HARVARD | BUSINESS | SCHOOL

Modeling a Paradigm Shift: From Producer Innovation to User and Open Collaborative Innovation

Carliss Y. Baldwin
Eric von Hippel

Working Paper

10-038

10-038

Modeling a Paradigm Shift: From Producer Innovation to User and Open Collaborative Innovation

Carliss Y. Baldwin*

Eric von Hippel†

November 2009

* Harvard Business School
cbaldwin@hbs.edu

† Massachusetts Institute of Technology
evhippel@mit.edu

Modeling a Paradigm Shift:
From Producer Innovation to User and Open Collaborative Innovation

Carliss Baldwin* and Eric von Hippel**

November 2009

SSRN download url:
http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1502864

*Harvard Business School (cbaldwin@hbs.edu)
**MIT Sloan School of Management (evhippel@mit.edu)

ABSTRACT

In this paper we assess the economic viability of innovation by producers relative to two increasingly important alternative models: innovations by single user individuals or firms, and open collaborative innovation projects. We analyze the design costs and architectures and communication costs associated with each model. We conclude that innovation by individual users and also open collaborative innovation increasingly compete with - and may displace – producer innovation in many parts of the economy. We argue that a transition from producer innovation to open single user and open collaborative innovation is desirable in terms of social welfare, and so worthy of support by policymakers.

Modeling a Paradigm Shift:
From Producer Innovation to Open User and Collaborative Innovation

1. Introduction and overview

Ever since Schumpeter (1934) promulgated his theory of economic development, economists, policymakers and business managers have assumed that the dominant mode of innovation is a "producers' model." That is, it has been assumed that most important designs for innovations would originate from producers and be supplied to consumers via goods and services that were for sale. This view seemed reasonable on the face of it – producer-innovators generally profit from many users, each purchasing and using a single, producer-developed design. Individual user innovators, in contrast, depend only on their own in-house use of their design to recoup their innovation-related investments. Presumably, therefore, a producer serving many customers can afford to invest more in an innovation design than can any single user. From this it has been generally assumed that producer-developed designs should dominate user-developed designs in most parts of the economy.

This long-held view of innovation has, in turn, led to public policies based on a theory of producer incentives. Producers, it is argued, are motivated to innovate by the expectation of profits. These profits will disappear if anyone can simply copy producers' innovations, and therefore, producers must be granted subsidies or intellectual property rights that give them exclusive control over their innovations for some period of time. (Machlup and Penrose, 1951; Teece, 1986; Gallini and Scotchmer, 2006.)

However, the producers' model is only one mode of innovation. Two increasingly important additional models are innovations by single user firms or individuals, and open collaborative innovation projects. Each of these three forms represents a different way to organize human effort and investments aimed at generating valuable new innovations. In the body of this paper we will analyze these three models in terms of their technological properties, specifically their design costs and architecture, and their communication requirements. In these two technological dimensions, each model has a different profile that gives it economic advantages under some conditions and disadvantages in others.

Our modeling of design costs and architectures and communication costs allows us to place bounds on the contexts in which each model will be economically viable. Our analysis will lead us to conclude that innovation by individual users and also open collaborative innovation are modes of innovating that increasingly compete with and may displace producer innovation in many parts of the economy. This shift is being driven by new technologies, specifically the transition to increasingly digitized and modularized design and production practices, coupled with the availability of very low-cost, Internet-based communication.

We will argue that when it is technologically feasible, the transition from closed producer or single user innovation to open single user or collaborative innovation is also desirable in terms of social welfare, hence worthy of support by policymakers. This is due to the free dissemination of innovation designs associated with the open model. Open innovation generates innovation without exclusivity or monopoly, and so should improve social welfare other things equal.

In section 2 of this paper we review relevant literature. In section 3 we present and explain conditions under which each of the three economic models of innovation we describe is viable. In section 4, we discuss some broader patterns related to our models, and also suggest some implications of open collaborative innovation for researchers, practitioners, and policymakers.

2. Literature review

In this section, we briefly review the literature on user innovation, on openness of intellectual property, and on modular designs and collaborative innovation.

2.1 Innovation by users

Users, as we define the term, are firms or individual consumers that expect to benefit from *using* a design, a product or a service. In contrast, producers expect to benefit from *selling* a design, a product, or a service. Innovation user and innovation producer are thus two general "functional" relationships between innovator and innovation. Users are unique in that they alone benefit directly from innovations. Producers must sell innovation-related products or services to users, hence the value of innovation to producers is derived from users' willingness to pay. Thus, in order to profit, inventors must sell or license knowledge related to their new designs; manufacture and sell goods embodying the innovations; or deliver and sell services incorporating or complementing the innovations.

Qualitative observations have long indicated that important process improvements are developed by employees working for firms that use them. Adam Smith (1776) pointed out the importance of "the invention of a great number of machines which facilitate and abridge labor, and enable one man to do the work of many." Smith went on to note that "a great part of the machines made use of in those manufactures in which labor is most subdivided, were originally the invention of common workmen, who, being each of them employed in some very simple operation, naturally turned their thoughts towards finding out easier and readier methods of performing it." Rosenberg (1976) studied the history of the US machine tool industry and found that important and basic machine types like lathes and milling machines were first developed and built by user firms having a strong need for them. Textile manufacturing firms, gun manufacturers and sewing machine manufacturers were important early user developers of machine tools.

Quantitative studies of user innovation document that many of the most important and novel products and processes commercialized in a range of fields are developed by users for in-house use. Thus, Enos (1962) reported that nearly all the most important innovations in oil refining were developed by user firms. Freeman (1968) found that the most widely licensed chemical production processes were developed by user firms. Von Hippel (1976, 1977) found that users were the developers of about 80 percent of the most important scientific instrument innovations, and also the developers of most of the major innovations in semiconductor processing. Pavitt (1984) found that a considerable fraction of invention by British firms was for in-house use. Shah (2000) found that the most commercially important equipment innovations in four sporting fields tended to be developed by individual users.

Empirical studies also show that many users—from 10 percent to nearly 40 percent—engage in developing or modifying products. This has been documented in the case of several specific types of industrial products and consumer products (Urban and von Hippel 1988, Herstatt and von Hippel 1992, Morrison et al. 2000, Lüthje et al. 2002, Lüthje 2003, 2004, Franke and von Hippel 2003, Franke and Shah 2003). It has also been documented in large-scale, multi-industry surveys of process innovation in both Canada and the Netherlands (Arundel and Sonntag 1999, Gault and von Hippel 2009, de Jong and von Hippel 2009).

When taken together, the findings of all these empirical studies make it very clear that users have long been and are doing a lot of commercially-signficant process development and product modification in many fields.

2.2: Innovation openness

Economic theorists have long thought that uncompensated "spillovers" of proprietary innovation-related knowledge developed by private investment will reduce innovators' expected profits from innovation investments – and so reduce their willingness to invest. Accordingly, many nations have long offered intellectual property rights grants that afford inventors some level of temporary monopoly control over their inventions. The assumption has been that losses incurred due to intellectual property rights grants will be more than offset by gains from related increases in innovation investment or innovation disclosure (Machlup and Penrose 1950, Penrose 1951, Foray 2004).

Given this argument, empirical research should show innovators striving to keep information on their innovations from being freely diffused. However, research instead shows that both individuals and firms often voluntarily "freely reveal" what they have developed. When we say that an innovator freely reveals information about an innnovation, we mean that exclusive intellectual property rights to that information are voluntarily given up by the innovator, and all interested parties are given access to it—the information becomes a public good (Harhoff et al 2003). (Intellectual property rights may still be used to protect the developers of these public goods from liability, and to prevent expropriation of their innovations by third parties (O'Mahony 2003).)

The practices visible in open source software development were important in bringing the phenomenon of free revealing to general awareness. In these projects it was clear policy that project contributors would routinely and systematically freely reveal code they had developed at private expense (Raymond 1999). However, free revealing of innovations has a history that began long before the advent of open source software. Allen (1983) and Nuvolari (2004), describe and discuss eighteenth-century examples. Contemporary free revealing by users has been documented by von Hippel and Finkelstein (1979) for medical equipment, by Lim (2000) for semiconductor process equipment, by Morrison, Roberts, and von Hippel (2000) for library information systems, and by Franke and Shah (2003) for sporting equipment. Gault and von Hippel (2009) and de Jong and von Hippel (2009) have shown in multi-industry studies in Canada and the Netherlands that user firms developing process equipment often transfer their innovations to process equipment suppliers without charge.

Reexaminations of traditional economic arguments triggered by evidence of free revealing show that innovators generally freely reveal for two economically rational reasons. First, it is in practice difficult to effectively protect most innovations via secrecy or intellectual property rights. Second, significant private benefits often accrue to innovators that do freely reveal their innovations.

With respect to the first point, consider that the real-world value of patent protection has been studied for more than 40 years. A number of researchers have found that, except in the case of pharmaceuticals, chemicals, and chemical processes, innovators generally do not think that patents are very useful either for excluding imitators or for capturing royalties. Most respondents also say that the availability of patent protection does not induce them to invest more in research and development than they would if patent protection did not exist (Taylor and Silberston, 1973; Levin et al. 1987; Mansfield 1968, 1985; Cohen et al 2000, 2002; Arundel 2001; Sattler 2003; Dosi et. al., 2006). Keeping an innovation secret is also unlikely to be successful for long – trade secrets tend to "leak" quite quickly (Mansfield 1985). And even if one innovator can manage to protect a trade secret, many generally know similar information that can serve as substitutes. Some holders of substitute information stand to lose little or nothing by freely revealing what they know. As a result, efforts of those who wish to protect or hide their trade secrets are often undercut by those with the least to lose by free revealing (von Hippel 2005).

With respect to the second point, evidence has now accumulated that innovators who elect to freely reveal their innovations, can gain significant private benefits – and also avoid some private costs.

