How Do Product Users Influence Corporate Invention?[1]

Abstract:

The extensive academic literature on innovation has long recognized product users as a potentially important source of ideas. While prior work has primarily focused on understanding the unique motivations and knowledge that allow users to generate their own innovations, we extend existing theory to investigate the contribution of users to corporate invention. We draw on the knowledge-based view of the firm, evolutionary theory, and the user innovation literature to theorize that corporate inventions that integrate user knowledge will be of greater importance than other corporate inventions, contribute to a broader set of follow-on technologies and occur earlier in the product life cycle. We test these propositions with a large data set of medical device inventions. We find support for our predictions, and discuss the implications of our results for the theoretical and empirical literature on organizational innovation.

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[1] There were two previous versions of this paper entitled “How Do Product Users Influence Technological Development? Physician and Manufacturer Inventions in the Medical Device Industry” and “Professional Users as a Source of Innovation: Physician Innovation in the Medical Device Industry.”

> *"I just had a natural inclination and inquisitive nature about building things. I looked at things and just naturally thought, 'Okay, how can I make this better?'"*
>
> Dr. Thomas Fogarty
> Inventor with more than 70 surgical patents

1. Introduction

In exploring the sources of innovation[2], most scholars have emphasized the role of firms in generating inventions and creating innovative products, placing the process predominately within corporate boundaries. However, some prior work has considered the multiple, inter-related sources of ideas that lead to innovations (Kline and Rosenberg 1986), emphasizing the value of external knowledge sources (Chesbrough, 2003). In particular, survey evidence indicates that customers often provide important insights for new research and development (R&D) projects (Cohen et al. 2000). A related literature highlights the innovations generated by end users of various products who possess distinct knowledge that is difficult to transfer to firms (von Hippel 1988; 1998). While this prior work demonstrates that user innovation is widespread and often significant, important conceptual gaps remain in our understanding of how users directly influence corporate invention. Specifically, despite some limited empirical evidence suggesting that user insights can be useful in developing new products (Cohen et al. 2002; Lilien et al. 2002), we know very little about the utility of user contributions in the earliest stages of the corporate innovation process. This topic is of increasing importance as numerous companies begin to pursue open innovation strategies (Hutson and Sakkab, 2006). This paper argues that distinct user knowledge enhances the importance and impact of corporate invention.

We draw from and extend existing theoretical work related to the knowledge-based view of the firm, evolutionary theory, and user innovation to generate predictions regarding expected differences between corporate inventions developed with product users and other corporate inventions. While evolutionary theory suggests that search within organizations is limited in terms of exploring new domains, the knowledge-based view contends that organization of knowledge assets within the firm

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[2] Consistent with Schumpeter (1934), we use the term “invention” to refer to a new technological discovery and “innovation” to refer to the entire process, including discovery, development, manufacture, and marketing.

promotes innovation by facilitating knowledge generation and integration. We develop theory to explain how incorporating user-based knowledge can help firms overcome the constraints of local search, and the conditions under which the benefits of knowledge gained from users may outweigh the costs of working across firm boundaries. The central claim of our work is that user inventors will help firms generate inventions of significantly greater importance, with broader impact, earlier in the product life cycle: attributes that have been associated with valuable inventions in previous studies (Lerner 1994; Reitzig 2003; Hall et al. 2005).

We test and confirm our predictions using a new, large-sample dataset of over 17,000 corporate inventions in the medical device field. Specifically, the presence of a physician inventor on a corporate patent is associated with receiving 10% more forward citations: an economically significant difference, given that Hall, Jaffe, and Trajtenberg (2005) found that one additional citation increased a firm's market value by more than 3%, and Harhoff et al. (1999) suggested a "million dollar" value per citation. Next, we find that corporate patents with physician inventors have 14% more citations from outside their own technology class than other corporate patents, suggesting that these inventions are more influential on a broader set of follow-on inventions. Finally, corporate inventions with physician inventors cite prior art that is on average 3.4 months younger than other corporate patents, consistent with an origin closer to the beginning of the product life cycle.

Our work makes theoretical contributions to several strands of organizational innovation literature. First, while the literature on user innovation demonstrates that users are valuable sources of product innovations, our work develops theory to explain how users shape corporate inventions along very specific dimensions that are associated with more valuable inventions. Second, our theoretical framework contributes to prior work on the knowledge-based view of the firm (Kogut and Zander 1992; Grant 1996; Nickerson and Zenger 2004; Macher 2006) and evolutionary theory (Nelson and Winter 1982; Rosenkopf and Nerkar 2001) by identifying the precise benefits of certain types of collaborations across firm boundaries, allowing for a more expansive perspective on how organizations create and integrate knowledge (Nickerson and Zenger 2004) and overcome the tendency toward incremental innovation (Rosenkopf and Nerkar 2001). In doing so, we pave the way for further multilevel analyses of innovation (Gupta et al. 2007), including the exploration of potentially fruitful collaborations across firm boundaries between complementary sources of innovation.

Furthermore, despite earlier empirical work documenting the innovative contributions of both hobbyist and professional users (Riggs and Von Hippel 1994; Franke and Shah 2003; Dahlin et al. 2004; Luthje et al. 2005; Baldwin et al. 2006), it has been difficult to identify a large sample of users, systematically document their inventive activity, and objectively assess their contributions relative to other sources of innovation. Thus, our results represent the first large-sample evidence of user impact on inventive activity. In addition, we provide new empirical evidence suggesting the importance of integrating knowledge between users and firms while also maintaining organizational boundaries.

In the next section, we review the prior, related literature, identify the theoretical gaps that we seek to address in this paper, and develop testable hypotheses. Section 3 describes the medical device industry and explains why it is an ideal context in which to study the role of users in innovation. We discuss data and measures in Section 4, and present our empirical methods and results in Section 5. We discuss the implications of our results and limitations to our analysis in Section 6, and conclude in Section 7.

2. Theoretical Development and Hypotheses

We seek to explain the contribution of product users to corporate invention. To do so, we will first review the literature on user innovation, which has primarily explored the distinct motivations and knowledge sets that allow users to create new product innovations. Next, by integrating insights from the knowledge-based view of the firm and evolutionary theory, we will build a theoretical argument to explain the value of user involvement at an earlier stage in the innovation process, and develop three testable propositions about their potential contribution to corporate invention.

2.1 Users as a Source of Invention and Innovation

While much of the prior innovation literature has emphasized centralized, corporate R&D, increasing attention is being paid to the role of end users in the innovation process. The Kline and Rosenberg (1986) “chain-linked model” of the innovation process -- with feedback loops linking the market potential, innovation, design, development and marketing functions -- implicitly indicates the potential value of information held by end users. The burgeoning literature on user innovation primarily examines cases where a final product is developed by an end user, often with little or no involvement with the firm. This work aims to understand the incentives that motivate users to innovate (von Hippel 1988), the particular type of knowledge they have access to (von Hippel 1986; Luthje et al. 2005), and the varying costs of transferring that knowledge into a firm (von Hippel 1988).

Prior work has suggested that users are motivated to innovate for many reasons other than pecuniary remuneration, including by their own needs and desires, by career concerns or reputational benefits, by the urge to reinforce or create a social identity, or simply by their interest as a hobbyist (Shah 2006). Furthermore, firms are concerned with developing new products for large markets, while users innovate to solve their own particular needs (von Hippel 2005). Finally, users may be motivated more by technical elegance or creating new product functionalities than by commercial viability. In short, users frequently innovate to meet (often personal) needs that firms have not yet anticipated, have ignored because of (perceived) lack of demand, or have not figured out how to address. We argue that the difference in motivations between users and firms is a key factor explaining how users may provide valuable and non-redundant ideas and inventions to firms.

