21.

Lilien GL, Morrison PD, Searls K, Sonnack M, von Hippel E (2002) Performance assessment of the lead user idea-generation process for new product development. *Management Sci.* 48(8):1042–1059.

Lin L (2008) Impact of user skills and network effects on the competition between open source and proprietary software. *Electronic Commerce Res. Appl.* 7(1):68–81.

MacCormack A, Rusnak J, Baldwin CY (2006) Exploring the structure of complex software designs: An empirical study of open source and proprietary code. *Management Sci.* 52(7):1015–1030.

Morlacchi P, Nelson RR (2011) How medical practice evolves: Learning to treat failing hearts with an implantable device. *Res. Policy* 40(4):511–525.

Nishikawa H, Schreier M, Ogawa S (2013) User-generated versus designer-generated products: A performance assessment at Muji. *Internat. J. Res. Marketing* 30(2): 160–167.

Ogawa S (1998) Does sticky information affect the locus of innovation? Evidence from Japanese convenience-store industry. *Res. Policy* 26(7–8):777–790.

Ogawa S, Pongtanalert K (2013) Exploring characteristics and motives of consumer innovators: Community innovators vs. independent innovators. *Res.-Tech. Management* 56(3):41–48.

Penrose E (1951) *The Economics of the International Patent System* (Johns Hopkins University Press, Baltimore).

Poetz MK, Schreier M (2012) The value of crowdsourcing: Can users really compete with professionals in generating new product ideas? *J. Product Innovation Management* 29(2):245–256.

Prügl R, Schreier M (2006) Learning from leading-edge customers at the Sims: Opening up the innovation process using toolkits. *R&D Management* 36(3):237–251.

Raasch C, von Hippel E (2013) Innovation process benefits: The journey as reward. *Sloan Management Rev.* (Fall).

Raasch C, Herstatt C, Lock P (2008) The dynamics of user innovation: Drivers and impediments of innovation activities. *Internat. J. Innovation Management* 12(3):377–398.

Riggs W, von Hippel E (1994) Incentives to innovate and the sources of innovation: The case of scientific instruments. *Res. Policy* 23(4):459–469.

Sanchez H, Mahoney J (1996) Modularity, flexibility, and knowledge management in product and organizational design. *Strategic Management J.* 17(S2):63–76.

Schilling M (2000) Toward a general modular systems theory and its application to interfirm product modularity. *Acad. Management Rev.* 25(2):312–334.

Schumpeter JA (1943/2003) *Capitalism, Socialism and Democracy* (Routledge, London).

Sen R (2007) A strategic analysis of competition between open source and proprietary software. *J. Management Inform. Systems* 24(1):233–257.

Smith SW, Shah SK (2013) Do innovative users generate more useful insights? An analysis of corporate venture capital investments in the medical device industry. *Strategic Entrepreneurship J.* 7(2):151–167.

Syam NB, Pazgal A (2013) Co-creation with production externalities. *Marketing Sci.* 32(5):805–820.

Teece DJ (1986) Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Res. Policy* 15(6):285–305.

von Hippel E (2005) *Democratizing Innovation* (MIT Press, Cambridge, MA).

von Hippel E, Katz R (2002) Shifting innovation to users via toolkits. *Management Sci.* 48(7):821–833.

von Hippel E, de Jong J, Flowers S (2012) Comparing business and household sector innovation in consumer products: Findings from a representative survey in the UK. *Management Sci.* 58(9):1669–1681.

von Hippel E, DeMonaco H, de Jong J (2014) Market failure in the diffusion of user innovations: The case of "off-label" innovations by medical clinicians. Working paper, MIT Sloan School of Management, Cambridge, MA. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2275562.

West J, Lakhani KR (2008) Getting clear about communities in open innovation. *Indust. Innovation* 15(2):223–231.

Willis N (2007) Lessons learnt from open source Xara's failure. *Linux.com* (October 13), http://www.linux.com/feature/119790.