Regarding private benefits, consider that innovators that freely reveal their new designs often find that others then improve or suggest improvements to the innovation, to mutual benefit (Raymond 1999, Lakhani and von Hippel, 2009). Freely revealing users also may benefit from enhancement of reputation, from positive network effects due to increased diffusion of their innovation, and from other factors such as obtaining a source of supply for their innovation that is cheaper than in-house production (Allen 1983, Lerner and Tirole 2002, Harhoff et al. 2003, Lakhani and Wolf 2005, von Hippel and von Krogh 2003).

With regard to cost, protecting design information is generally expensive, requiring security walls and restricted access or the enforcement of intellectual property rights (Blaxill and Eckardt, 2009). For this reason preventing others from viewing and using a new design may be significantly more costly than leaving the design open for inspection or use by any interested party (Baldwin, 2008).

Not surprisingly, the incentive to freely reveal decreases if the agents compete with one another, for example, if they are firms making the same end product or individuals competing in a sport (Franke and Shah, 2003; Baldwin, Hienerth and von Hippel, 2006). Selective openness strategies illustrate this point nicely. Thus, Henkel (2003) has documented selective free revealing among producers in the case of embedded Linux software. The producers partition their code into open modules on which they collaborate, and closed modules on which they compete (Henkel and Baldwin, 2009).

2.3 Collaboration and Modularity

Collaboration is a well-known attribute of online, multi-contributor projects such as open source software projects and Wikipedia (Raymond, 1999; Benkler, 2002). Lakhani and von Hippel (2009) studied a sample of 241 software features being developed for the improvement of PostgreSQL open source database software. They found that the average number of individuals collaborating in the development of a single software feature was 9, and that on average 7 of these were users. Franke and Shah (2003) studied user innovators in four sporting communities and found that all had received assistance in their development efforts by at least one other user from their communities. The average number of users assisting each userinnovator was three to five. Finally, a study of process equipment innovations by high-tech small and medium enterprises (SMEs) in the Netherlands conducted by de Jong and von Hippel (2009) found that 24% of 364 user firms drawn from a wide range of industries had received assistance in their innovation development work from other process equipment users.

Modular design architectures are an important aid to collaborative work. A modular system is one in which the elements, which may be decisions, tasks or components, are partitioned into subsets called modules. Within each module, elements of the system are densely dependent and interconnected: changing any one will require changes in many others. Across modules, however, elements are independent or nearly so; a change in one module by definition does not require changes in others (Baldwin and Clark, 2000). Modular systems can be easily broken apart, thus Herbert Simon called such systems "near-decomposable" (Simon, 1962). Furthermore, given appropriate knowledge, a non-modular system can be made modular (or near-decomposable) by creating a set of coordinating design rules that establish interfaces and regulate the interactions of the modules (Mead and Conway, 1980; Baldwin and Clark, 2000). Most design-relevant knowledge and information does not need to cross module boundaries. This is the property of "information hiding" (Parnas 1972).

Modularity is important for collaboration in design because separate modules can be worked on independently and in parallel, without intense ongoing communication across modules. Designers working on different modules in a large system do not have to be co-located, but can still create a system in which the parts can be integrated and will function together as a whole. In small projects or within modules, designers can utilize "actionable transparency" rather than modularity to achieve coordination. When projects are small, each designer's activities are "transparent" to his or her collaborators. In open collaborative projects, modularity and actionable transparency generally go hand in hand, with both factors contributing to the divisibility of tasks (Colfer, 2009).

Building on arguments of Ghosh (1998), Raymond (1999), and von Hippel and von Krogh (2003), Baldwin and Clark (2006 b) showed formally that, if communication costs are low relative to design costs, then any degree of modularity suffices to cause rational innovators that do not compete with respect to the design being developed to prefer collaborative innovation over independent innovation. This result hinges on the fact that the innovative design itself is a non-rival good: each participant in a collaborative effort gets the value of the whole design, but incurs only a fraction of the design cost.

3. Where is Each Model Viable?

Previous work has demonstrated the existence of the three basic ways of organizing innovation activity and has eludicated their characteristics. However, to our knowledge, there has been no systematic thinking about the conditions under which each model is likely to appear, and whether each is expanding or contracting relative to the other two. To make progress on these questions, it is necessary to develop a theoretical framework that locates all three models in a more general space of attributes. That is our aim in this section.

Our methodololgy is that of comparative institutional analysis. In this diverse literature, laws, social customs, modes of governance, organizational forms, and industry structures are compared in terms of their incentives, economic consequences, and ability to survive and grow in a given historical setting or technological context. In the particular branch we are most concerned with, organizational forms and industry structures are taken to be endogenous and historically contingent (Chandler, 1962, 1977; Williamson, 1985, 1991; Nelson and Winter, 1982; Aoki, 1984, 2001; Langlois, 1986a, 2002; Baldwin and Clark 2000; Jacobides, 2005). Different forms may be selected to suit different environments and then adaptively modified. Thus organizational forms emerge in history and recede as technologies and preferences change.

Our approach is modeled after Williamson's (1985, 1991) analysis of different forms of transactional governance and especially Fama and Jensen's (1983a, b) account of how agency costs affect the allocation of residual claims. However, in contrast to this prior work, we will not attempt to determine which model is most efficient in terms of minimizing transaction or agency costs, but instead will establish bounds on the viability of each model. When more than one form is viable, we do not expect to see one form drive out the other (as is the common assumption), but rather expect to see creative combinations of the forms to take advantage of what each one does best.

Finally in contrast to virtually all prior work except for Chandler (1962, 1977), we take an explicitly technological approach to the question of viability. Fundamentally we assume that in a free economy, the organizational forms that survive are ones with benefits exceeding their costs (Fama and Jensen, 1983a, b). Costs in turn are determined by technology and change over time. Thus Chandler (1977) argues that the modern corporation became a viable form of organization (and the dominant form in some sectors) as a consequence of the (partly endogenous) decline in production costs for high-flow-through technologies, together with (exogenous) declines in transportation and energy costs. Adopting Chandler's logic, we should expect a particular organizational form to be prevalent when its technologically determined costs are low, and to be ascendent—i.e., growing relative to other forms—when its costs are declining relative to the costs of other forms.

Today, design costs and communication costs are declining rapidly, and modular design architectures are becoming common for many products. In the rest of this section, we argue that these largely exogenous technological trends make single user innovation and especially open collaborative innovation viable across a wider range of innovation activities than was the case before the arrival of technologies such as personal computers and the Internet. We have seen, and expect to continue to see, single user innovation and open collaborative innovation growing in importance relative to producer innovation in most sectors of the economy. We do not believe that producer innovation will disappear, but we do expect it to become less pervasive and ubiquitous than was the case during most of the 20th century.

3.1 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, and an individual consumer creating a new piece of sporting equipment in order to use it.

A producer innovator is a single, non-collaborating firm. Producers anticipate profiting from their design by selling it to users or others: by definition they obtain no direct use-value from a new design. We assume that through secrecy or intellectual property rights a producer innovator has exclusive access and control over the innovation, and so is a monopolist with respect to its design. Examples of producer innovators are: (1) a firm or individual that patents an invention and licenses it to others; (2) a firm that develops a new process machine to sell to its customers; (3) a firm that develops an enhanced service to offer its clients.

An open collaborative innovation project involves contributors who *share* the work of generating a design and also reveal the outputs from their individual and collective design efforts openly for anyone to use. The defining properties of this model are twofold: (1) the participants are not rivals with respect to the innovative design (otherwise they would not collaborate) and (2) they do not individually or collectively plan to sell products or services incorporating the innovation or intellectual property rights related to it. An example of such a project is an open source software project.

A design is a set of instructions that specify how to produce a novel product or service (Simon, 1981; Suh, 1990; Baldwin and Clark, 2000, 2006a). These instructions can be thought of as a recipe for accomplishing the functional requirements of the design (Suh, 1990; Winter, 2008; Dosi and Nelson, 2009). 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 such as a wrench or a car, the design recipe must be converted into a physical form before it can be used.

A given mode of innovation is *viable* with respect to a particular innovation opportunity if the innovator or each participant in a group of innovators finds it worthwhile to incur the requisite costs to gain the anticipated value of the innovation. By focusing on anticipated benefits and costs we assume that potential innovators are rational actors who can forecast the likely effects of their design effort and choose whether or not to expend the effort (Simon, 1981; Langlois, 1986b; Jensen and Meckling, 1994; Scott, 2001).

Our definition of viability is related to: the contracting view of economic organizations; to the concept of solvency in finance; and to the concept of equilibrium in institutional game theory.

In contracting literature, firms and other organizations are viewed as a "nexus of contracts,", that is, a set of voluntary agreements (Alchian and Demsetz, 1972; Jensen and Meckling, 1976; Fama and Jensen, 1983a, b; Demsetz, 1988; Hart, 1995). For the firm or organization to continue in existence, each party must perceive himself or herself to be better off within the contracting relationship than outside of it.

In finance, a firm assembles resources by issuing claims (contracts) in the form of debt and equity. It uses the proceeds to purchase assets and to bridge the gap between cash outflows and inflows. A firm is solvent as long as it can pay off or refinance all its debt claims and have something left over. If this condition is not met, the firm is bankrupt: it ceases to be a going concern, and must be liquidated or reorganized.

In institutional game theory, an institution is defined as the equilibrium of a game with self-confirming beliefs (Aoki, 2001). Within the institutional framework, participants join or contribute resources in the expectation that other parties will enact their respective roles. If all behave as the others expect, everyone's initial beliefs are confirmed: the pattern of action then becomes a self-perpetuating institution. When the participants in the institution are rational actors, one of their self-confirming beliefs must be, "I am better off participating in this institutional arrangement than withdrawing from it." On this view, a stable nexus of contracts, a solvent firm, and an active open collaborative innovation project are all special cases of institutional equilibria.