In addition to different motivations, users also draw from a knowledge set that differs from firms. As von Hippel and others point out, users draw on “local” knowledge in developing new inventions. The set of local knowledge that users possess is distinct from the types of knowledge that guide the search for inventions within firms. While firms rely on in-house technical expertise, organizational capabilities, and complementary assets, users likely have none of the above (von Hippel 2005; Lettl et al. 2006). Instead, users possess knowledge derived from their use of a particular product, narrowly focused around their own needs. This knowledge is distinct from that which firms can develop in-house because firm researchers are not usually engaged in sustained and intimate use of the product. This distinct user knowledge shapes the inventions that users conceive of and create, and is the second key factor explaining the potential contribution of users to corporate invention.

Much of the empirical work in this literature has focused on explicating the distinct knowledge and motivations of users and documenting the extent of user innovation in a particular industry. In several previous industry studies, Eric von Hippel and his colleagues found that 20%-80% of important innovations were generated by users (von Hippel 1988). In these studies, von Hippel and his colleagues explored the differences in motivation and knowledge between users and firms, and linked these differences to variation in innovative outputs.

Despite significant work on the role of users in product innovation, these studies have seldom developed and tested theory about the contribution of users to corporate inventions. First, with few exceptions (e.g., Riggs and Von Hippel 1994), most prior work has not examined the early stages of the innovation process, most notably invention. Second, while a few studies have empirically examined the impact of user contributions to corporate product innovations (Cohen et al. 2002; Lilien et al. 2002), none that we know of have explored the user contribution to corporate inventions and made specific predictions about the resulting inventive output. In the next sub-section, we address this gap and present three hypotheses predicting the contribution of users to corporate inventions in terms of technological importance, technical breadth, and position in the product life cycle.

2.2 The Contribution of Users to Corporate Invention

Building on the prior literature on user innovation and integrating insights from the knowledge-based view of the firm and evolutionary theory, we develop predictions regarding how user contributions can influence corporate inventions. We focus on three dimensions across which we expect differences: the importance of the invention, the breadth of contribution to future technological development, and the position in the product life cycle.[3] In each case, we seek to contrast corporate inventions developed with input from product users from those developed without user input, which we will call "traditional corporate inventions".

Technical Importance

Previous work on corporate innovation suggests that firms have advantages in the generation of innovations that users do not. For example, the knowledge-based theory of the firm asserts that firms exist to encourage "knowledge formation", knowledge integration, and innovation (Nickerson and Zenger 2004; Macher 2006). One implication of this work is that firms will be able to exploit the cumulative knowledge base that they have built through prior R&D and marketing activities to achieve competitive advantage, since much of the knowledge is experiential and difficult to transfer. Furthermore, internal firm governance allows for superior management of the knowledge assets necessary for invention, and provides the coordination and adaptation necessary for effective search for new inventions (Grant 1996). These insights imply that firms have an advantage in terms of integrating knowledge assets and coordinating knowledge-based activities, especially when knowledge is tacit and problem solving is complex (Heiman and Nickerson 2002).

However, other work suggests that firms might not have an absolute advantage in developing inventions of high technological importance. Cohen (1995) summarized justifications for larger firm disadvantages in R&D productivity, including loss of managerial control, too much bureaucracy, dilution of incentives experienced by firm scientists and inventors, and increasing conservatism associated with the hierarchies in large corporations (von Hippel 2005; Lettl et al. 2006). Prior work on evolutionary theory has also documented the tendency of firms to engage in local search, focusing search for new products or processes in areas closely related to their own accumulated knowledge rather than searching for innovative ideas in new technological areas (March and Simon 1958; Helfat 1994; Rosenkopf and Nerkar 2001).

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[3] While we argue that these criteria are important for scholars to consider, these three dimensions are not the only relevant characteristics of an invention. Traditional corporate inventions may indeed compare more favorably along other dimensions, most notably commercial importance.

For their part, product users may also exhibit a tendency towards local search, but with different implications due to variations in the accumulated knowledge they possess. The local search of firms is local in the sense of being close to accumulated knowledge and experiences from prior R&D, while the local knowledge of users contains insights accumulated from *personal use*. Indeed, this local user knowledge can sometimes be the only source of knowledge utilized by user inventors (Luthje et al. 2005). Knowledge accumulated through use provides users with the ability to identify unmet needs and opportunities, and potentially to generate solutions for these needs. Based on their intimate understanding of how a product functions in practice, users have an enhanced ability to envision various solutions, foresee potential implementation obstacles, and rule out inferior alternatives.

Other authors have theorized that tightly linked communities may also help users develop influential inventions (Jeppesen and Frederiksen 2006). These communities, in addition to providing emotional support and resources, are also a space in which users can share and refine their ideas based on feedback from other users (Franke and Shah 2003; von Hippel and Krogh 2003). In addition, a community often provides a screening mechanism, whereby low-quality inventions are abandoned.

Previous empirical work has traditionally compared stand-alone user innovations to traditional corporate innovations, and found interesting differences in scientific and commercial importance. Riggs and von Hippel (1994) concluded that users of scientific instruments developed a large percentage (44%) of new instruments, and that these innovations tended to have higher scientific importance than firm innovations, according to industry experts. However, firm innovations were rated as having higher commercial importance. The authors theorized that these differences were driven by the varying assessments of expected benefits across users and firms. While users are primarily motivated by peer recognition and a sense of achievement, firms are concerned with generating profits. These different motivations lead naturally to different innovative outcomes, with each source of innovation contributing ideas that are important for different reasons (scientific versus commercial).

Other scholars have focused more narrowly on technical merit. Lettl et al. (2006) found that individual inventions in the medical equipment industry were ultimately as significant (in terms of patent citations) as corporate inventions, though they were unable to identify which patents came from users. However, without being able to classify individual inventors into physicians and non-physicians, the authors are limited in their ability to make inferences about the contribution of physician knowledge to medical device invention. Dahlin et al. (2004) hypothesized that while users might be more likely to challenge the dominant design in the industry and create a truly novel product, they often lack the support and resources required to contribute an important invention. The authors found support for their hypotheses in the tennis racket industry, showing that tennis players provided inventions of both the highest and lowest technical merit.

While the literature remains mixed on whether stand-alone user inventions will outperform traditional corporate inventions, we focus on a different comparison. We argue that the complementary knowledge sets and capabilities between users and firms will produce collaborative inventions that are more technically important than traditional corporate inventions. Consistent with prior literature, we argue that variation in motivations to innovate, character of knowledge, and innovative environment (community) will allow users to contribute valuable and distinct knowledge to corporate inventions. Thus, we predict:

> *Hypothesis 1: Relative to traditional corporate inventions, corporate inventions that incorporate user knowledge will have greater importance.*

Breadth of Impact

An important facet of technological importance that has rarely been considered in prior user innovation research is the breadth of impact on follow-on technologies. The breadth of impact of a particular invention is the extent to which the knowledge contained therein is utilized in future work, spread across multiple technological domains. While prior work has looked primarily at the importance of inventions as rated by experts or by citation counts, we theorize that an additional dimension of importance lies in the diversity of follow-on work. Inventions that contribute more broadly to follow-on developments are important not only as stand-alone inventions but also as drivers of technological progress generally. Among firms seeking to identify new markets or complementary assets to acquire, the breadth of impact of their inventions can be an important variable to consider.

