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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. We analyze the design costs and architectures and communication costs associated with each model. We conclude that both innovation by individual users and open collaborative innovation increasingly compete with and may displace producer innovation in many parts of the economy. We explain why this represents a paradigm shift with respect to innovation research, policymaking, and practice. We discuss important implications and offer suggestions for further research.

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

1. Introduction and Overview

Ever since Schumpeter (1934) promulgated his theory of innovation, entrepreneurship, and 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. 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. Each has a valuable role to play in the economy.

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 user firms, 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 show that under the right technological and architectural conditions, users seeking direct value can disintermediate producers seeking profit. Our analysis therefore challenges the assumption that the profits are the only economically important motive causing innovators to create new designs. Profits to innovation arise because users are willing to pay for a new or superior product or process. Thus profit itself is derived from users' willingness to pay. We are not suggesting that the profit motive is not a major stimulus to investment in innovation. But value to users is both a necessary condition for profits to exist, and an alternate motive for investing in innovative designs.

We will argue that, taken in combination, the patterns and findings we describe create a significant change in the "problem-field" in innovation research, policymaking and practice, and so represent a paradigm shift in these fields (Kuhn 1962).

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 offer suggestions for further research.

2. Literature Review

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

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. Inventors creating knowledge to sell rather than use are producers, as are those that innovate in order to manufacture and sell goods embodying or complementing the innovation.

Qualitative observations have long indicated that important process improvements are developed by employees working for firms that use them. Adam Smith (1776, 17) pointed out 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. 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) and Hienerth (2006) found that the most commercially important product innovations in several sporting fields tended to be developed by individual users.

Empirical studies also show that many users—from 6 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 firms developing process innovations for in-house use in both Canada and the Netherlands (Arundel and Sonntag 1999, Gault and von Hippel 2009, de Jong and von Hippel 2009). Finally, via a survey of a representative sample of consumers in the UK, it has been found that 6.2 percent of the UK population – about 3 million people – have recently developed or modified consumer products to better serve their personal needs (Flowers et al. 2010).

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 product and process development and modification in many fields.

2.2: Innovation Openness

An innovation is 'open' in our terminology when all information related to the innovation is a public good - non-rivalrous and non-excludable. This usage is closely related to the meaning of open in the terms 'open source software' (Raymond 1999) and 'open science'

(Dasgupta and David 1994). It differs fundamentally from the recent use of the term to refer to organizational permeability - an organization's "openness" to the aquisition of new ideas, patents, products, etc from outside its boundaries, often via licensing protected intellectual property (Chesbrough 2003).

Economic theorists have long thought that innovation openness is undesirable – 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 to society from related increases in innovation investment, and increased disclosure of information otherwise be kept hidden as trade secrets (Machlup and Penrose 1950, Penrose 1951, Foray 2004, Heald 2005).

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 innovation, 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 19th-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. In the case of consumer products, several studies have shown that it is quite rare for consumers to attempt to protect or restrict access to innovations they have developed (Shah 2000, Raasch et al. 2008, Flowers et al. 2010).

Evidence has now accumulated that innovators who elect to freely reveal their innovations, can gain significant private benefits – and also avoid some private costs. With respect to private benefits, 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 2010). 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 (2010) 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 nine, and that on average seven 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 assisting each user innovator 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 interdependent: 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: 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; Brusoni and Prencipe 2006). 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 the targeted design is small, each designer's activities will be "transparent" to his or her collaborators. Each contributor can then take separate action to improve the design, building on the transparently visible contributions of the others. In open collaborative projects, modularity and actionable transparency generally go hand in hand, with both factors contributing to the divisibility of tasks (Colfer and Baldwin 2010).

Building on arguments of Ghosh (1998), Raymond (1999), and von Hippel and von Krogh (2003), Baldwin and Clark (2006b) 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 open 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 1977, Woodward 1965, 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 transaction costs and especially Fama and Jensen's (1983a, 1983b) account of how agency costs affect organizational forms. 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 (1977) and Woodward (1965), 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) argued 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 grow 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 more common for many products and processes. In the rest of this section, we argue that these largely exogenous technological trends are making single user innovation and 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, and to be combined with user and open collaborative innovation in many settings.