We define an *innovation opportunity* as the opportunity to create a new design. With respect to a particular innovation opportunity, each of the three models of innovation may be viable or not, depending on the benefits and costs flowing to the actors.

In terms of benefits, we define the *value of an innovation, V,* as the benefit that a party expects to gain from converting an innovation opportunity into a new design—the recipe—and then turning the design into a useful product, process or service. Different individuals and organizations may benefit in different ways. By definition, users benefit from direct use of the product, process, or service specified by the new design. Producers benefit from profitable sales, which may take the form of sales of intellectual property (a patent or license) or sales of products or services that embody the design. Ultimately, however, a producer's benefit, hence value, derives from the users' willingness to pay for the innovative design.

Each innovation opportunity has four generic costs: design cost, communication cost, production cost and transaction cost. Consistent with our assumption that innovators are rational actors, we assume that these costs (as well as benefits) are known *ex ante* to potential innovators, although there may be uncertainty in their assessments. As with value, the costs may differ both across individuals and across the three models of innovation.

Design cost, d, is the cost of creating the design for an innovation—the instructions that when implemented will bring the innovation into reality. Following Simon (1962, 1981), these costs include (1) the cost of identifying the functional requirements (that is, what the design is supposed to do); (2) the cost of dividing the overall problem into sub-problems, which can be solved separately; (3) the cost of solving the sub-problems; and (4) the cost of recombining the sub-problems' solutions into a functioning whole.

Communication cost, c, is the cost of transferring design-related information among participants *in different organizations* during the design process. Under this definition, single user innovators, because they are in the same organization incur no communication cost. (Of course there can be intra-organization costs of communication. However, for our purposes it is sufficient if the costs of communication are less within an organization than across organizational boundaries.) Producer innovators and innovators collaborating in an open project must communicate across organizations, and thus incur communication costs.

Production cost, u, is the cost of carrying out the design instructions to produce the specified good or service. The input is the design instructions —the recipe—plus the materials, energy, and human effort specified in those instructions; the output is a good—the design converted into usable form.

Transaction cost, t, is the cost of establishing property rights and engaging in compensated exchanges of property. For an innovation, transaction cost includes the cost of creating exclusive rights to the design, by keeping it secret or by obtaining a patent or copyright. It also includes the cost of controlling opportunistic behavior (Williamson, 1985); writing contracts (Hart, 1995); and accounting for transfers and compensation (Baldwin, 2008).

3.2 Bounds on Viability

Every innovation opportunity, that is, every potential new design, can be characterized in terms of its value and the four dimensions of cost described above. The criterion of viability can thus be specified mathematically as follows:

Bounds on Viability 1: *For a given innovation opportunity, a particular model of innovation is viable if and only if for each necessary contributor to the model:*

$$V_i > d_i + c_i + u_i + t_i \ . \qquad (1)$$

(The subscripts indicate that the benefits and costs may vary by contributor and across models.)

For single user innovators and producer innovators, there is only one contributor to be considered. (Producer innovators may employ many people, but the producer's contracts with employees are subsumed in its costs.) In open collaborative innovation projects, however, there are several or many contributors, and the inequality must hold for each one individually. Notice we have defined the criterion as a strict inequality: we assume that the actors must anticipate a strictly positive gain in order to undertake the effort and cost of innovation. We do not rule out the possibility that the activities of design, communication, production, or exchange might be pleasurable for some agents: if this is the case, the relevant cost would be negative for those agents. However, the cases of interest here are those for which the sum of costs is positive, that is to say, the innovation is not a free good.

As indicated in the introduction, design costs and communication costs have declined and are continuing to decline very rapidly because of the advent of personal computers and the Internet. We believe these largely exogenous technological trends are the main causes of the increasing importance of single user and open collaborative innovation models in the economy at large. To make this argument as clear as possible, we will first focus our analysis on these costs alone, holding production costs and transaction costs constant across all three economic models. Once we have established bounds on viability for the three models with respect to design and communication costs, we will reintroduce the other two dimensions of cost and show how they affect the results.

To simplify our notation in the next few sections, we define v as the value of an innovation opportunity net of production and transaction costs. Because it subtracts out production and transaction costs, v can be thought of as the (expected) value of the design alone, before it is put up for sale or converted into a useful thing. The bounds of viability can then be restated as:

Bounds on Viability 2: *For a given innovation opportunity, if production and transaction costs are constant, a particular model of innovation is viable if and only if for each necessary contributor to the model:*

$$v_i > d_i + c_i \ . \qquad (2)$$

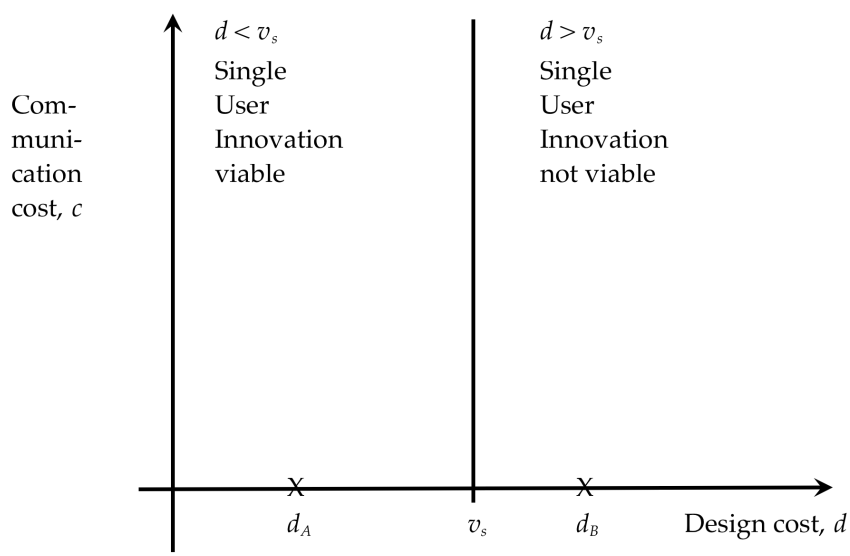
With this simplifying assumption, we can now represent innovation opportunities with different costs as points in a graph with design cost and communication cost on the x and y axes respectively. We next ask the question, for what combinations of design and communication cost will each model be viable?

3.3 Single User Innovation

Consider first a single user innovator – an individual or a firm - contemplating investment in a design whose value to her is v_s. The effort of innovation is worthwhile (for this innovator and this design) if this value is greater than the user's design cost: $d_s < v_s$. In figure 1, we draw a vertical line at $d = v_s$. Points to the left of the vertical line will satisfy the constraint hence be viable; those to the right will not. Thus the constraint $d = v_s$ bounds the region in which single user innovation is viable for this opportunity.

As advances in design technology progressively reduce design cost (which is the trend), more innovation opportunities become viable for more users. Note, however, that design costs of individual users will differ. For example, if user A has better skills or equipment than user B, the design cost for a given innovation may fall within an attractive range for user A but not B (as shown in the figure).

Figure 1: Bound on Single User Innovation



Communication costs don't enter the analysis, because the user is a single agent that both designs and benefits from the use of an innovation. As was mentioned earlier, a single user innovator does not need to engage in inter-organization communication as part of either the design process or the process of reaping value from the design. For this reason, as shown in figure 1, the institution of single user innovation is viable independent of the cost of communication: single users will innovate even if communication technology is very primitive and the costs of communication are very high.

3.4 Producer Innovation

Producers can economically justify undertaking larger designs than can single users, because they expect to spread their design costs over many purchasers. Even though they are single organizations, however, they are affected by communication costs because to sell their products they must make potential buyers aware of what they have to sell.

Non-innovating users will purchase the innovation from a producer as long as their value is greater than the producer's price: $v_i > p$, where v_i denotes the value of the innovation to the *i*th user, and p denotes the producer innovator's price. (Both value and price are measured net of production and transaction costs.)

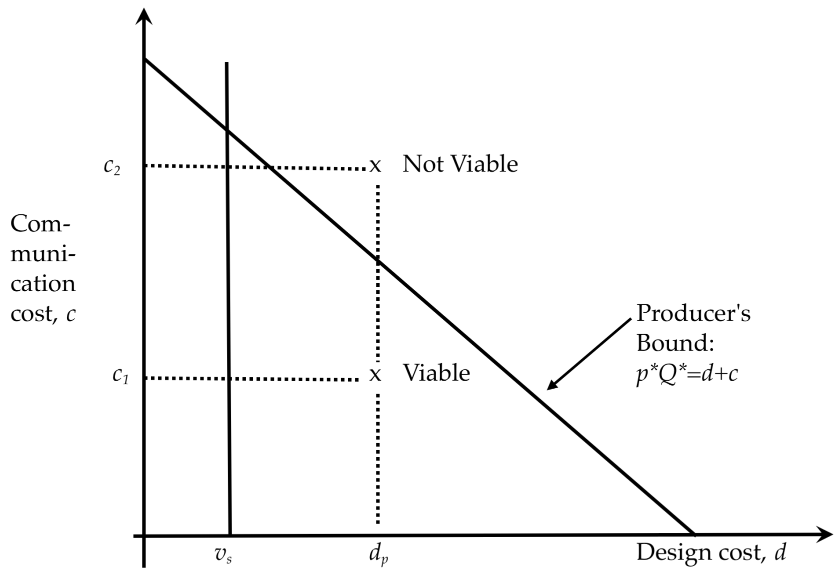
As we mentioned earlier, we assume that if the producer undertakes a design effort, it will obtain property rights that give it some predictable degree of effective monopoly on the design. We also assume that the producer knows the value v_i that each potential user places on the innovation. In other words it knows its customers' willingness-to-pay for the innovative product or service and can subtract the relevant production and transaction costs from their willingness-to-pay. The producer innovator can convert this customer knowledge into a demand function, $Q(p)$, which relates each price it might charge to the number of units of the product or service it will sell at that price (Baldwin, Hienerth and von Hippel, 2006). From the demand function, the producer innovator can solve for the price, p^*, and quantity, Q^*, that maximize its expected revenues (again net of production and transaction costs), and subtract its design (d_p) and communication (c_p) costs from (net) revenue to calculate expected profit, Π:

$$\Pi = p^* Q^* - d_p - c_p \qquad (3)$$

If the producer anticipates positive profit, then as a rational actor, it will enter the market to supply the innovation. In this case, the producer innovator model is viable with respect to the innovation opportunity. Conversely, if its anticipated profit is negative, the producer will not enter, and the producer model of innovation is not viable.