Previous work provides some guidance as to the sources of knowledge for inventions that have broad impact on future work. This research suggests that those inventions built upon a more-diverse knowledge set will have an impact on a more diverse set of follow-on technologies. Rosenkopf and Nerkar (2001:290) argued that radical exploration, that is, exploration that "builds upon distant technology that resides outside of the firm", would have the broadest impact on future technological development outside of the firm's core area. Likewise, Trajtenberg et al. (1997: 45) concluded from their analysis that "originality breeds generality, coming from far away in technological space leads far away as well." We argue that since product users develop distinct knowledge sets (von Hippel 1988), their contributions to the corporate invention process are more likely to motivate search beyond local knowledge, as compared to the traditional corporate innovation process.

The implication is that because users bring distinct knowledge to the corporate invention process, the resulting output is more likely to be relevant to multiple domains than traditional corporate inventions, resulting in a greater potential to influence a wide spectrum of future inventions. Left to their own devices, incumbent firms are more likely to make investments in new R&D projects that are close to prior R&D experiences, with substantial overlap in technological characteristics (Stuart and Podolny 1996). Resulting corporate inventions are therefore more likely to be relevant to technological development in the same narrow field, rather than across multiple domains. By integrating user knowledge into their inventions, corporations are more likely to develop inventions that influence a broad swath of future work. Thus, we propose:

> *Hypothesis 2: Relative to traditional corporate inventions, corporate inventions that incorporate user knowledge will exhibit a broader impact on future inventions.*

Position in Product Life Cycle

We also propose that user contributions to corporate inventions will be associated with the invention's position in the product life cycle. A large prior literature explains the industry or product life cycle as a common sequence of phases that describes the evolution of an industry over time.[4] Williamson (1975:215-216) described three phases of an industry's development: an early "exploratory state", a second "intermediate" stage, and a third "mature" stage. This perspective is largely consistent with later work by Anderson and Tushman (1986; 1990), Nelson and Winter (1982) and Winter (1984). The first stage typically involves a new product, "relatively primitive" in design, with no specialized large-scale manufacturing and no established marketing and distribution (Williamson 1975: 215). This phase, called an "era of ferment" by Anderson and Tushman and the "entrepreneurial regime" in Winter (1984: 295), is characterized by substantial variation and experimentation with many technologies and/or designs, widening innovative activities, new entrants, a growing industry, and falling concentration ratios. During this period, the sources of knowledge which are critical to generating new inventions lie outside of established routines (Agarwal and Gort 2002) and there exists tremendous uncertainty with regard to users' preferences and the optimal technological solution to satisfy their needs (Dosi 1982; Clark 1985).

This era ends with the emergence and selection of a technology design, called the "dominant design" (Utterback and Abernathy 1975; Anderson and Tushman 1990). The emergence of this dominant design brings the era of uncertainty and experimentation to an end and provides standardization in design and a refined understanding of the market. This second phase is characterized by a more developed and specialized product. Also, as the "market definition is sharpened" and output grows, the uncertainty endemic to the first stage begins to decrease.

In the mature stage, termed the "routinized regime" in Winter (1984: 295), standards emerge, and innovation becomes more related to the accumulated knowledge base. Complementary activities such as management, manufacturing, and marketing are all developed and refined. In this stage, called "retention" by Anderson and Tushman, inventions are more infrequent and are more likely to be incremental

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[4] Some existing studies refer to "product" life cycle while others use the term "industry" life cycle. As Klepper (1992) notes, there have been various versions of what constitutes the life cycle, but the commonalities are much greater than the differences. In fact, many of the studies using the term "industry" life cycle either explicitly or implicitly consider an industry consisting of homogenous products, which is conceptually interchangeable with the product life cycle. Here, we focus on variation in life cycle phases within the medical device industry, and we use the term "product" life cycle, consistent with Klepper (1991, 1995).

improvements focused around the dominant design. Innovative activity shifts to being determined by the accumulated stock of internalized market-based experience (Gort and Klepper 1982; Nelson and Winter 1982). Established firms have an advantage as path-dependent complementary assets (reputation, distribution, etc.) become more important for competitive advantage, and serve as barriers to entry (Malerba and Orsenigo 1996).

Given these differences in the nature of innovative activity across the product life cycle, actors with varying capabilities are expected to innovate more often during the phase(s) in which their capabilities provide a greater relative advantage. We extend the prior literature on user innovation to argue that the motivations and capabilities of product users are most valuable in the early stages of the product cycle, where there is significant uncertainty over the dominant design.

Prior work has argued that users, especially lead users (von Hippel 1986; Urban and von Hippel 1988; Franke et al. 2006), are better able to forecast demand for a new product in nascent markets because of information they glean from their own use and feedback from the user community (Shah and Tripsas 2007). Indeed, since users have often tested the product under extreme conditions that are difficult to replicate in the firm's R&D process, they frequently acquire "sticky " information (von Hippel 1994; Ogawa 1998; von Hippel 1998) that will allow them to better understand the needs of other users. This may be particularly true in new markets or when customer preferences change substantially over time, as described by Tripsas (2008), which makes it more difficult for incumbent firms to anticipate demand conditions before the dominant design has been established (Shah and Tripsas 2007, Tripsas 2008).

In addition, differences in motivations drive the choice of when to pursue inventions. In nascent markets where future market size is unknown, users may still innovate to derive use-related benefits, while firms may prefer to wait until the market develops further. As a result, users may be more likely to develop substantially novel technologies that will later gain momentum and serve mainstream demand (von Hippel 2007). This is consistent with the prediction that user entrepreneurship is more likely in turbulent markets, such as those for new products and in markets with high levels of uncertainty and ambiguity (Utterback 1996; Shah and Tripsas 2007). Indeed, Tripsas (2008) found that product users were responsible for beginning multiple product generations in the typesetter industry.

Corporations, on the other hand, have resources and capabilities that are more valuable for inventions in the later phases of the life cycle. Inventions during the later phases draw on the accumulated knowledge about product design, manufacturing, and distribution of established products. Based on these differences between corporate- and user-knowledge bases, we expect user knowledge to be most influential on corporate invention early in the product life cycle.

Position in the product life cycle is important because it suggests an additional way that user knowledge can contribute to corporate inventions. As described above, the local search inherent in corporate research processes can be detrimental to the innovation process in established firms. In fact, as Christensen and Bower (1996) described, established firms often fail to recognize emerging customer needs, particularly when potential new customers are outside of their existing customer base. Input from product users, who we suggest are uniquely positioned to support inventions in the earliest phases of a product life cycle, can help corporations overcome this challenge. Indeed, survey results reported by Cohen, Nelson, and Walsh (2002) suggest that customers are the most important source of information for suggesting new projects, more useful than even the firm’s own manufacturing operations. This finding provides some related empirical support for the notion that user-influenced corporate inventions are more likely to be concentrated in the early phases of the product life cycle compared to traditional corporate inventions.

Thus, we argue that based on their ability to forecast demand, their inclination to search early for solutions regardless of market size, and because they possess sticky information, user contributions to corporate inventions will result in inventions at earlier stages in the product life cycle than traditional corporate inventions.

Hypothesis 3: Relative to traditional corporate inventions, corporate inventions that incorporate user knowledge will be earlier in the product life cycle.