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

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. Many, but not all, open source software projects have these characteristics.

A design is a set of instructions that specify how to produce a novel product or service (Simon 1981, Romer 1990, 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, the concept of solvency in finance, and the concept of equilibrium in institutional game theory.

In the 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, 1983b, 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 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, Greif 2006). 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 that "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 (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. Many of these tasks require calculations, and thus design cost is strongly affected by the cost of computation.

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 across models, a particular model of innovation is viable if and only if for each necessary contributor to the model:*

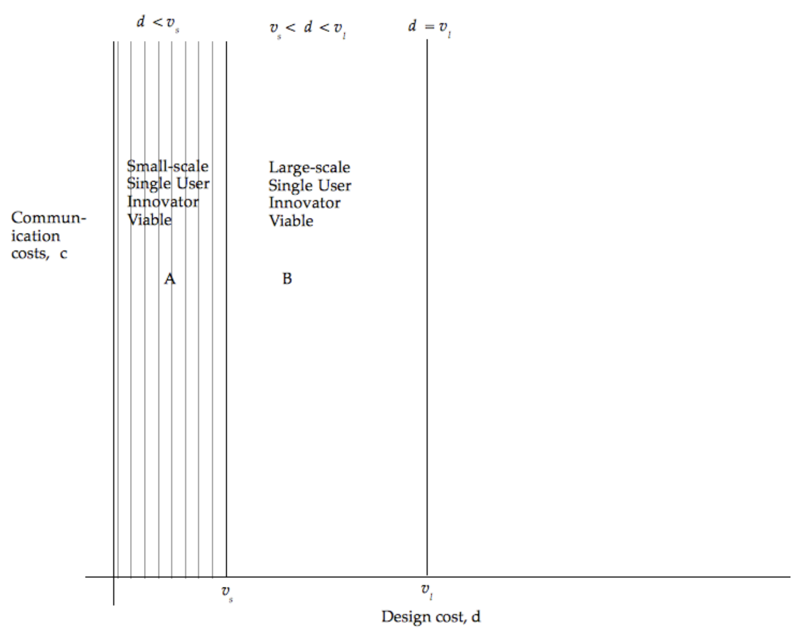
$$v_i > d_i + c_i \ . \qquad (2)$$

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. This measure of benefits includes all aspects of the innovation that the user values. It may reflect, for example, improved performance, lower cost, lower environmental impact, greater flexibility, and/or enhanced capabilities. 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.

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.

Some innovations developed by users are intended to be consumed in-house with little or no external economic impact – for example, innovations intended to improve the comfort or convenience of individual users or the safety of user firm employees. Others, especially in the case of process innovations developed by user firms, reduce the process user's costs (production, transactions, communication, design) without changing consumers' willingness to pay for the product. (When a process innovation changes the consumer's willingness to pay by changing product or context characteristics, it is at least in part a product innovation by a producer – which we consider in the next section.)

A small unit cost savings, when applied to a large volume of production, will have a large total value. Hence, as a general rule, firms running large-scale operations will be viable as user innovators in regions where small-scale firms and individual users are not. In Figure 1, innovation B is attractive only to a large-scale user, while innovation A is attractive to both large- and small-scale users. As advances in design technology progressively reduce design cost, more innovation opportunities become viable for more users. Opportunities like B shift to the left, becoming targets of design effort by smaller-scale firms and even individuals.

3.4 Producer Innovation

Producers can often 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 contribution (expected revenues net of production and transaction costs).