The zero profit constraint on the producer defines a negative 45-degree line in the space of design and communication costs: $p^* Q^* = d + c$. Figure 2 shows this bound in relation to a hypothetical single user innovator's bound for the same opportunity. As we have drawn the figure, the design costs are higher than the value of the innovation to a single user, hence the single user innovation model is not viable for this design. We then show two possible outcomes for the producer. In the first case, communication costs are low so that the sum of design and communication costs falls below the producer's bound. In the second case, the sum falls above the bound. Producer innovation is a viable model for the first combination of costs but not for the second.

Figure 2: Bound on Producer Innovation



From this analysis we learn that the viability of producer innovation is affected by two things that don't affect single user innovation. The first is the size of the potential market. In large markets, the producer will have many customers and its revenue will be far in excess of any single user's value: the producer is able to "aggregate demand." The need to communicate is the second factor differentiating producer innovators from single user innovators. To sell goods, one's customers have to know the innovation exists. In effect a producer innovator must split its (net) revenue between design cost and communication cost, and still have something left over. Thus, if communication costs fall because of technological progress, a producer innovator may become viable even if design cost stays the same. (In figure 2, consider the impact of an exogenous drop in communication cost from c_2 to c_1.)

3.5 Open collaborative innovation

Consider finally the model of open collaborative innovation. Recall that open collaborative innovation projects involve users and others who share the work of generating a design and also reveal the outputs from their individual and collective design efforts openly for anyone to use. In such projects, some participants benefit from the design itself – directly in the case of users, indirectly in the case of suppliers or users of complements that are increased in value by that design. Each of these incurs the cost of doing some fraction of the work but obtains the value of the entire design, including additions and improvements generated by others. Other participants obtain private benefits such as learning, reputation, fun, etc that are not related to the project's innovation outputs. For ease of exposition, we will derive the bounds of the model for user innovators first, and then consider the impact of other participants on those bounds.

For the contributing user innovators, the key advantage of open collaborative innovation is that each contributor can undertake some of the work but rely on others to do the rest (von Hippel and von Krogh, 2003; Baldwin and Clark, 2006 b). This ability to divide up design tasks eliminates the design cost bound, $d < v_s$, that made large-scale innovations infeasible for single user innovators.

Communication costs, however, are a major concern for open collaborative innovation projects. To divide their work effectively, and then to put it back together to form a complete design, contributors must communicate with one another rapidly and repeatedly. This means that low communication costs, as recently enabled by the Internet, are critical to the viability of the open collaborative innovation model.

User innovators will choose to participate in an open collaborative innovation project if the increased communication cost each incurs by joining the project is more than offset by the value of designs obtained from others. To formalize this idea, assume that a large-scale innovation opportunity is perceived by a group of N communicating designers. As rational actors, each member of the group (indexed by i) will estimate the value of the large design and parse it into two subsets: (1) that part, valued at v_{si}, which the focal individual can complete himself at a reasonable cost (by definition, $v_{si} > d_{si}$); and (2) that part, valued at v_{oi}, which would be "nice to have", but which he cannot complete at a reasonable cost given his skills and other sticky information on hand (by definition $v_{oi} \leq d_{oi}$).

We assume that member i has the option to communicate his portion of the design to other members and receive their feedback and complementary designs at a cost c. It makes sense for i to share his designs if he expects to receive more value from others than his communication cost. His expected benefit from communicating can be parsed into (1) the probability, ρ_j that member j will respond in kind; (2) the fraction (α_j) of the remaining design that member j can provide; (3) the value v_{oi} that i may obtain from others. As a rational actor, member i will communicate his design to the other members of the group, if:

$$\sum_{j \neq i}^{N-1} \rho_j \cdot \alpha_j \cdot v_{oi} > c \quad . \tag{5}$$

This is the first bound on the open collaborative innovation model. It establishes the importance of communication cost and technology for the viability of the open collaborative model of innovation. The lower the cost of communicating with the group, the lower the threshold other members' contributions must meet to justify an attempt to collaborate. Higher communication costs affect inequality (5) in two ways: they increase the direct cost of contributing and they reduce the probability that others will reciprocate. It follows that if communication costs are high, an open collaborative project cannot get off the ground. But if communication costs are low for everyone, it is rational for each member of the group to contribute designs to the general pool and expect that others will contribute complementary designs or improve on his own design. This is in fact the pattern observed in successful open source projects and other forums of open collaborative innovation (Raymond, 1999; Franke and Shah, 2003; Baldwin et. al. 2006; Lakhani and von Hippel, 2009).

The second bound determines the maximum scale of the design. If there are *N* members of the group and each contributes his or her own part, the total design investment will be the sum of their individual design costs. The upper bound on design cost is then:

$$\sum_{i=1}^{N} d_{si} < \sum_{i-1}^{N} v_{si} = N\overline{v}_s \quad ; \tag{6}$$

where $\overline{v}_s$ is the average value each places on his or her own portion of the design. Note that this bound is *N* times greater than the bound on the design cost of the average single user innovator. Thus given low-enough costs of communication, open collaborative user innovators operating within a task-divisible and modular architecture can pursue much larger innovation opportunities than single user innovators acting alone.

Open collaborative projects, as we said earlier, may attract participants who are *not* in a position to benefit from the design produced by the project, but are instead motivated by such incentives as learning, reputation, and the fun of participation. For such contributors, the sum of their design cost and communication cost must be less than whatever benefit they do obtain from the project. Thus, instead of inequality (5), the non-user's (*nu*) criterion for contributing is "does my expected benefit – such as reputational benefits - exceed the sum of my design and communication costs?"

$$\rho_{nu} \cdot v_{nu} > d_{nu} + c_{nu} \tag{5'}$$

Other things equal, this bound is more likely to be satified if the non-users' communication costs are low. Thus communication costs constrain non-user participants as well as users.

The presence of non-users further relaxes the bound on the scale of the design. If there are M non-users in addition to N users contributing to the design, the upper bound on total design value is:

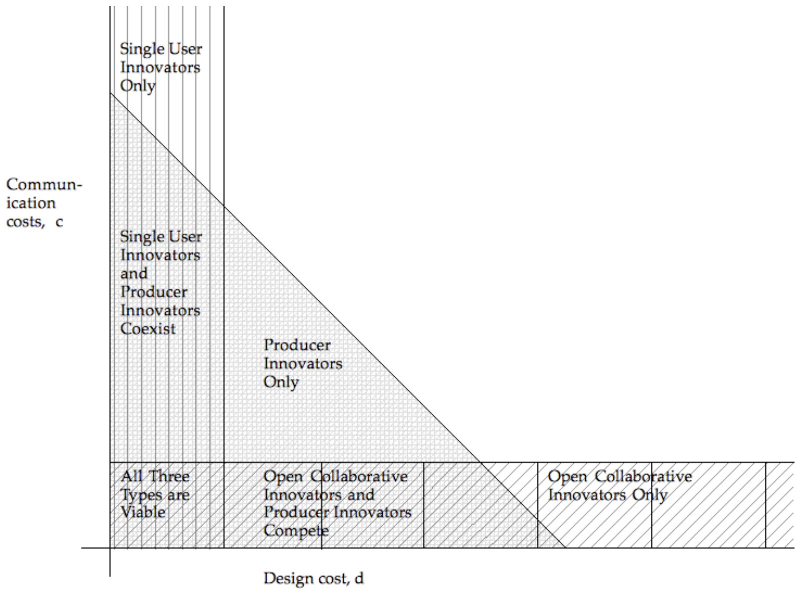
$$\sum_{i=1}^{N} d_{si} + \sum_{nu=1}^{M} d_{nu} < N\overline{v}_s + M\overline{w}_{nu} \quad ; \qquad (6')$$

where $\overline{w}$ is value of participating (net of communication cost) to the average non-user. Thus the scale of an open collaborative project is expanded—and may be greatly expanded—by attracting non-users who value learning, fun, reputation, etc. more than the design itself.

All in all, the two bounds indicate both the limitations and the possibilities associated with the open collaborative innovation model. The first bound [(5) and (5')] shows that this mode of innovation is severely restricted by communication costs. If the value of the "other" part of the system is low or the expectation that others will actually contribute is low relative to the cost of communication, single user innovators will "stick to their knitting" and not attempt to collaborate, and non-user participants will find some other outlet for their talents. But if communication costs are low enough to clear these hurdles, then the second bound [(6) and (6')] shows that, using a modular design architecture as a means of coordinating their work, a collaborative group can develop an innovative design that is many times larger in scale than any single member of the group could manage alone.

Figure 3 places all three models of innovation—single user innovation, producer innovation and open collaborative innovation—in the same figure. The shadings and text in the figure indicate areas in which one, two or all three models are viable. Basically, single user innovation is viable when design costs are low, for any level of communication cost. Open collaborative innovation is viable when communication costs are low, for high levels of design cost, as long as the design can be divided into modules that one or a few contributors can work on independently. Producer innovation is viable when the *sum* of design and communication costs falls below the producer's expected net revenue as indicated by the negative 45-degree line.