3. The Medical Device Industry

The medical device industry is comprised of over 6,000 companies[5] that spend significant sums on R&D (greater than 11% of sales[6]) and produce increasingly rapid product innovations (with product cycles sometimes lasting as little as 18 months[7]). In this dynamic industry environment, internal development is rarely able to keep up with the demands of the market, and companies are compelled to identify and integrate ideas and inventions from outside the boundaries of the firm. In addition, R&D managers in medical equipment reported the highest degree of appropriability through patents of any industry surveyed in a recent study – even higher than that reported by R&D managers in the pharmaceutical industry (Cohen et al. 2000).

While physicians using medical devices share some characteristics with other product users, there are important differences to consider. Physicians are professional users who have undergone extensive training and have higher opportunity costs than the average hobbyist. They also work in a highly regulated industry with necessary safeguards against experimentation. Like other kinds of users, however, physicians work in well-defined professional communities that expose them to sources of knowledge that are distinct from what firms draw upon, and can help these product users identify unmet market needs. Moreover, the knowledge that physicians acquire through repeated, interactive use of devices often provides insights into technical shortcomings of products and possible solutions. These attributes suggest that physicians could be very valuable in helping companies develop new ideas. Drawing on previous studies of user motivations to innovate, we expect that physicians will be motivated to solve technical problems in part because they expect to derive use-related benefits in future procedures. Indeed, a recent study found that approximately 20% of medical device patents filed between 1990-1996 had at least one physician as an inventor (Chatterji et al. 2008).

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[5] Advanced Medical Technological Association, AdvaMed Website, (http://www.advamed.org/MemberPortal/About/Industry/) Last accessed June 5th, 2007.

[6] Advanced Medical Technological Association, AdvaMed Website, (http://www.advamed.org/MemberPortal/About/Industry/) Last accessed June 5th, 2007.

[7] The Food and Drug Administration Website, (http://www.fda.gov/cdrh/ocd/mdii.html), Last accessed June 5th, 2007

For the purposes of our analysis, we consider only patented inventions assigned to medical device companies. Of these assigned patents, we consider those with at least one physician inventor to be a corporate invention that has incorporated the knowledge of a product user. In our empirical analysis, we perform robustness checks to ensure that we are measuring true collaborations across the boundaries of the firm, not simply user inventions that are later sold to companies, or inventions by doctors who are full-time employees of medical device firms.

4. Methodology

Our hypotheses predict significant differences between corporate inventions with user contributions and traditional corporate inventions on three dimensions: importance, breadth of impact, and position in the product life cycle. We test these hypotheses using data on the patented inventions of medical device companies, controlling for other invention characteristics.[8] The importance of patents in this industry suggests that using patents to measure inventions is an appropriate and informative approach.

4.1 Sample and Data

We generate a new dataset from two existing sources: the NBER patent data (Hall et al. 2001) and the American Medical Association Physician Masterfile.[9] We begin with a sample of patents containing all successful U.S. medical device patents[10] applied for between 1990 and 1996. We limit our analysis to patents with at least one inventor located in the United States because our physician data is limited to physicians located in the United States. We use the patent data to identify all of the inventors on each patent, including data on inventors' first, middle, and last names, and their city and state locations. The Physician Masterfile contains the name, demographic information, address, history of prior locations,

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[8] Although patents are not a perfect measure of innovation, using patent data offers substantial benefits in terms of data availability and objectivity. As prior literature notes, patented inventions reflect only a subset of all inventions (for example Trajtenberg et al. 1997). We follow substantial prior literature using patented innovations to study innovation and comment on the limitations of this approach below.

[9] This data file is distributed by Medical Marketing Service and is maintained on behalf of the American Medical Association.

[10] We use the USPTO's definition of medical device patents, as reported in the Technology Profile Report for Medical Devices (USPTO 2005).

type of practice, and medical school information for all U.S. physicians.[11] With this information, we are able to identify which of the inventors listed on medical device patents are in fact physicians, and for those that are, obtain details regarding their employment and practice.

We perform this match in several steps, using an iterative evaluation of potential matches in software code we developed for this purpose. First, we identify any physicians in the AMA data with the same last name, first name, and state location as an inventor listed on a medical device patent. We use the historical and current license locations for each doctor in the AMA database and the address data for each inventor in the patent database for this match. Once these possible matches are identified, they are evaluated to assure a true match. For each potential match, if there is a middle name or initial available from both sources, we verify that these match and eliminate any for which it does not. When one or both of the data sources fails to report the middle initial, we verify that the observations match according to the city in the inventor address in the patent database and the physician location in the AMA masterfile. Those observations lacking sufficient middle name data that do not match exactly based on city are flagged for closer evaluation to determine a match.[12]

This sample yields 26,156 patents in medical-device technology areas applied for between 1990 and 1996 with 38,399 unique inventors, based on unique combinations of last name, first name, and middle initial. Of these inventors, we identify approximately 3,400 as physicians, based on the AMA data. Approximately 20% of the medical device patents during this period (5053 of 26,156) include at least one physician inventor. This finding demonstrates the enormous frequency of user invention in this field. We select from this set of patents all those that are assigned to corporations. During this period, 56% of the inventions with physician-inventors were assigned to corporations. In the empirical approach

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[11] The AMA claims on their website that these data include “virtually every licensed physician in the United States.”

[12] We could not match according to the middle name or initial in the first step because this field was missing in one or both of the data files for enough records that it would have disturbed the matching process. Records flagged for mismatched cities were evaluated manually to explore whether the city names listed were really the same (perhaps spelled or abbreviated differently) or if the cities were geographically near enough that it was a likely match. We were conservative in assigning a “match”.

described below, we compare corporate-assigned medical device inventions that include user (physician) inventors to other corporate-assigned medical device inventions that do not include physician inventors.

4.2 Model Specification and Variables

We test the hypotheses by estimating a reduced form model predicting the characteristics of a patented invention, as a function of inventor and invention characteristics. To test our predictions, we make use of both the citations to patented prior art in the sample patents (i.e., backward citations) and the record of citations made to our sample patents by all other (follow-on) patents (i.e., forward citations).

We test our first hypothesis regarding the importance of corporate inventions that incorporate user knowledge, as compared to traditional corporate inventions, using the number of citations made to the focal patent by future follow-on patents (forward citations), *CitesReceived*. This reflects the contribution of the focal invention to future work and has been used as a measure of invention importance in many prior studies (see, for example, Trajtenberg et al. 1997). To test the second hypothesis, the breadth of impact of the invention is measured by the concentration of forward citations across patent technology classes using the generality index, *GenIndex*, as described by Trajtenberg (1997) and adjusted for bias at low numbers of forward citations following Hall (2001). The generality index is equal to one minus the Herfindahl index of the concentration of citing patents across technology categories. As in Trajtenberg et al. (1997),

$$\text{Generality} = 1 - \sum_{j}^{n_i} s_{ij}^2$$

where S_{ij} is the percentage of citations received by patent i that are in class j, out of n_i citing patent classes. A high value for generality (close to one) indicates that a patent has a widespread impact, in terms of the breadth of technologies that cite it as prior art. A lower value (close to zero) indicates a patent that is cited very narrowly, indicating an impact in very few areas of technology. There is some evidence that this measure, although widely used, may not adequately capture the breadth of impact of a patented technology (Moser and Nicholas 2004). Therefore, we also use a second measure of breadth of impact: a count of citing patents from outside of the patent's own technology class, *OUTSIDE_CitesReceived*.