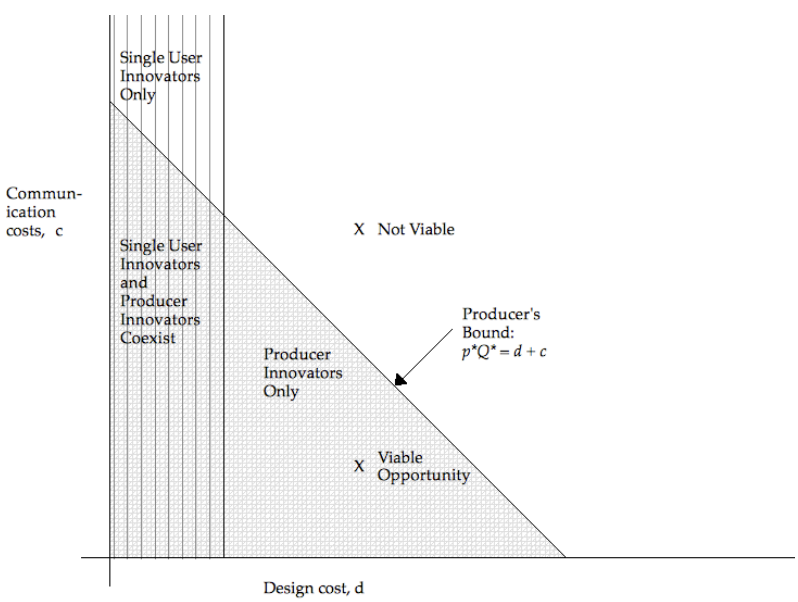
It can subtract its design (d_p) and communication (c_p) costs from this net revenue to calculate expected profit, *Π*:

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

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 three things. First, through the demand curve, a producer's profit is determined by its customers' willingness to pay. Producers' incentives are derived from and depend on users' valuations. As a general rule in a free market, without use value there can be no profit. (Products whose purchase is mandated by the state or some other authority constitute exceptions to this rule.)

Second, like large-scale single user innovators, producer innovators are affected by the size of the market for their goods. In large markets, the producer will have many customers, thus its net revenue (after production and transaction costs) will generally be far in excess of the value of the product to any one customer. Because the producer can "aggregate demand," it can invest in both product and process innovations that its own customers (acting as single user innovators) would not find attractive.

Finally, the need to communicate differentiates producer innovators from single user innovators. As was mentioned earlier, to learn about which designs and goods will be profitable to sell, producers must communicate with and learn from their potential customers via marketing research. To sell goods, a firm's potential customers have to be told about the innovative and meritorious features of the firm's products and services. The percentage of cost devoted to "marketing expenses" is a rough measure of what a given producer spends communicating with customers. 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.

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 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 2006b). The ability to divide up design tasks via modular design architectures eliminates the design cost bound, $d < v_s$, that made large-scale innovations infeasible for single user innovators.

Creating a modular architecture that supports distributed innovation across geographical and organizational boundaries will add to the upfront cost of a new design if detailed and comprehensive modularity is designed in from the start. This was famously the case, for example, for IBM's System/360 and also for Pirelli's modular integrated robotized system for tire production (MIRS) (Baldwin and Clark 2000, Brusoni and Prencipe 2006). However, modular architectures need not add significantly to costs if, as is typical modern practice, modularity is largely emergent. In such cases, the original architect designs a small functional core and a set of interfaces. New modules can then be attached to the system even if they were not originally envisaged by the architects, as long as they comply with the interface specifications. Examples of this type of architecture include the IBM PC and the Linux operating system (Ferguson and Morris 1993, Raymond 1999). Emergent modularity is compatible with the constraints of open collaborative projects, where the design cost of each contributor (including project architects) needs to be relatively low.

Communication costs 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_i. 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 total value, v_{oi} , that i can obtain from others' contributions.

As a rational actor, member i will communicate his design to the other members of the group if:

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

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 (c_i) and they reduce the probability that others will reciprocate (ρ_j). 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).

Note that open collaborative projects do not as a general rule discourage or prevent free-riding. This feature of their makeup can be understood in light of the fact that the cost of screening or other protective measures to exclude free-riders would raise communication costs and thus shrink the pool of potential contributors, hence the overall scale of the project. The network properties of the open collaborative model (the fact that the value to everyone increases as the total number of contributors increases) mean that this reduction in the contributor pool would reduce the value of the project to the contributors that remain as well as to free riders (Raymond 1999, Baldwin and Clark 2006b, Baldwin 2008).