Figure 3: Bounds of viability for all three innovation models



3.6 Bringing Back Production and Transaction Costs

At the beginning of this section, in order to focus on the contrasting effects of design and communication costs on the three models of innovation, we made the simplifying assumption that production costs and transaction costs were similar across all three, and so had no effect on any model's viability relative to the other two. We did this by defining the value of the design (v_i) as the total value of the innovation to the innovator (V_i) minus the costs of production and transactions:

$$v_i \equiv V_i - u_i - t_i \quad . \tag{7}$$

(Subscripts indicate that values and costs may differ across individuals and models.)

From this definition it is clear that if production costs or transaction costs are systematically higher for a particular model of innovation, then for the same willingness-to-pay (V_i), there will be less value in the design (v_i) to cover the "upstream" costs of design and communication. The range of viability for the model with higher costs is then reduced. In terms of the bounds derived above, the single user innovator's bound would move to the left, the producer's bound would move toward the origin; and the open colloborative project's bounds would move both down and left.

We now consider whether there are systematic differences in production or transaction costs across the three models.

Production Costs. At the start of this section, we explained that a design is the *information* required to produce a novel product or service – the "recipe." For products that themselves consist of information such as software, production costs are simply the cost of copying and instantiating the design. For digitized products and services, these costs are very low. In the case of a physical products, however, the design recipe must be converted into a physical form before it can be used. In such cases, the input is the design instructions —the recipe—plus the materials, energy, and human effort specified in those instructions; the output is a good—the design converted into usable form.

One of the major advantages producers have historically had over single user innovators and open collaborative innovation projects is, of course, economies of scale with respect to mass production technologies. Mass production, which became widespread in the early 20th Century is a set of techniques whereby certain physical products can be turned out in very high volumes at very low unit cost (Chandler, 1977). The economies of scale in mass production generally depend on using a single design (or a small number of designs) over and over again. In classic mass production, changing designs interrupts the flow of products and causes setup and switching costs, which reduce the overall efficiency of the process. There is no room for variety, as indicated by Henry Ford's famous quote, "[A] customer can have a car painted any color ... so long as it is black." (Ford, 1922, Chapter 4.)

Can single user innovators or open collaborative innovation projects, convert their various designs into a physical products that will be economically competitive with the products of mass producers? Increasingly, the answer is 'Yes'. Consider that, today, modularization is affecting the interface between design and production, as well as the interfaces between design tasks. This means that mass producers can design their production technologies to be independent of many of the specifics of the designs they produce. Such processes are said to provide "mass customization" (Pine, 1993; Tseng and Piller, 2003). When mass customization is possible—that is, when designs are no longer for *technical* reasons tied to production technologies—producers can in principle make their low-cost, high-throughput factories available for the production of designs created by single users and collaborative open projects.

Some producers might resist this idea, wanting to capture profits from a proprietary design as well as proprietary production capabilities. But, if there is competition among producers, some will be willing to produce outside designs as well as their own and forgo the rents they formerly obtained from proprietary designs. Indeed, this possibility is manifest in many industries where "toll" production is common. For example, "silicon fabs" produce custom designs to order via very sophisticated and expensive production processes, as do producers of specialty chemicals.

Nevertheless, even when it is technically feasible to modularize design and production, users might still value standardized goods and services that are reliably the same in different places and at different times. In effect, the value of innovation for such goods and services is low relative to the value of other attributes such as safety, familiarity, or guaranteed performance. Single user innovators and open collaborative innovation projects are not well-suited to designing mass-produced products requiring product-specific production systems. Thus we expect producer innovators to continue to have an advantage in designing and producing mass-produced goods and services for large numbers of people.

Transaction costs. If producer innovators have a production cost advantage for some (but not all) production technologies, free-revealing single user and open collaborative innovators have an advantage with respect to transaction costs. As indicated, the transaction costs of innovation include the cost of establishing exclusive rights over the innovative design, for example through secrecy or by obtaining a patent. Also included are the costs of protecting the design from theft: for example, by restricting access, and enforcing non-compete agreements (Teece, 2000; Marx, Strumky and Fleming, 2009). Finally transaction costs include the costs of legally transferring rights to the good or service embodying the innovation, receiving compensation, and protecting both sides against opportunism (Williamson, 1985; Baldwin, 2008).

Producer innovators must incur transaction costs. By definition, they obtain revenue and resources from compensated exchanges with users, employees, suppliers, and investors. A considerable amount of analysis in the fields of economics, management, and strategy considers how to minimize transaction costs by rearranging the boundaries of firms or the structure of products and processes. (For reviews of this literature, see Williamson, 2000, and LaFontaine and Slade, 2007.) The bottom line is that for producer innovators, transaction costs are an inevitable "cost of doing business."

Single user innovators incur transaction costs when they seek to assert exclusive rights over their innovative designs. Patents on internal processes and equipment, the enforcement of secrecy and "need-to-know" policies within a firm, and non-compete agreements with key employees are all visible evidence of transaction costs that single user innovators incur to protect valuable intellectual capital. In such cases, as rational actors, single user innovators would have to find a net gain after subtracting *both* design and transaction costs from the expected value of an innovative design to themselves.

However, single user innovators have a choice as to which innovations are worth protecting and which are not. As discussed in the literature review, empirical research suggests that single users innovators generally do not treat all or even most of their innovations as valuable property that must be sequestered within their walls. They often find it more practical and profitable to freely reveal their designs, in order to achieve network effects, reputational advantages, and other benefits. By definition, when single user innovators freely reveal an innovation, they do not incur transaction costs, and the region of viability for the innovation opportunity is thereby expanded.

Open collaborative innovation projects do not sell products nor do they pay members for their contributions. In this respect, they do not incur transaction costs of exchange. However, when an open collaborative project becomes large and successful, its members generally find that they must incur costs to protect the now-valuable design from malfeasance and expropriation. For example, virtually all large open source projects have a system of hierarchical access that prevents anyone from changing the master copy of the source code without authorization by a trusted member of the project. The General Public License (GPL) was explicitly designed to protect the rights of users to view, modify and distribute code derived from the licensed code (Stallman, 2002; O'Mahony 2003). The costs of restricting access and of editorial review, and the costs of enforcing the GPL are like classic transaction costs in that they assert and enforce property rights in order to prevent vandalism and theft.

Notwithstanding these necessary expenditures, open collaborative innovation projects do avoid the "mundane transaction costs" of defining, counting and paying for goods in formal legal transactions (Baldwin, 2008). Their contributors do not have to figure out what to sell, how much to charge, or how to collect payment — costly activities that producers must perform in the normal course of business. In this respect, open collaborative innovation projects (and free revealing single user innovators) have a transaction cost advantage over producer innovators.

Regulation is also a transaction cost. Drugs, commercial aircraft, and automobiles are among the product types that must meet heavy safety-related regulatory burdens before being allowed to enter the marketplace. Regulation in the form of standard-setting affects many other industries such as telecommunications. Within our theoretical framework, one can think of regulation and standard-setting as tending to move design and communication costs upward, possibly taking them outside the bounds of viability for single user and open collaborative innovators, into the region where producers alone are viable.

4. Discussion

There is a widespread and longstanding perception among academics, policy makers and practitioners that producer innovation is the primary mode of innovation in market economies. In this view, innovations are undertaken by firms that can aggregate demand, or not at all. In the 1930s, Joseph Schumpeter placed producers at the center of his theory of economic development, saying: "It is … the producer who as a rule initiates economic change, and consumers are educated by him if necessary." (Schumpeter, 1934, p. 65.) Sixty years later, David Teece echoed Schumpeter: "In market economies, the business firm is clearly the leading player in the development and commercialization of new products and processes" (Teece, 1996, p. 193; see also 2002, p. 36). William Baumol placed innovation at the center of his theory of oligopolistic competition: "in major sectors of US industry, innovation has increasingly grown in relative importance as a instrument used by firms to battle their competitors" (Baumol, 2002, p. 35).

However, like all human endeavors, the organizations and institutions that create innovations are historically contingent. They are solutions to the problems of a specific time and place using the technologies of that time and place. It is the case that, until quite recently, centralized groups within firms were the most economical way to design *mass-produced* products and related production processes. Four technological factors contributed to the pre-eminence of mass-produced products in the economy. First, computational resources were scarce thus the cost of creating individual designs was quite high. Second, there was a close tie between design of items to be produced and the complex requirements of mass production technologies. Third, modular design methods were not well understood. And fourth, cheap, rapid communication enabling distributed design among widely separated participants in a design process was not technically possible. Taken together, these factors made it cheaper to design mass-produced products centrally, and in conjunction with the manufacturing processes that would be used to produce them. Given these conditions, it is reasonable to speculate that Schumpeter and later Teece and Baumol were simply observing the most visible innovation processes of their times when they stated that producers (business firms) were the leading developers of innovation in market economies.

Today, as was mentioned earlier, conditions facing would-be innovators are changing rapidly and radically. Just as the rise of producer innovation was enabled by interdependencies beween centralized product design and the technologies of mass production, today the rapid growth of single user and open collaborative innovation is being assisted by technologies that both enhance the capabilities of individual designers and support distributed, collaborative design projects. These technologies include: powerful personal computers, standard design languages, representations, and tools; the digitization of design information; modular design architectures; and low-cost any-to-any and any-to-all communication via the Internet. Of course, we should remember that the institutions of single user and open collaborative innovation have long existed (Rosenberg 1976; von Hippel 1976; Shah 2005). However, they are growing more prominent today because of the largely exogenous technological developments just mentioned.

Technological trends suggest that both design costs and communication costs will be further reduced over time. To visualize this effect in terms of the bounds on viability of the three institutions we have been discussing here, imagine figure 3 being populated with numerous points each representing an innovation opportunity. As design and communication costs fall, each point would move down and to the left. As a result of this general movement, some points would cross the thresholds of viability for single user and open collaborative innovation. Increasing standardization and conversion of some designs from small-scale to mass production would cause some points to move in the opposite direction, against the general trend. But for the most part, technological progress along both dimensions of cost will have the effect of moving whole classes of innovation opportunities from the region where only producer innovation is viable to regions where single user innovation or collaborative innovation are also viable. In these cases, what was previously a dominant model—the only feasible way to cover the costs of innovation—becomes subject to competition from other, newly viable models. This means that producer innovators increasingly must contend with single user innovators and open, collaborative innovation projects as alternative sources of innovative products, processes and services.