To test the third hypothesis, regarding invention position in the product life cycle, we rely on several measures because there is not one ideal measure for this construct. An invention near the beginning of a product life cycle is expected to have several characteristics: (1) It will not build on much prior art (Lanjouw and Schankerman 2004) because it is distinct from what has come before, so few existing technologies are relevant to defining the scope of the new patented technology; (2) The prior art that it does build on will be more recent, because it is substantially different from the older technologies; (3) It will be in a patent technology class that was formed more recently; and (4) It will be utilized in a larger number of follow-on inventions developed in industry as the life cycle unfolds.

We measure each of these characteristics. First, the number of prior art (backward) citations, *CitesMade*, is an indication of the amount of prior art related to the invention. Second, the average age of the cited prior art, *CiteAge*, is an indication of the recentness of the prior art being built upon. This is measured by the average number of years between the grant date of the cited patents and the application date of the focal patent. Third, the age of the technology class is measured as the number of years between the formation of the technology class and subclass at the USPTO and the patent application year, *TechClassAge* (Shane 2001). Finally, the number of citations received from follow-on corporate-generated inventions, *IND_CitesReceived*, indicates the degree to which the invention is utilized in subsequent industry developments.

The counts of total prior art citations made and citations received are non-negative integer count variables, so ordinary least squares would produce inefficient coefficient estimates. Accordingly, we rely on a Poisson model to estimate the following regression model for patent *i* in application year *t*:

$$E(\#Cites_i) = \exp\{\beta_1 DoctorID_i + X_i{'}\beta_2 + \sum_t \alpha_t Year_t\}$$

where *#Cites* is one of the four variables measuring citations made or received by the focal patent (*CitesReceived*, *CitesMade*, *IND_CitesReceived*, and *OUTSIDE_CitedReceived*) and *PhysicianID* is an indicator variable equal to one for patents including at least one physician inventor. We estimate this equation using Poisson quasi-maximum likelihood conditional fixed effects estimation, including conditional technology-class fixed effects, to control for unobserved differences across technology areas. The quasi-maximum likelihood estimation does not rely on the often-violated assumption of the equality of the conditional variance and the mean (Wooldridge 1997). The estimation method, as presented by Wooldridge (1999) and coded for Stata by Simcoe (2007), provides an estimator that is consistent under very general assumptions, and standard errors that are robust to arbitrary patterns of serial correlation.

We use an OLS model to estimate an analogous equation for the continuous dependent variables of the generality index, *GenIndex*, age of citations, *CiteAge*, and age of technology class, *TechClassAge*, with linear technology-class fixed effects and robust standard errors. Note that the adjusted generality index is undefined when either zero or one citation is received. In order to account for this, we set the index equal to zero in these cases and supplement the equations with a dummy variable equal to one when one or zero citations are received.

X_i is a vector of patent-specific controls, including the number of claims.[13] The number of claims is used as a proxy for the "size" of the patent (Lanjouw and Schankerman 2004). If one expects that physician inventors are more inclined to bundle several inventions together into one patent, this patent may contain more backward citations and receive more forward citations (and be cited more broadly) simply because it covers more ground. Although the number of claims is not a perfect control for patent size (Moore 2003), it is preferable to the available alternatives. In estimates predicting the number of citations outside of a patent's own class or the generality index, we also include a control for the total number of citations received. Note that we include application-year dummy variables (Year_t) to control for differences across time.

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[13] Note that the number of claims is unavailable for 1065 patents, 174 (16%) of which are user inventions. These were dropped from the analysis.

4.3 Summary Statistics

Comparing the summary statistics (see Table 1) of the sub-sample of medical device patents which include physician inventor(s) with traditional corporate patents, we find that corporate patents that incorporate user knowledge (1) contain fewer citations to corporate-generated patented prior art and more citations to non-patent prior art, (2) cite more recent prior art, (3) are cited more by other (future) patents as prior art, (4) are cited more broadly, (5) occur in younger technology classes, and (6) contain more claims (suggesting greater scope). This comparison suggests that corporate inventions generated with physicians do draw from substantially different knowledge bases than corporate inventions generated without physician inventors, consistent with previous theoretical insights from the user innovation literature. The differences are also consistent with the predicted differences in importance, breath of impact, and position in the product life cycle.

Table 2a provides a tabulation of the present employment listed for all physician inventors in the sample. Large portions of the sample were in either group or solo practice. A smaller portion of the physicians were employed in medical schools or working in hospital settings. Over all, the composition of the sample matches our conceptualization of physician inventors as practicing doctors. In order to address concerns that some licensed physicians may not be practicing doctors, and therefore not “users”, we make use of another data field in the AMA data, the “major professional activity” of the physician inventor. For about 11% of our sample, “inactive” was recorded as the major professional activity. The majority (57%) of the sample worked in office-based practices, with an additional 10% working full-time on hospital staffs. We examine the relative importance of active and inactive doctor inventors below.

Table 2b reports the percentage of physician inventors in each specialty. There was considerable heterogeneity in the specialty of inventing physicians in our sample. The most common specialty, Orthopedic Surgery, made up only 11% of the sample. Not surprisingly, many of the physician inventors were involved in a surgical practice of some kind. However, Internal Medicine and Anesthesiology (for example) were also well represented.

4.4 Empirical Concerns

There are limitations to our analysis that should be considered. We observe only the inventions that result in a granted patent, possibly introducing selection bias. For example, if physician inventors use a different threshold than firms when deciding whether to patent a particular idea, a comparison of patented inventions could be a biased indication of differences in the underlying inventions. While we cannot observe all of the underlying inventions (both patented and non-patented) in order to assess whether this is the case, we pursue two strategies to test for potential selection bias. First, our analysis compares only patents that are assigned to corporations at the time of the patent grant, so all of the patents in our analysis have passed a similar threshold. Second, we further explored whether patterns in our data are consistent with a bias associated with the potential differences in the threshold for patenting. Suppose that variation in costs (real or opportunity costs) generate differing hurdles of expected value for a given invention that must be overcome in order to pursue a patent for physicians and corporations. For example, if the costs incurred by physician inventors are systematically greater than those incurred by corporate inventors, the set of inventions associated with physicians that we observe will be, on average, more valuable and important.[14] In order to examine this potential bias, we make use of the "primary employment" data for the physician inventors to examine whether or not physicians that we would expect to incur greater (opportunity and real) costs when pursuing a patent application demonstrate the expected bias in the outcome variables. As we discuss below, we do not find such a pattern. Instead, the pattern is consistent with the theory we propose above. This result gives us confidence that the basic differences we find between corporate inventions with physician inventors and traditional corporate inventions are not driven by differences in opportunity costs.

A second limitation is that we do not observe the contractual relationship between the doctors and the corporations to which the patents are assigned. From our data, we cannot directly assess whether there is a consulting relationship, an ongoing employment contract, or a one-off sale of a technology (prior to the patent being granted) between the physician and the firm. However, the AMA data lists the "major

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professional activity" of each doctor, and we find that only 10% of the physician inventors on corporate patents in our sample were listed as "inactive." The majority of the doctors were in an "office practice", with much smaller cohorts serving as full time hospital staff, residents or in research capacities. This suggests that physicians working full time in medical device companies are in the distinct minority in our sample. Since our hypotheses hinge on physicians using products extensively to gain new insights and ideas, we perform robustness checks to ensure that inactive physicians (who are presumably less active users) are not driving our results. At the other end of the spectrum, we also wish to confirm that arms length transactions between firms and doctors with independently conceived inventions are not driving our results either. Thus, we utilize data below on the composition of inventor teams, comparing solo physicians and teams comprised solely of physicians to those teams which include both physicians and company employees. In both cases, the results provide assurance that these data limitations do not influence the interpretation of our results.