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 do not plan to use the design created by the project, but are instead motivated by incentives such 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 ancillary contributors (denoted by the subscript *a*) criterion is "does my expected benefit – such as reputational benefits - exceed the sum of my design and communication costs?"

$$v_a > d_a + c_a \quad . \tag{5'}$$

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

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

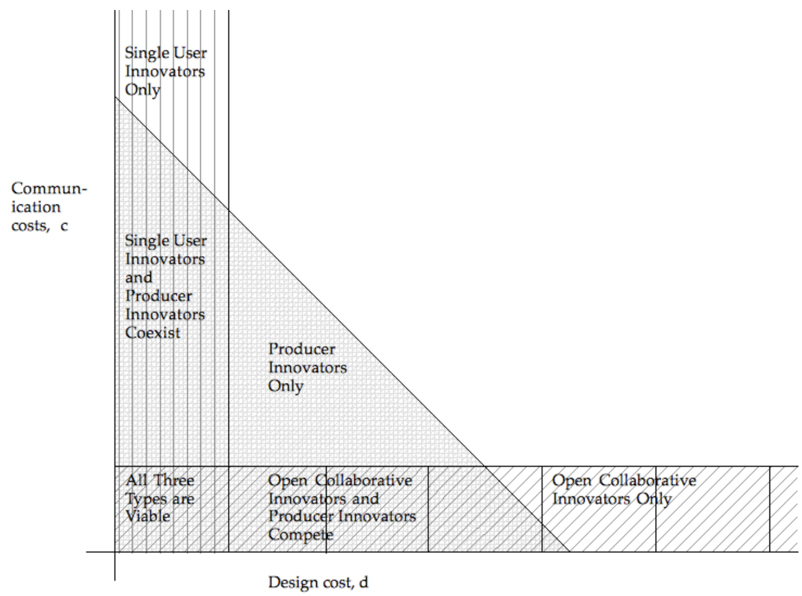
$$\sum_{i=1}^{N} d_{si} + \sum_{a=1}^{M} d_a < N\overline{v}_s + M(\overline{v}_a - \overline{c}_a) \tag{6'}$$

where $\overline{v}_a - \overline{c}_a$ is value of participating (net of communication cost) to the average ancillary contributor. Thus the scale of an open collaborative project is expanded—and may be greatly expanded—by attracting ancillary contributors who value learning, fun, reputation, etc., more than using 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 ancillary contributors 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 the 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:

$$v_i \equiv V_i - u_i - t_i \quad . \qquad (7)$$

(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 collaborative 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 now 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 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, Hounshell 1985). 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 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 particular 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 product designs 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 and contract manufacturers of consumer electronic goods (Sturgeon 2002).

Nevertheless, for a long time to come, there will continue to be instances where economies in mass production significantly depend upon careful and subtle co-design of products and product-specific production systems. In such instances, we expect producer innovators to continue to have an advantage in designing and producing goods and services for mass markets.

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, including process 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 and/or to avoid the cost of protecting their innovations. For example, many user firms that develop process equipment innovations for in-house use freely reveal them in order to get an outside source of equipment production and improvements from others (Harhoff et al. 2003, de Jong and von Hippel 2009). This free revealing decreases as the importance of process innovation as a source of competitive advantage increases (Franke and Shah 2003, Raasch et al. 2008, de Jong and von Hippel 2010). 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. 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 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, free-revealing single user innovators and open collaborative innovation projects have a transaction cost advantage over producer innovators.

Regulation can be viewed as a form of transaction cost imposed by the government on all three innovation models. 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, regulation and standard-setting tend to decrease the value of innovation opportunities, thus shrinking the bounds of viability. In Figure 3, all three bounds will move down and to the right and the areas of viability will become smaller.

4. Discussion

As we said at the start of this paper, there is a widespread and longstanding perception among academics, policymakers, and practitioners that innovation by producers 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, 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, 193; see also Teece 2002, 36). At about the same time Paul Romer made the predominance of producer innovation the basis for his model of endogenous growth: "The vast majority of designs result from the research and development activities of private, profit-maximizing firms" (Romer 1990, S74). And William Baumol placed producer 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, 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, throughout most of the 20th century, single user and open collaborative innovation were extant, but centralized R&D, product development, and process engineering groups within firms were the most economical way to design *mass-produced* products and related production processes (Chandler 1977, Hounshell 1985).