Prior research allows us to elaborate on this basic pattern in several interesting ways, as we discuss next.

4.1 Interactions between the three models

From figure 3 it is evident that for some combinations of design and communication costs, two or even all three models of innovation will be viable. How will the presence of one influence the other(s)? In other words, how will the models interact?

When single user innovation and producer innovation are both viable, the single user innovators must evaluate an innovation opportunity, not only in relation to their design cost, but also in relation to the producer's product and price. If the producer offers a good-enough product at a low-enough price, purchasing the innovation may dominate developing it in-house, and some single user innovators may switch to becoming customers of the producer. (This happens regularly when companies switch from custom software developed by an in-house IT department to off-the-shelf, purchased software.) To attract users who can innovate on their own, a producer's price must be less than the user's design cost, which by definition is less than the user's value: $p < d_s < v_s$. Given users with a range of design capabilities and costs, rational producers are likely to target as customers users with high design costs, and leave single user innovators to work out their own solutions.

Because of their distinct roles, it is possible for producer innovators and single user innovators to have a symbiotic relationship. Empirical studies have shown that most single user innovation is done by a subset of all users called "lead users" that are ahead of the bulk of the market with respect to an important trend and also have a high incentive to innovate to solve needs they encounter at the leading edge (von Hippel 1986). Often, lead users have no interest in commercializing their innovations. However, these innovations may serve as an attractive source of field-tested product prototypes for producers. By monitoring and incorporating lead user innovations into their own offerings, producer innovators may enhance their product and service offerings, while at the same time reducing their design costs and increasing their likelihood of success in the marketplace (Lilien et al 2002, von Hippel 2005).

User innovations that are widely distributed at no cost can also become an important source of complementary products for producers. For example, open source software has become an important complementary source of code for many software producers. In the presence of open source codebases, a software producer can focus on developing one or a few modules of a larger system, without leaving itself vulnerable to the threat of holdup by suppliers of complementary code (Baldwin, 2008; Henkel and Baldwin, 2009).

4.2 Hybrid innovation models

Hybrids of the three basic models thrive in the real world. This is because the architecture of a design to achieve a given function can often take a number of forms – and different architectures may be suited to development by one or a combination of our three basic models. For example, producers or users can choose to modularize a product architecture into a mix of large, monolithic elements suitable for investment only by producers, plus many smaller elements suited for development by single user innovators or open collaborative innovation projects. We can see this pattern when producers develop expensive and complex platforms such as central processing unit (cpu) chips for computers. Software that runs on standardized cpus is developed by single users, by for-profit producers, and by open collaborative projects. However, to date, the cpu chips themselves have been developed as monolithic projects by single producers such as Intel (Colwell, 2005). Another example is the development of software "engines" for computer games by producer firms, upon which platform individual gamers or groups of gamers acting collaboratively develop "mods" (Jeppesen 2004).

Large, monolithic innovation design projects, which have traditionally been in the producer-only zone of figure 3 may be shifted to other regions of the figure not only as a result of steady declines in design and communication costs, but also as a result of the re-architecting of traditional, producer-centered design approaches. For example, drug development costs are commonly argued to be so high that only a producer innovator, buttressed by strong intellectual property protection for drugs, can succeed. Increasingly however, we are learning how to subdivide drug trials—a large cost traditionally borne by drug producers—into elements suitable for voluntary, unpaid participation by users acting within a collaborative open innovation framework. This possibility has recently been illustrated in a trial of the effects of lithium on ALS (Lou Gehrig's disease) carried out by ALS patients themselves with the support of a toolkit and website developed by the firm PatientsLikeMe.

4.3 Implications for social welfare

New knowledge is a non-rival, partially excludable good (Romer, 1990). The use of a design by one person does not inherently preclude its use by others. With rare exceptions such as the design of dangerous goods, society *benefits* if designs are public goods, available to anyone to use or study at no charge (Machlup and Penrose, 1950; Nelson, 1959; Arrow, 1962).

However, from the time of the Enlightenment, many have held the view that providing inventors with incentives in the form of property rights to their "writings and discoveries" would induce them to invest in the creation of useful new ideas, i.e., innovations. This theory was expressed in the U.S. Constitution, which sanctioned the creation of intellectual property: "[Congress shall have the power] — To promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries." Abraham Lincoln, himself the holder of a patent, approved: "The patent system … added the fuel of interest to the fire of genius, in the discovery and production of new and useful things." (Lincoln 1858).

Of course, it was also known that grants of intellectual property rights would create undesirable monopolies. Producers create deadweight losses when they exploit intellectual property rights to reap monopoly profits and spend money to protect or extend their monopoly positions. Indeed while a system of intellectual property rights was enshrined in the U.S. Constitution, patent systems were extremely controversial in Europe during the second half of the 19th century. (Machlup and Penrose, 1950; Penrose, 1951; MacLeod, 2007.)

The work in this paper and that of many others, suggests that this traditionally-struck 'devil's bargain' may not be beneficial. First, there is increasing evidence that intellectual property protection does *not* increase innovation. As we saw in section 2.2, studies carried out over 40 years do not find that firm managers are inclined to increase their innovation investments due to the availability of patent grant protections. There are also many examples in which strong intellectual property rights may have impeded subsequent progress (Dosi, Marengo and Pasquali, 2006; Merges and Nelson, 1994). Indeed, recent empirical work has actually shown a *negative* relationship between patenting and subsequent progress in both biotechnology (Murray and Stern 2007) and software (Bessen and Meurer 2008). Second, the ascendent user and open collaborative innovation models that we have discussed in this paper mean that alternatives that are open by participants' free choice – and to the economic benefit of those participants – are now ascendent alternatives to the traditional, closed producer innovation model. And openness, as we noted above, increases social welfare, other things equal.

4.4 Implications for government policy

If open collaborative innovation and open innovation by single users are indeed social welfare-enhancing relative to closed producer innovation and closed user innovation, an important question for policymakers then immediately emerges: Are government policies currently at least even-handed with respect to these innovation models? Or do they on balance encourage closed innovation relative to open user and open collaborative innovation? We suspect the latter is the case.

Essentially all governments have invested heavily to create the intellectual property rights infrastructure needed for innovators to either maintain exclusivity in the use of their innovations or to sell them for a fee. Indeed, even today there is an impetus in public policy in many countries to strengthen intellectual property rights in order to foster innovation. (See Blaxill and Eckardt, 2009, Chapter 8, on efforts to strengthen intellectual property rights in China, India and Japan.)

Beyond such infrastructural investments, governmental incentives and exhortations to obtain and use intellectual property rights are endemic. For example, departments of the US government allow – one might even say encourage - firms and individuals to retain title to inventions developed with government funds, in order to "promote commercialization of federally funded inventions" (NIH 2003). Government-funded business assistance programs also invariably teach that acquiring intellectual property rights is the sensible, business-like thing to do. Thus SCORE, a non-profit business advisory organization funded by the U.S. Small Business Administration advises: *"5 Tips on Patents* If your company has an invention that you think is patentable, take steps at once. You may lose your right to patent it if you offer it for sale or disclose it publicly without patent protection." (SCORE 2008)

The roots of this apparent bias in favor of closed, producer-centered innovation are certainly understandable – the ascendent models of innovation we have discussed in this paper were less prevalent before the radical decline in design and communication costs brought about by computers and the Internet. But once the welfare-enhancing benefits of open single user innovation and open collaborative innovation are understood, policymakers can – and we think should - take steps to offset any existing biases. Examples of useful steps are easy to find.

First, as was mentioned earlier, intellectual property rights grants can be used as the basis for licenses that help keep innovation open as well as keep it closed (O'Mahony 2003). Policymakers can add support of "open licensing" infrastructures such as the Creative Commons license for writings, and the General Public License for open source software code, to the tasks of existing intellectual property offices. More generally, they should seek out and eliminate points of conflict between present intellectual property policies designed to support closed innovation, but that at the same time inadvertently interfere with open innovation.

Second, as design costs fall, many more innovations will originate with single users. Unlike participants in open collaborative innovation projects many single users have no institutionalized system for sharing. They share or do not share *ad hoc.* Policymakers should therefore develop systems to encourage and support free revealing of innovations by single user innovators. They could, for example, institute a system of tax credits analogous to R&D tax credits for innovators that freely reveal well-documented results of their private innovation developments. Documentation of qualifying innovations might take a form analogous to a patent, vetted for novelty by patent office examiners, and then granted "open patent" status.

Third, just as in the case of single user innovators discussed previously, it would be useful to create policies that reward openness by sponsors of collaborative projects. Many collaborative innovation projects exist in which the innovation-related information generated is *closed* rather than open. How is this possible? Basically there are two reasons why the outputs generated by a collaborative innovation project are open rather than closed. In the first place, when project participants are users of project output, open access to that output is an incentive that induces them to participate (see the analysis in section 3.5 above). In the second place, when effective problem-solving requires contributors to know and understand the solution being developed, open access is the low-cost default solution.

Sponsors of collaborative projects can close and own the innovative output of a collaborative project if they can create a project that escapes these two constraints. To escape the first, sponsors can create incentives that will attract *non*-user contributors to their project. For example, they can offer payment, or process-related rewards such as learning or fun (Raymond, 1999; Lerner and Tirole, 2002; Lakhani and Wolf, 2005; Benkler 2006). To escape the second constraint, project sponsors can employ an extreme form of modularity in which no participant knows (or needs to know) what the others are doing, and only the sponsor sees everything.