5. Results

5.1 Primary Results

As described above, we use multiple measures as indicators of importance, breadth, and position in the product life cycle. Our results are organized by the hypothesis to which they relate. Results reported in Table 3 are consistent with hypothesis 1: that corporate inventions that incorporate user knowledge will be of greater importance than other medical-device company inventions. Corporate-assigned inventions with a physician inventor do, in fact, receive more citations relative to inventions without physician inventors. The presence of a physician inventor is associated with receiving 10% more citations, or 1.5 more citations for the mean patent, holding all other variables at their mean. This is an economically substantial difference, given that Hall, Jaffe, and Trajtenberg (2005) found that one additional citation increases a firm's market value by more than 3%, and Harhoff et al. (1999) suggested a "million dollar" value per citation.

Results reported in Table 4 provide support for hypothesis 2. The analyses using the generality index (column 1) and the number of citations from outside of the patent's own technology class (column

2) both confirm that corporate inventions involving user inventors are more fundamental, influential, and more broadly cited than other medical device company patents. Note that this specification contains a control for the number of citations received. Therefore, the results indicate that relative to another equally oft-cited patent, a patent that includes at least one physician inventor will be cited more broadly. In fact, a patent containing a physician inventor will have 14% more citations from outside of its own technology class (or 0.9 such citations at the mean). This is consistent with the expectation that physicians contribute distinct knowledge to the invention process, and thereby create inventions that are influential and useful to a broader set of follow-on inventions.

Results in Table 5 provide evidence consistent with hypothesis 3: corporate inventions with user inventors occur closer to the beginning of product life cycles. Corporate inventions with physician inventors cited prior art that was on average 3.4 months younger than other patents, consistent with a position near the beginning of the life cycle, where the only relevant prior art is very recent. Corporate inventions with physician inventors also received 8.5% more citations from industry, indicating greater follow-on development in industry. Inventions including a physician inventor also tended to occur in technology classes that were 0.8 years younger (where the mean age is 5.7 years), although the coefficient is significant at only the 10% level. Inventions with physician inventors contained fewer citations to prior art, consistent with these inventions occurring closer to the beginning of a new product life cycle, where there is less relevant prior art to cite, though this result is not statistically significant. Overall, these results provide evidence that inventions with physician inventors display characteristics that we argue are associated with proximity to the beginning of the product life cycle.

As stated above, there is a potential concern that sample selection could be responsible for our results. We have attempted to compare “apples-to-apples” by comparing only corporate-assigned physician and non-physician patents. In order to examine further the possibility that physicians experience greater costs to patent inventions, and therefore only patent the most valuable inventions, we pursue one additional analysis. As noted above, the AMA details the present employment of each physician. We expect that the relative costs of patenting differ across these employment positions. For example, physicians maintaining a solo practice have very high opportunity costs associated with their time, since their compensation is directly related to the number of patients they see. These physicians would be expected to have a relatively high hurdle of anticipated value for pursuing a patent. On the other hand, physicians at a medical school presumably have access to their university's technology licensing office, which often performs the patent application process for university employees. Therefore, physicians at medical schools would be expected to have a lower cost to patent an invention. If we in fact observe a pattern where physicians that we expect to incur higher costs of patenting (solo-practice physicians) have patents with a higher number of citations or generality score, while those with lower relative costs (physicians at medical schools) have fewer citations or lower levels of generality, we would be concerned that our results were generated in large part by selection.

Results in Table 6 display the physician-inventor indicator according to these types, as well as by other relevant categories, and report estimates of the regressions for the forward citation measures (citations received, generality, citations received from other technology areas, and citations received from industry patents). With the exception of the generality results, where estimates are very imprecise, the coefficients indicate precisely the *opposite* pattern that such a selection bias would generate. Medical school physicians, who might be expected to have a higher propensity to patent due to lower costs, in fact had a higher number of citations received, the greatest breadth, and the most follow-on development in industry. Self-employed physicians by no means appear to patent only the "best" patents. These results provide at least some evidence that the main results were not driven primarily by differential patent propensities across types of inventors.

5.2 Robustness Checks and Extensions: The Permeability of Organizational Boundaries

Our analysis thus far has relied on evidence of joint patenting between medical device firms and physicians. One weakness of this approach is that these patents could be the products of at least three scenarios: (1) An inactive physician is a full-time employee of a medical device company and is listed as an inventor on a patent; (2) An independent practicing physician is granted a medical device patent and later assigns it to a company; or (3) An independent practicing physician collaborates with a medical device firm across organizational boundaries to develop a new patent. While we implicitly assume that the final scenario explains the majority of our observations, we have yet to test this assumption. This is a key assumption since each scenario has distinct implications for our understanding for organizational innovation. In the analysis below, we attempt to differentiate between these scenarios, and discuss the implications of our findings in the next section.

First, the AMA provides a record of the major professional activity of each doctor, including whether the doctor is “inactive”. If our theory is correct, practicing doctors should be contributing valuable user knowledge to the invention process. We replicate the analysis above to test this expectation, splitting inventions with a doctor inventor into those with active (89%) and inactive (11%) doctor inventors. Without exception, our results were driven by the contributions of active doctors. In every regression, the presence of an inactive doctor as an inventor is not significantly related to the outcome measure.

Second, our patent data include a list of every inventor on each patent, and we attempted to match all inventor records to the AMA membership file. Therefore, for each patent that we identified as including a physician, we can further explore the composition of the inventing team. One possibility is that the physician is a solo inventor. A second possibility is that there are multiple inventors, but all are physicians. These two cases are most consistent with physicians inventing a device as part of their practice, and selling the rights to the invention to a company before the patent is granted. Of the 2782 corporate inventions with physician inventors, 645 had only one inventor, and 121 had multiple inventors that are all physicians. A final possibility is that a patent contains both physician and non- physician inventors. This category includes 2016 of the 2782 (72%) physician inventions. These inventions fit best with our theoretical approach, which develops propositions based on collaborations between physicians and medical device firms.

Our theory would predict that the inventions involving both physician and non- physician inventors would be more important and of greater breadth than the patents with only physician inventors. Inventing teams comprised only of physicians would be less likely to bring to bear the complementary capabilities of users and corporations. To test this, we replicate our analyses again, splitting the physician inventions into those with only physicians and those with some physicians and some non- physicians. With the exception of the generality index, for which the two categories are indistinguishable, this expectation holds. That is, patents involving mixed physician/non-physician teams generated patents of greater importance and breadth (as measured by the citations from other technology areas).

6. Discussion

6.1 Theoretical Implications for Organizations

This research contributes to the large body of work investigating the origins of innovation by highlighting the role of users in sparking new corporate inventions. We build on previous theory to argue that product users will make valuable contributions to corporate invention. We posit that those corporate inventions which include user contributions will be of greater importance, greater breadth and earlier in the product life cycle as compared to traditional corporate inventions. These are patent characteristics that have been demonstrated to be associated with highly valuable patents (Lerner 1994; Reitzig 2003; Hall et al. 2005).