Four technological factors contributed to the pre-eminence of mass-produced products, and thus the dominance of producer and large-scale process innovators in technologically advanced economies in the early and middle parts of the 20th century. First, computational resources were scarce, and therefore the cost of creating individual designs was quite high. Second, as discussed above, there was generally a close tie between design of items to be produced and the complex requirements of process technologies. Third, modular design methods were not well understood and seldom implemented. 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 standardized and uniform products centrally and in conjunction with their manufacturing processes. Given these conditions, it is reasonable to speculate that Schumpeter and later Teece, Romer, 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, 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. 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 regions where only innovation by firms able to aggregate demand 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.

The declining cost of computation most directly affects the cost of designs that can be developed and tested on computers – and today, one is hard-pressed to think of a type of design that does not fall into this domain. Of course, computer-based design is central to the design of software. Increasingly, it is also central to the development of hardware-embodied designs ranging from consumer products to buildings. Design processes for both software and hardware generally require designers to represent different states of the design using text, pictures, and models; store and analyze data; compute rates, bounds, and tolerances; and simulate behavior under various conditions. Technologies that automate the tasks of writing, drawing, modeling, data storage and analysis, computation, and simulation all have the effect of reducing design cost.

The declining cost of communication most directly affects the design of products and services where design is informed by community trial-and-error learning. The design of physical games and the equipment used for them are an example, because the final shape of successful games only emerges via collaborative play and related redesign. Wikis like Wikipedia are an example of open collaborative innovation in the world of text: they co-exist and compete with producer-designed compendia. Social networking sites like Facebook also have features of both single user innovation (each person designs her page) and open collaborative innovation (she and friends contribute content to each others' pages).

Although not all designs are equally affected, we believe declining computation and communication costs are having enough of an impact across the economy to change the relative importance of the three different models of innovation discussed above.

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

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 potential 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.) However, to attract users who can innovate on their own, the 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 differentiated users, rational producers are likely to target as customers users with high design costs and leave those with low design costs to work out their own solutions.

Indeed, because of their distinct roles, producer innovators and single user innovators may develop 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). Some of these lead users have no interest in commercializing their innovations. However, their innovations may nonetheless serve as an attractive feedstock 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). In other instances, individual lead users may found companies for the purpose of commercializing their designs. Such firms, which generally serve market niches not large enough to attract established firms, are often the first to introduce new products into the economy (Baldwin et al. 2006, Shah and Tripsas 2007).

Open collaborative innovation projects are more likely to pose a threat to producer innovators than are single user innovators. In the first place, by attracting effort and dividing up tasks, collaborative projects can in principle match the scale of a producer's design. Second, as a matter of policy and to reduce transaction costs, open collaborative projects make their designs available to all comers a little or no charge. The existence of a free design, even if it must be adapted by end users, puts price pressure on a producer innovator. Indeed users have incentives to collaborate for this purpose precisely in those cases where the producer innovator can deter other producers from entering its market. If the price of a design will collapse on entry of a second contender, no profit-seeking producer will find the second-in opportunity attractive. In contrast, users directly gain from any price drop, hence will benefit by supporting a collaborative project aimed at breaking the producer's monopoly (Baldwin and Clark 2006b). Supporting this logic, some open source projects have been founded with the aim of preventing or breaking producers' monopolies. The most famous is the GNU Project, begun by Richard Stallman in 1984, for the express purpose of providing a free alternative to commercially owned software (Stallman 2002).

However, the openness and modularity of open collaborative projects make pure head-to-head competition with producers an unlikely end result. Once an open collaborative project has been started, producer innovators can adapt their own strategies in response. The monopolist challenged by the project may withdraw to parts of the market that are locked in, are not price sensitive, or demand high levels of service (Casadesus-Masanell and Ghemawat 2006). Alternatively producers may become contributors to open collaborative projects for which they supply complements. Thus, in 1999, IBM became an important supporter of and contributor of code to Linux. IBM sells products and services that complement Linux ranging from computers to proprietary software to consulting services. Similar examples are legion, such as Google's support for an open source software stack for mobile devices (Android).