Finally, open collaborative innovation projects thrive, as we have seen, upon low communication costs. In recent history, these low costs have resulted from steady advances in Internet distribution capabilities in conjunction with open standards. A lack of policy attention to these critical infrastructural factors can threaten or reverse this progress. For example, a firm that owns both a channel and content (e.g., a cable network) may have strong incentives to shut out or discriminate against open content in favor of content it owns. The transition from the chaotic, fertile early days of radio in the United States when many voices were heard, to an era in which the spectrum was dominated by a few major networks—a transition pushed by major firms and enforced by governmental policy making—provides a sobering example of what can happen (Lessig 2001). It will be important for policy makers to be aware of this kind of incentive problem and address it—in this case perhaps by mandating "net neutrality," or that ownership of content and ownership of channel be separated, as has long been the case for other types of common carriers (Zittrain 2009).

We conclude by observing again that we belive we are in the midst of a major paradigm shift: technological trends are causing a change in the way innovation gets done in advanced market economies. As design and communication costs exogenously decline, single user and open collaborative innovation models will be viable for a steadily wider range of design. They will present an increasing challenge to the traditional paradigm of producer-based design – but, when open, they are good for social welfare and should be encouraged.

Acknowledgements

We thank Jeroen de Jong, Karim Lakhani, Scott Stern, and conference and many seminar participants at DRUID, Harvard Business School, and the MIT Sloan School, for comments and suggestions that led to significant improvements of this paper.

References

Alchian, Armen A. and Harold Demsetz (1972) "Production, Information Costs, and Economic Organization," *American Economic Review* 52:777-795.

Allen, R. C. (1983) "Collective Invention." *Journal of Economic Behavior and Organization* 4(1): 1-24.

Aoki, Masahiko (1988) *Information, Incentives, and Bargaining in the Japanese Economy*, Cambridge University Press, Cambridge, UK.

Aoki, Masahiko (2001) *Towards a Comparative Institutional Analysis*, Cambridge, MA: MIT Press.

Arrow, Kenneth J. (1962) "Economics of Welfare and the Allocation of Resources for Invention," in *The Rate and Direction of Inventive Activity*, (R. R. Nelson, ed.) Princeton, NJ: Princeton University Press, pp. 609-625.

Arundel, A. (2001). "The Relative Effectiveness of Patents and Secrecy for Appropriation." *Research Policy* 30(4): 611–624.

Arundel, Anthony and Viki Sonntag (1999) Patterns of Advanced Manufacturing Technology (AMT) Use in Canadian Manufacturing: 1998 AMT Survey Results, Catalogue No. 88F0017MIE, No. 12, Ottawa: Statistics Canada.

Baldwin, Carliss Y. (2008) "Where Do Transactions Come From? Modularity, Transactions and the Boundaries of Firms," *Industrial and Corporate Change* 17(1):155-195.

Baldwin, Carliss Y. and Kim B. Clark (2000) *Design Rules, Vol. 1: The Power of Modularity*, MIT Press, Cambridge, MA.

Baldwin, Carliss Y. and Kim B. Clark (2006a) "Between 'Knowledge' and the 'Economy': Notes on the Scientific Study of Designs," *Advancing Knowledge and the Knowledge Economy*, (B. Kahin and D. Foray, eds.) Cambridge, MA: MIT Press.

Baldwin, Carliss Y. and Kim B. Clark (2006b) "The Architecture of Participation: Does Code Architecture Mitigate Free Riding in the Open Source Development Model?" *Management Science* 52(7):1116-1127.

Baldwin, Carliss Y., Christoph Hienerth and Eric von Hippel (2006) "How user innovations become commercial products: a theoretical investigation and case study" *Research Policy,* Vol 35 No. 9 (November) pp. 1291-1313

Benkler, Yochai (2002) "Coase's Penguin, or Linux and the Nature of the Firm," *Yale Law Journal*, 112(3):369-447.

Benkler, Yochai (2006) *The Wealth of Networks* Yale University Press, New Haven CT.

Bessen, James and Michael Meurer (2008) *Patent Failure: How Judges, Bureaucrats, and Lawyers Put Innovators at Risk*, Princeton University Press, Princeton, NJ

Blaxill, Mark and Ralph Eckhardt (2009) *The Invisible Edge: Taking Your Strategy to the Next Level Using Intellectual Property*, New York, NY: Portfolio.

Chandler, Alfred D. (1962) *Strategy and Structure*, Cambridge, MA: MIT Press.

Chandler, Alfred D. (1977) *The Visible Hand: The Managerial Revolution in American Business*, Cambridge, MA: Harvard University Press.

Cohen, W. M., A. Goto, A. Nagata, R. R. Nelson and J. P. Walsh (2002). "R&D Spillovers, Patents and the Incentives to Innovate in Japan and the United States." *Research Policy* 31(8-9): 1349–1367.

Cohen, W. M., R. R. Nelson and J. P. Walsh (2000). *Protecting their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or not).* NBER Working Paper 7522.

Colfer, Lyra (2009) "Decoupling Product Architecture from Organizational Structure: When and How Organizations "Break the Mirror" unpublished manuscript (September).

Colwell, Robert P. (2005) *The Pentium Chronicles: The People, Passion, and Politics Behind Intel's Landmark Chips*, Hoboken, NJ: Wiley-IEEE Computer Society de Jong, Jeroen P. J., and Eric von Hippel (2009) "Transfers of user process innovations to process equipment producers: A study of Dutch high-tech firms" *Research Policy* (September) Vol 38, No 7 pp 1181-1191.

Demsetz, Harold (1988) "The Theory of the Firm Revisited," *Journal of Law, Economics and Organization*, 4(1):141-161.

Dosi, Giovanni and Richard R. Nelson (2010) "Technical Change and Industrial Dynamics as Evolutionary Processes," in *Handbook of Innovation* (B. Hall and N. Rosenberg, eds.) Amsterdam: North Holland.

Dosi, Giovanni, Marengo, Luigi, Pasquali, Corrado (2006) "How much should society fuel the greed of innovators? On the Relations Between Appropriability, Opportunities and Rates of Innovation," *Research Policy* 35 (8), 1110-1121.

Elrod, T. and A. P. Kelman (1987). "Reliability of New Product Evaluation as of 1968 and 1981." *Owen Graduate School of Management, Vanderbilt University.* Working Paper.

Enos, J. L. (1962). *Petroleum Progress and Profits: A History of Process Innovation.* Cambridge MA: MIT Press.

Fama, Eugene F. and Michael C. Jensen (1983 a) "Separation of Ownership and Control" *The Journal of Law and Economics*, 26(2): 301-325.

Fama, Eugene F. and Michael C. Jensen (1983 b) "Agency Problems and Residual Claims," *The Journal of Law and Economics*, 26(2): 327-349.

Ford, Henry (1922) My Life and Work, Garden City, NY: Garden City Publishing Company, available at http://books.google.com/books?id=4K82efXzn10C&pg=PA72&dq=%22My+Life+and+Work%22+%22it+is+black%22#v=onepage&q=&f=false (viewed November 2009).

Foray, D. (2004). *Economics of Knowledge.* Cambridge, MA: MIT Press.

Franke, N. and E. von Hippel (2003). "Satisfying Heterogeneous User Needs via Innovation Toolkits: The Case of Apache Security Software." *Research Policy* **32**(7): 1199-1215.

Franke, N. and S. Shah (2003). "How Communities Support Innovative Activities: An Exploration of Assistance and Sharing Among End-Users." *Research Policy* 32(1): 157-178.

Freeman, C. (1968). "Chemical Process Plant: Innovation and the World Market." *National Institute Economic Review* 45(August): 29-57.

Gallini, Nancy and Suzanne Scotchmer (2002) "Intellectual Property: What is the Best Incentive System?" in *Innovation Policy and the Economy, Volume 2* (A. Jaffe, J. Lerner and S. Stern, eds.) Cambridge, MA: MIT Press.

Gault, Fred and Eric von Hippel (2009) "The prevalence of user innovation and free innovation transfers: Implications for statistical indicators and innovation policy" MIT Sloan School of Management Working Paper #4722-09 (January)

Ghosh, Rishab Aiyer (1998) "Cooking Pot Markets: An Economic Model for the Free Trade of Goods and Services on the Internet," First Monday, 3(3) http://www.firstmonday.dk/issues/issue3_3/ghosh/index.html viewed 5/22/03.

Gulley, Ned and Karim R. Lakhani (2009) "The Determinants of Individual Performance and Collective Value in Private-Collective Software Innovation," Harvard Business School Working Paper (November).

Harhoff, D., J. Henkel and E. von Hippel (2003). "Profiting from Voluntary Information Spillovers: How Users Benefit by Freely Revealing their Innovations." *Research Policy* 32(10): 1753-1769.

Hart, Oliver (1995) *Firms, Contracts and Financial Structure*, Oxford, UK: Oxford University Press.

Henkel, J. (2003). "Software Development in Embedded Linux – Informal Collaboration of Competing Firms." In: W. Uhr, W. Esswein, and E. Schoop (eds.), *Proceedings der 6. Internationalen Tagung Wirtschaftsinformatik 2003*, Vol. 2: 81-99. Heidelberg: Physica.

Henkel, Joachim and Carliss Y. Baldwin (2009) "Modularity for Value Appropriation: Drawing the Boundaries of Intellectual Property," Harvard Business School Working Paper 09-097 (April).

Herstatt, C. and E. von Hippel (1992). "From Experience: Developing New Product Concepts Via the Lead User Method: A Case Study in a "Low Tech" Field." *Journal of Product Innovation Management* 9(3): 213-222.

Jacobides, Michael G. (2005). "Industry Change Through Vertical Dis-Integration: How and Why Markets Emerged in Mortgage Banking," *Academy of Management Journal*, 48(3):465-498.