Our theoretical approach contributes to at least three strands of prior work on innovation. First, the user-innovation literature has developed theoretical insights primarily related to explaining how the unique knowledge and motivations of product users facilitates user innovations across a wide variety of industries (von Hippel 2006). Our paper argues that the unique knowledge sets and motivations of users will also allow them to contribute valuable ideas to the corporate invention process, directly resulting in more valuable inventions. By arguing for the importance of the user at an early stage in the innovation process, and generating and testing specific predictions about the outputs of corporate-user collaborations, our theory fills a gap in the previous work on user innovation. Our work also brings the user innovation literature together with the research on product life cycle to consider when user input might be most valuable.[15] In doing so, we address the recent call (Gupta et al. 2007) for more multilevel research on innovation.

Second, most prior theoretical work on the knowledge-based view of the firm has argued that firm governance provides benefits for knowledge integration, coordination, and development within the firm (Grant 1996; Nickerson and Zenger 2004; Santos and Eisenhardt 2005). As Nickerson and Zenger (2004) point out, there may be particular types of problems that are best solved across organizational boundaries, most likely those involving new technologies and markets where the dominant design has not been solidified. We provide a boundary condition to this theory by uncovering a previously unconsidered cost of internalizing knowledge resources. Specifically, when the value of the knowledge resource derives its distinctness from the body of corporate knowledge, and the distinction is based on an activity that is inconsistent with being internal to the firm, such as use, internalizing the knowledge resource may in fact destroy its value. As a consequence, our theory predicts that integration of knowledge *across firm boundaries* will result in higher-quality knowledge production than attempts to internalize such knowledge. In short, the benefits from internalization are outweighed by the costs of compromising the unique knowledge available from users.

Finally, our theoretical framework also informs evolutionary theory. While this body of work has recognized the constraints of local search in dictating organizational innovation (Rosenkopf and Nerkar 2001), we offer a new mechanism for helping firms overcome these barriers to disruptive innovation. By incorporating insights from product users, we argue that corporations can produce inventions that are technically important, broad, and at the beginning of the product life cycle -- at least partially overcoming the local search problem in comparison to their other inventions. This insight places users alongside other sources of extramural knowledge, including regional networks, other firms, or universities, that have been found to help firms surmount the tendency toward local search (Saxenian 1990; Mowery et al. 1996;

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[15] Our work is related to but distinct from Baldwin et al. (2006), who propose a theory of how product users who become manufacturers themselves may influence the evolution of an industry. Our theory proposes that users will impact the product life cycle through their interaction with incumbent firms, armed with the ability to conduct prescient forecasting of future needs and unique knowledge about solutions to emerging technical problems.

Powell et al. 1996; Almeida and Kogut 1999; Stuart 2000; Ahuja and Katila 2001; Cohen et al. 2002; Grant and Baden-Fuller 2004).

6.2 Empirical Implications

We find empirical support for each of our hypotheses and make several other contributions to the empirical literature on corporate and user innovation. A rich body of prior literature has examined user invention (Riggs and Von Hippel 1994) and innovation (von Hippel 1976; von Hippel 1988) in much smaller samples using qualitative approaches. These studies have successfully established that user innovations are widespread and significant; we find empirical support for their findings using a dataset of more than 17,000 patents.

Our empirical results suggest that there is tremendous potential for firms to tap into the knowledge of some product users, at even earlier stages of the innovation process than revealed by earlier studies (Cohen et al. 2002; Lilien et al. 2002; Jeppesen and Molin 2003; Jeppesen and Frederiksen 2006). Based on their accumulated experience-based knowledge and interactions within the user community, physicians possess knowledge that may be valuable both for identifying new problems and potential solutions, and for assisting in the selection and development of new inventions. Tapping into the unique knowledge sets of users could enhance a firm's inventive output and eventually its innovative performance.

However, our analyses suggest that the best way to organize these interactions may be across firm boundaries. While internalization may promote coordination and knowledge sharing, it may also be detrimental to preserving the differences that drive valuable contributions by product users. If firms attempt to bring users into the firm to capture their unique knowledge assets, they risk losing the attributes that make user input valuable in the first place.

At the other extreme, however, our work also suggests that firms should do more than purchase promising ideas from outside users and develop them inside the firm. Rather, our results imply that joint invention between firms and users will result in the most valuable inventions, which suggests that a deeper collaboration across firm boundaries is advisable.

6.3 Limitations and Future Research

There are important limitations to our analyses. First, we use patents as a proxy for inventions. This is consistent with a large body of literature examining inventive (or sometimes innovative) outcomes using the paper trail provided by patented inventions (Henderson and Cockburn 1996; Trajtenberg et al. 1997). Most of the work in this literature notes that patents are imperfect indicators of underlying inventive activity, but also note that patents do provide a systematic measure of inventive activity that would otherwise by unavailable. Other studies provide evidence that the citation-weighted patent count (used here) is a better measure of the gains from innovation than a simple patent count (Trajtenberg 1990; Hall et al. 2005).

The appropriateness of inferring characteristics of the underlying inventions from patents varies by industry setting. In our particular context, patented inventions provide an especially appropriate window on inventions because prior work has found that patents are extremely effective in protecting product innovations in the medical device industry (Cohen et al. 2000). Thus, it is more likely in this industry than others that the set of patented inventions is representative of the underlying body of inventions.

It would also be useful to conduct a similar analysis in another industry, for example using software or scientific instrument patents. In the medical device industry, physicians and companies work together very closely and physicians are increasingly being provided incentives to invent new medical devices and engage in business (e.g., the creation of hospital venture capital funds and joint M.D./MBA programs). Moreover, physicians are highly skilled, well compensated, participate in user communities, and have undergone years of training. As discussed above, their use of medical devices is deeply interactive, providing the knowledge and foresight to craft inventive solutions to the problems that they encounter. In other industries, users will likely have different attributes and incentives to invent, patent, and collaborate with firms, leading to patterns that are distinct from those observed in our work. Thus, future work should consider how variation in user characteristics influences the theory advanced in this paper.

Future research should also explore other aspects of collaboration between product users and incumbent firms in the medical device industry. For example, collaborations between companies and physicians could have differential benefits depending on firm characteristics (Argyres and Silverman 2004; Chatterji and Fabrizio 2009), and firms may make corporate venture capital investments in medical device start-ups founded by physicians (Smith 2009). By considering these temporal and organizational boundaries distinctions more carefully, we may uncover novel insights about how and why these collaborations occur. In addition, future work should consider the matching process that brings together physicians and companies. While physicians may be attracted to work for the most inventive companies, these firms may also acquire valuable knowledge from physicians that improves the quality of future inventions (Chatterji and Fabrizio 2009). Separating out these effects should be an important priority for future work. Finally, further work should be conducted to isolate other differences between product-using physicians and engineers working inside medical device firms. While medical school and graduate programs in engineering both have selective admissions and rigorous coursework, there may be unobserved differences between the knowledge sets and inclinations of doctors and engineers that influence their patenting activities.

7. Conclusion

In sum, our theoretical and empirical contributions to the literature will hopefully spark new research on the sources of innovation. Our study design allows for other scholars to replicate our analysis in new industries at different points in time, potentially providing insight into the generalizability of our results. This paper provides strong evidence for the theoretical proposition that corporate inventions that incorporate user knowledge differ predictably from traditional corporate inventions across many dimensions, including importance, breadth, and impact on later work. Along with other firms and universities, users can now be included in a broader conception of open innovation (Chesbrough 2003), whereby firms take advantage of a variety of external sources of knowledge. Through collaboration, we suggest that users and firms can play complementary roles in advancing the technological frontier.