4.2 Hybrid Innovation Models

A hybrid innovation model combines elements of the three polar models analyzed in previous sections. 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 suited to development by combinations of our three basic models. For example, producers or users can choose to modularize a product architecture into a mix of large components which can today best be created by producers, plus many smaller components suited for development by single user innovators or open collaborative innovation projects. Thus Intel develops expensive and complex central processing unit (cpu) chips for computers. Complementary software and hardware designs are then developed by for-profit producers, by single user innovators, and by open collaborative projects. Another example is the development of software "engines" for computer games by producer firms upon which platforms individual gamers or groups of gamers acting collaboratively develop "mods" (Jeppesen 2004).

Large indivisible design projects, which have traditionally been in the producer-only zone of Figure 3 may become hybrids 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.

Innovation platforms and the innovations appended to them are often a hybrid of single user innovation, producer innovation, and/or collaborative open innovation. Innovation platforms are components that provide a stable framework or binding surface which serves to support and organize the innovation contributions of many complementors (Gawer and Cusumano 2002, Gawer and Henderson 2007, Baldwin and Woodard 2009, Gawer, 2009). Platforms can range from interface standards such as an application programming interface (api) or a screw thread specification, to open source software platforms like Apache or Linux, to social networking sites like Facebook. In the case of Apache the platform is an open, collaboratively built one, and appended innovations are developed by innovators representing all three of our polar models. In contrast, Facebook and YouTube are producer-built and owned platforms, and appended creative content is generated primarily by individual users.

Innovation platforms can be a great source of profit for their owners when entry costs are low and network effects are strong. Indeed, under such conditions platform owners often face a 'winner take all' situation, and so vie fiercely to attract free content to leverage their internal resources, attain category leadership, and thereby improve their financial performance (Gawer and Cusumano 2002).

Closed collaborative innovation, often termed "crowdsourcing," is a hybrid of open collaborative innovation and producer innovation. In this hybrid model, a producer innovator poses a problem, solicits proposed solutions from numerous third parties (the "crowd"), and then selects the best solution or combination. Members of the crowd do not see nor do they have rights to use the proposed solutions: the outputs are closed and owned by the sponsor (Howe 2006, Pisano and Verganti, 2008, Jeppesen and Lakhani 2010).

To understand closed collaborative innovation, consider that there are two reasons to open up a collaborative project. In the first place, open access to the outputs of a collaborative project acts as an inducement to single user innovators to join and contribute instead of innovating on their own (Baldwin and Clark 2006b). 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 escape 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. Examples of closed collaborative projects are design contests such as the Netflix Prize or the Cisco I-Prize in which many contestants compete for a monetary prize and reputational gains (Jeppesen and Lakhani 2010, Boudreau et al. 2010).

Like open collaborative projects, hybrids generally rely on an underlying modular architecture to provide the basis for splitting up design tasks among various participants. The modular architecture also makes it possible to create a structure of intellectual property rights so that producer innovation, single user innovation, and open collaborative innovation can all take place within the same technical framework (Henkel and Baldwin 2009).

4.3 Suggestions for Further Research

In this paper we have argued that a paradigm shift is occurring in our understanding of innovation. Kuhn (1962, 103) writes: "[Paradigms] are the source of the methods, problem-field, and standard of solution accepted by any mature scientific community at any given time. As a result, the reception of a new paradigm often necessitates a redefinition of the corresponding science. Some old problems may be relegated to another science or declared entirely 'unscientific.' Others that were previously non-existent or trivial may, with a new paradigm, become the very archetypes of significant scientific achievement."

Taken in combination, we think the patterns and findings we have described represent a significant change in the "problem-field" of innovation research, policymaking, and practice. In brief recapitulation, we have found that technological progress is moving whole classes of innovation opportunities from the region where only producer innovation is viable to regions where single user innovation or open 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.