Jensen, Michael C. and William H. Meckling (1976) "Theory of the Firm: Managerial Behavior, Agency Costs, and Ownership Structure," *Journal of Financial Economics,* 3(4):305-360, reprinted in *Foundations of Organizational Strategy*, Harvard University Press, Cambridge, MA.

Jensen, Michael C. and William H. Meckling (1994) "The Nature of Man," *Journal of Applied Corporate Finance*, 7(2):4-19.

Jeppesen, L. B. (2004). "Profiting from Innovative User Communities: How Firms Organize the Production of User Modifications in the Computer Games Industry." *Department of Industrial Economics and Strategy, Copenhagen Business School, Copenhagen, Denmark.* Working paper WP-04.

Lakhani, Karim R. and Eric von Hippel (2009) "No Managers Required: A case study of collaborative innovation using managerial toolkits" MIT Sloan School of Management Working Paper.

Lakhani, Karim R. and Robert G. Wolf (2005). "Why Hackers Do What They Do: Understanding Motivation and Effort in Free/Open Source Software Projects." In: J. Feller, B. Fitzgerald, S. Hissam, and K.R. Lakhani (eds.), *Perspectives on Free and Open Source Software.* Cambridge, MA: MIT Press.

Langlois, Richard N. (1986a) "The New Institutional Economics: An Introductory Essay," in *Economics as a Process* (R.N. Langlois, ed.) Cambridge: Cambridge University Press.

Langlois, Richard N. (1986b) "Rationality, Institutions and Explanation," in *Economics as a Process* (R.N. Langlois, ed.) Cambridge: Cambridge University Press.

Langlois, Richard N. (2002). "Modularity in Technology and Organization," *Journal of Economic Behavior and Organization*, 49(1):19-37.

Lerner, J. and J. Tirole (2002). "Some Simple Economics of Open Source." *Journal of Industrial Economics* 50(2): 197-234.

Lessig, L. (2001). *The Future of Ideas: The Fate of the Commons in a Connected World.* New York: Random House.

Levin, R. C., A. Klevorick, R. R. Nelson and S. G. Winter (1987). "Appropriating the Returns from Industrial Research and Development." *Brookings Papers on Economic Activity* 3: 783-820.

Lilien, Gary L., Pamela D. Morrison, Kathleen Searls, Mary Sonnack, Eric von Hippel, (2002) "Performance Assessment of the Lead User Idea Generation Process," *Management Science*, Vol 48, No 8 (August) pp. 1042-1059.

Lim, K. (2000). "The Many Faces of Absorptive Capacity: Spillovers of Copper Interconnect Technology for Semiconductor Chips." *MIT Sloan School of Management*. Working paper # 4110. Forthcoming, *Industrial and Corporate Change* (2009).

Lincoln, Abraham (1858) "Discoveries and Inventions" (Speech, April 6 *before the Young Men's Association of Bloomington, Illinois.)* http://showcase.netins.net/web/creative/lincoln/speeches/discoveries.htm (viewed September 2009).

Lüthje, C. (2003). "Customers as Co-Inventors: An Empirical Analysis of the Antecedents of Customer-Driven Innovations in the Field of Medical Equipment." *Proceedings from the 32th EMAC Conference* 2003, Glasgow.

Lüthje, C. (2004). "Characteristics of Innovating Users in a Consumer Goods Field: An Empirical Study of Sport-Related Product Consumers." *Technovation* (September)

Lüthje, C., C. Herstatt and E. von Hippel (2002). "The Dominant Role of Local Information in User Innovation: The Case of Mountain Biking." *MIT Sloan School*. Working Paper #4377-02.

Machlup, Fritz and Edith Penrose (1950) "The Patent Controversy in the Nineteenth Century," *Journal of Economic History*, 10(1):1-29.

MacLeod, Christine (2007) *Heroes of Invention: Technology, Liberalism and British Identity 1750-1914*, Cambridge, UK: Cambridge University Press.

Mansfield, E. (1968). *Industrial Research and Technological Innovation: An Econometric Analysis*. New York: Norton.

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

Marx, M., D. Strumsky, and L. Fleming (2009) Mobility, Skills, and the Michigan Non-Compete Experiment, *Management Science*, 55(6) 875-889.

Mead, Carver and Lynn Conway (1980) *Introduction to VLSI Systems.* Reading, MA: Addison-Wesley Publishing Company.

Morrison, P. D., J. H. Roberts and E. von Hippel (2000). "Determinants of User Innovation and Innovation Sharing in a Local Market." *Management Science* 46(12): 1513-1527.

Murray, Fiona and Scott Stern (2007). "Do formal Intellectual Property Rights Hinder the Free Flow of Scientific Knowledge? *Journal of Economic Behavior and Organization*, Vol. 63:4, pp. 648-687.

Nelson, Richard R. (1959) "The Simple Economics of Basic Scientific Research," *Journal of Political Economy*, 67(3):297-

306.

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

NIH Grants Policy Statement (12/03) Part II: Terms and Conditions of NIH Grant Awards Subpart A: General -- File 4 of 5, Office of Extramural Research, National Institutes of Health, U.S. Department of Health and Human Services http://grants.nih.gov/grants/policy/nihgps_2003/NIHGPS_Part7.htm#_Toc54600131 (viewed September 2009).

Nuvolari, A. (2004). "Collective Invention during the British Industrial Revolution: The Case of the Cornish Pumping Engine." *Cambridge Journal of Economics* 28(3): 347-363.

O'Mahony, S. (2003). "Guarding the Commons: How Open Source Contributors Protect their Work." *Research Policy* 32(7): 1179–1198.

Parnas, David L. (1972) "On the Criteria to Be Used in Decomposing Systems into Modules," *Communications of the ACM* 15: 1053-58.

Pavitt, Keith (1984) "Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory." *Research Policy* 13, no.6 (December 1984): 343-73.

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

Pine, J. B. II. (1993). *Mass Customization: The New Frontier in Business Competition.* Cambridge, MA: Harvard Business School Press.

Raymond, E. (1999). *The Cathedral and the Bazaar: Musings on Linux and Open Source by an accidental revolutionary.* Sebastopol, CA.: O'Reilly.

Romer, Paul M. (1990) "Endogenous Technological Change," *Journal of Political Economy*, 98(5):S71-S102

Rosenberg, N. (1976). *Perspectives on Technology.* New York: Cambridge University Press.

Sattler, H. (2003). "Appropriability of Product Innovations: An Empirical Analysis for Germany." *International Journal of Technology Management* 26(5-6): S. 502–516.

Schumpeter, Joseph A. (1934) *The Theory of Economic Development*, Cambridge, MA: Harvard University Press.

SCORE "5 Tips on Patents," http://www.score.org/5_tips_leg_8.html (viewed January 2008)

Scott W. Richard (2001) *Institutions and Organizations*, Thousand Oaks, CA: Sage Publications.

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

Shah, Sonali K. (2005) "Open Beyond Software," *Open Sources 2*, (C. Dibona, D. Cooper, and M. Stone, eds.) O'Reilly Media, Sebastopol, CA.

Simon, Herbert A. (1962) "The Architecture of Complexity," *Proceedings of the American Philosophical Society* 106: 467-482, repinted in *idem.* (1981) *The Sciences of the Artificial*, *2nd ed.* MIT Press, Cambridge, MA, 193-229.

Simon, Herbert A. (1981). *The Sciences of the Artificial, 2nd Ed.* Cambridge, MA: MIT Press.

Smith, Adam (1776). *An Inquiry into the Nature and Causes of the Wealth of Nations. 1776; 5th ed., 1789.* Modern Library Edition. Edited by Edwin Cannan. New York: Random House, 1937.

Suh, Nam (1990) *The Principles of Design*, Oxford UK: Oxford University Press.

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

Teece, David J. (1986)."Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy," *Research Policy*, 15(6): 285-305.

Teece, David J. (1996). "Firm Organization, Industrial Structure, and Technological Innovation," *Journal of Economic Behavior and Organization*, 31(2): 193-224.

Teece, David J. (2000) *Managing Intellectual Capital* Oxford, UK: Oxford University Press.

Tseng, Mitchell and Frank Piller (eds.) (2003) The Customer Centric Enterprise: Advances in Mass Customization and Personalization, New York/Berlin: Springer.

Urban, G. L. and E. von Hippel (1988). "Lead User Analyses for the Development of New Industrial Products." *Management Science* 34(5): 569-82.

von Hippel, Eric (1976) "The Dominant Role of Users in the Scientific Instrument Innovation Process," *Research Policy* 5, no. 3 (July):212-39.

von Hippel, Eric (1977) "The Dominant Role of the User in Semiconductor and Electronic Subassembly Process Innovation," *IEEE Transactions on Engineering Management* EM-24, no. 2 (May):60-71.

von Hippel, Eric (1986) "Lead Users: A Source of Novel Product Concepts," *Management Science* 32, no. 7 (July):791-805.

von Hippel, Eric (2005) *Democratizing Innovation*, Cambridge, MA: MIT Press (April).

von Hippel, Eric and Georg von Krogh (2003), "Open Source Software and the "Private-Collective" Innovation Model: Issues for Organization Science" *Organization Science* 14 (2)208-223.

von Hippel, Eric and Stan N. Finkelstein (1979). "Analysis of Innovation in Automated Clinical Chemistry Analyzers." *Science & Public Policy* 6(1): 24-37.

Williamson, Oliver E. (1985). *The Economic Institutions of Capitalism*, New York, NY: Free Press.

Williamson, Oliver E. (1991) "Comparative Economic Organization: The Analysis of Discrete Structural Alternatives," *Administrative Science Quarterly*, 36(2):269-296

Winter, Sidney G. (2008) "The Replication Perspective on Productive Knowledge," manuscript (April).

Zittrain, Jonathan (2009) "The future of the Internet – and how to stop it" Caravan Books Caravanbooks.org