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Table 1a

Sample Summary Statistics
N = 17,468 (full sample)

Variable	Mean	St Dev	Min	Max
# Cites Rec'd	14.57	19.61	0	286
# Industry Cites Rec'd	12.59	17.89	0	265
# claims	18.34	13.56	1	184
# Cites Made	18.53	20.76	0	365
Mean Cite Lag	6.77	3.67	0	32
# Industry Cites Made	12.60	14.91	0	280
Generality	0.41	0.32	0	1
# Other Class Cites Rec'd	5.98	11.45	0	218
Tech Class Age	5.74	6.91	-10	77

Table 1b

Correlation Matrix
N = 17,468 (full sample)

	Variable	1	2	3	4	5	6	7	8
1	# Cites Rec'd								
2	# Industry Cites Rec'd	0.99							
3	# claims	0.08	0.08						
4	# Cites Made	0.05	0.05	0.12					
5	Mean Cite Lag	-0.14	-0.14	-0.03	0.20				
6	# Industry Cites Made	0.05	0.07	0.13	0.95	0.13			
7	Generality	0.17	0.17	0.04	0.05	-0.01	0.07		
8	# Other Class Cites Rec'd	0.83	0.83	0.06	0.07	-0.10	0.08	0.31	
9	Tech Class Age	-0.08	-0.08	-0.00	0.11	0.07	0.11	0.02	-0.01

Table 2
Sample Summary Statistics: Means and Test for Difference of Means
N = 17,468 (full sample); 2782 (physician); 14686 (non-physician)

Variable	Full Sample	Inventions w/ User Contribution	Inventions w/o User Contribution	Difference
	(1)	(2)	(3)	(2)-(3)
# claims	18.34	19.14	18.18	0.95**
# Non-patent Cites	3.33	5.49	2.93	2.57**
# Cites Made	18.53	18.21	18.59	-0.38
Mean Cite Lag	6.77	6.51	6.81	-0.30**
# Industry Cites Made	12.60	11.36	12.83	-1.47**
# Cites Rec'd	14.57	16.34	14.24	2.10**
# Industry Cites Rec'd	12.59	13.97	12.33	1.64**
Generality	0.41	0.43	.40	0.02**
# Other Class Cites Rec'd	5.98	6.87	5.82	1.06**
Tech Class Age	5.74	5.03	5.88	-0.85**

Table 3a
Tabulation of Primary Present Employment
for Physician Inventors on Corporate Patents

Primary Employment	**% Sample**
Group Practice	34%
No Classification	17%
Medical School	14%
Self-Employed Solo Practice	12%
Non-Gov't Hospital	8%
Other Non-Patient Care	6%
City/County/State Hospital	3%
2-Physician Practice	2%
Fed Gov't Hospital (Vet)	2%
Other Patient Care	1%
All Other	<0.5%

Table 3b
Tabulation of Specialty
for Physician Inventors on Corporate Patents

Primary Specialty	**% Sample**
Orthopedic Surgery (ORS)	11.32%
Internal Medicine (IM)	6.4%
General Surgery (GS)	7.1%
Cardiovascular Disease (CD)	10.6%
Anesthesiology (AN)	6.8%
Ophthalmology (OPH)	4.3%
Family Medicine (FM)	3.1%
Diagnostic Radiology (DR)	6.0%
All Other	<3.0% each

Table 4

Invention Importance as a Function of User-Inventor Contribution
Corporate Patents, 1990-96

Dependent Variable:	# Citations Received
	(1)
Physician ID	**0.096**
	(0.033)**
# Claims	0.008
	(0.001)**
# Patent Citations Made	0.005
	(0.002)**
Tech Class FE	YES
Year FE	YES
# Observations	17468
Log Likelihood	-151668

Robust standard errors in parentheses.
**significant at 1%; *significant at 5%

Table 5

Invention Breadth as a Function of User-Inventor Contribution
Corporate Patents, 1990-96

Dependent Variable:	Generality Index	# Other Class Citations Received
	(1)	(2)
Physician ID	**0.016**	**0.134**
	(0.006)**	**(0.041)****
# Claims	0.001	0.005
	(0.000)**	(0.001)**
# Patent Citations Made	0.001	0.003
	(0.000)**	(0.001)**
# Patent Citations Received	0.002	0.020
	(0.000)**	(0.002)**
Zero Cites Dummy	-0.386	
	(0.012)**	
Constant	0.387	
	(0.008)**	
Tech Class FE	YES	YES
Year FE	YES	YES
# Observations	17468	17468
Log Likelihood		-69442
R-squared	0.10	

Robust standard errors in parentheses.
**significant at 1%; *significant at 5%

Table 6
Invention Position in Product Life Cycle as a Function of User-Inventor Contribution
Corporate Patents, 1990-96

Dependent Variable:	# Industry Citations Received	# Total Citations Made	Mean citation lag	Tech Class Age
	(1)	(2)	(3)	(4)
Physician ID	**0.082**	-0.019	**-0.028**	**-0.84**
	(0.036)*	(0.047)	**(0.011)****	**(0.47)**
# Claims	0.008	0.009		
	(0.002)**	(0.001)**		
# Patent Citations Made	0.005		0.006	
	(0.002)**		(0.000)**	
Constant			1.818	
			(0.013)**	
Year FEs	YES	YES	YES	YES
Tech Class FEs	YES	YES	YES	YES
# Observations	17468	17468	17360	17468
Log Likelihood	-145768	-158144		
R-squared			0.06	0.05

Robust standard errors in parentheses. **significant at 1%; *significant at 5%

Table 7
Invention Characteristics as a Function of User-Inventor Contribution
Physician Inventors by Type of Present Employment
Corporate Patents, 1990-96

Dependent Variable:	# Citations Received	Generality Index	# Other Class Citations Received	# Industry Citations
	(1)	(2)	(3)	(4)
Physician – Group Practice	**0.106**	0.011	0.125	0.080
	(0.046)*	(0.010)	(0.065)	(0.050)
Physician – Medical School	**0.105**	0.008	**0.247**	**0.105**
	(0.038)**	(0.015)	**(0.065)****	**(0.043)***
Physician – No PPE	**0.191**	0.024	0.012	0.191
	(0.094)*	(0.014)	(0.033)	(0.101)
Physician – Self Employed	-0.080	0.023	0.142	**-0.134**
	(0.052)	(0.017)	(0.080)	**(0.057)***
Physician – Other	0.097	0.021	**0.168**	0.096
	(0.061)	(0.012)	**(0.061)****	(0.065)
# Claims	0.008	0.001	0.005	0.008
	(0.001)**	(0.000)**	(0.001)**	(0.002)**
# Patent Citations Made	0.005	0.001	0.003	0.005
	(0.002)**	(0.000)**	(0.001)**	(0.002)**
# Patent Citations Received		0.002	0.020	
		(0.000)**	(0.002)**	
Zero Cites Dummy		-0.386		
		(0.012)**		
Constant		0.387		
		(0.008)**		
Year FEs	Yes	Yes	Yes	Yes
Tech Class FEs	Yes	Yes	Yes	Yes
Observations	17468	17468	17468	17468
Log Likelihood	-151555		-69396	-145629
R-squared		0.10		

**significant at 1%; *significant at 5%