In the course of explaining the viability of these additional innovation models, we have also uncovered a challenge to two fundamental assumptions in prior work on innovation. Recall that, since the time of Schumpeter, the pre-eminence of producer innovation, and also the need for intellectual property rights to enable producer-innovators to protect their rents, have gone largely unquestioned by scholars and policymakers alike. These two assumptions have deeply permeated academic scholarship, policymaking, and practice in many fields. Both assumptions are now challenged by the viability of the single user and open collaborative innovation models we have described in this paper. Users are now seen to be an important source of innovation; and value to users is seen as an alternate motive to profits for investing in innovative designs. The net result is, we think, to greatly change the problem-field in innovation research, policymaking, and practice.

With respect to research, consider that one of the signal accomplishments in economics in the 1990s was to incorporate rent-seeking investment into macroeconomic growth models, thereby endogenizing technological change at the level of the economy (Romer 1990, Aghion and Howitt 1998). In its most common interpretation, "endogenous growth theory" supports political and legal moves to strengthen intellectual property rights. The basic argument is that without the ability to exclude others from using new designs, incentives to invest in innovation would disappear, and in the absence of such investments, technological progress and economic growth would not occur.

Recall that our analysis suggests that this view is too stark. We have shown that users working alone, or in the context of open collaborative projects and in conjunction with ancillary contributors, have the potential to supply innovations for their own direct benefit without the inducement of excludability or monopoly. Such users cannot themselves be strong rivals, but the non-rivalrous nature of consumers is a longstanding implicit assumption in most of economics. (If a firm can sell goods with the same design to many users, by definition, those users do not need to exclude other users from access to the design. Such users are excellent prospects for forming a collaborative project to supply the design without the intermediation of a monopolistic producer innovator.)

Thus, one avenue for future theoretical research is to develop micro and macroeconomic models that allow for the possibility of non-rivalrous user innovation as well as producer innovation. Another is to explore further the technological and institutional factors needed for collaborative non-rivalrous innovation to become an important contributor to technological progress and economic development.

With respect to policymaking, an area that clearly must be reviewed – and that would strongly benefit from research along the lines described above – is intellectual property rights. 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. 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 (Machlup and Penrose 1950, Penrose 1951, MacLeod 2007). Value in use as an alternative incentive for single user innovators and participants in open collaborations indicates that there can be ways to support robust innovation without the "devil's bargain" inherent in the granting of intellectual property rights.

Today essentially all national governments support costly intellectual property rights infrastructures to support inventors who wish to restrict access to their innovations. At the same time, governments have done very little to create an infrastructure to support inventors and innovators who may wish to practice open innovation. The result is that "open" innovators are forced to operate within an framework of intellectual property rights designed for closed innovators (Strandburg 2008). This framework imposes significant costs upon open innovation: Because innovation-related information can be "owned," all developers and users of such information must conduct extensive and expensive searches for potential owners -- and still run the risk of litigation from undiscovered owners -- before they can freely utilize or reveal what they know. In effect, public policymaking today has created a non-level playing field between open and closed innovation (Dreyfuss 2010).

Research is urgently needed into the basic matter of the social welfare effects of closed vs. open innovation in order to establish the basis for an appropriate balance. If, as we expect, increased support for open innovation is found to be desirable from the perspective of social welfare, then expansion of "fair use" rights and other forms of safe harbors for those seeking to freely use and reveal innovation-related information will be among the types new policies that should be considered (Strandburg 2008).

With respect to corporate practice of innovation, research should be pursued on new business models that create private profits for producers without proprietary control of innovative product and service designs. Creation of new product and service designs is a cost for producers. Early evidence shows there are ways for producers to thrive by adopting open innovation designs and shifting to profit-seeking based upon other forms of private advantage such as lead time, high-quality service, and superior distribution channels (Raymond 1999, von Hippel 2005). Of course, producers will predictably resist open innovation until they have made successful transitions to these new business models. Energetic pursuit of practioner-oriented research can aid and speed these needed transitions. In addition, of course, when and where each organizational form is most efficacious is an important question for both theory and practice in innovation management.

The paradigm shift we describe from producer innovation to user and open collaborative innovation offers both inescapable challenges and opportunities to researchers, to policymakers, to firms -- indeed, to all of us who have a stake in innovation. We think that both personal freedoms and social welfare will increase as a result of this shift. We suggest that further explorations will be valuable.

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