INNOVATION, SOCIAL STRUCTURE & THE CREATION OF NEW INDUSTRIES

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ABSTRACT
An industry is a set of firms producing products and a market of consumers for those products. Firms and markets are the basic institutions of capitalism, and yet we know little about the emergence of (1) an industry's *initial* firms and (2) a product's *initial* market. Using comparative, longitudinal data from probe microscopy and three sports, this paper inductively derives a framework for understanding the social and economic processes that lead to the development of new industries seeded by user innovations. We identify four modes of social, economic, and technological development around each product: innovator, community, network exchange, and industry. Each mode describes a distinct social structure through which producers and users interact. Specifically, we distinguish between *who produces* and *who consumes* as the social structure evolves from innovator mode (when the producer and the consumer are the same individual) to industry mode (when firms produce and consumers consume). We describe the individual-level motives that trigger each mode and the social structures that underlie them. The four modes form a temporal sequence in some industries; in others a single mode dominates over time or the modes emerge in a variety of sequences.

Keywords
Industry development, innovation, entrepreneurship, motivation, community-based innovation, user innovation

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1. INTRODUCTION

"The future is already here, it's just not very evenly distributed."

- William Gibson (1999)

Academics across various social science disciplines are interested in how new industries are seeded and formed. Most studies of industry formation and development use the firm as the focal unit of analysis (e.g. Klepper et al. 1990, Utterback 1994, Agarwal et al. 1996). This focus on firms has provided many useful insights, particularly with respect to how an industry – once formed – evolves and changes over time. But, using firms as the focal unit of analysis has also created gaps in our understanding of the earliest stages of industry emergence. The question of why firms chose to populate a new market remains unanswered, as does the question of how new markets emerge (White 1981, Astley 1985, Fligstein 2001, Schoonhoven et al. 2001, Beckert 2002, Helfat et al. 2002). In other words, why would a profit-seeking firm situate itself in an area with few or no other firms, no market, and no product?

This study examines the innovation and commercialization histories of four products to discern the social and economic processes that seed the formation of new firms and markets. By shifting our unit of analysis to the product (rather than the firm) and by comparing and contrasting the manner in which social and economic structures develop around these four products, we bring the precursors of industry formation into focus. We identify four distinct modes of social and economic development around an innovative product. Our labels for these modes are: innovation, community, network exchange, and industry.

These modes are distinguished, first, by a growing distance between those who create and produce a product and those who consume it, and, second, by the participation of an *additional* set of actors. In the innovation mode, innovators create products for themselves only. In the community mode, innovators share their ideas with a group of modifiers who add features or refine existing features to improve a product. Interactions between innovators and modifiers tend to take place within informal, transparent social structures – innovation communities – and are characterized by cooperation and the sharing of ideas and resources. In the network exchange mode, innovators and modifiers trade partial products to kitters (who receive directions and kits for constructing the product) in return for items such as materials, personnel, prestige, etc. Interactions between kitters and others generally involve the exchange of non-pecuniary items and are characterized by cooperative problem solving and discussions. In the industry mode, firms provide products to consumers. These firms may be staffed by (or broker the innovations of) the innovators, modifiers, and kitters. However, interactions in the industry mode tend to be quite different from interactions in the other modes: profit-driven firms generally establish arms-length relationships with consumers and other actors; compete with other firms; and seek to secure proprietary ownership of ideas and resources.

Since our modes progress from less to more social differentiation between producers and consumers, they will often emerge sequentially and lead to industry formation. However, our model is not teleological: actions taken by key actors can lead to a mode (or modes) being omitted and the modes can occur in varying orders.[1] We also identify key factors that trigger or block the transition of social structures from one mode to another.

Our intended contribution is to understand the rise and creation of industries by building a largely endogenous framework around sets of individuals with different needs or desires for *using* a product.[2] The benefits of the framework we propose are that (1) the activities in each mode present incentives and disincentives for moving to another mode of industry development, and (2) firms and markets both arise from social and economic activities occurring in the earlier modes of a product's development. This allows our framework to depart from existing explanations for entrepreneurial activity that rely on risk-taking, personality, or other exogenous factors (Thornton 1999). Finally, we show how (3) open, cooperative social structures for innovation creation and diffusion can give rise to proprietary structures, and how open and proprietary structures may coexist. This finding contributes to ongoing academic discussions about the role of open and collective R&D environments in fostering innovation.

We compiled detailed innovation and commercialization histories for four products – scanning probe microscopes, windsurfing boards, skateboards, and snowboards - using primary-source and archival data. These products are heterogeneous on multiple dimensions, facilitating a comparative case-study approach. Data are analyzed using an inductive and qualitative methodological approach based on the principles of grounded theory building. We stay close to our data by focusing on industry formation in instances where *user innovators and their communities create novel products*. While other pathways towards industry development may exist, this paper leverages deep and rich empirical data to offer useful insights that can be generalized and extended to other industries or further refined in future research.

Some might argue that our focus on users and on the pre-industrial modes of technological development gives too much weight to a negligible source of innovations. We offer three reasons why this is *not* the case and why our model is, in fact, quite generalizable. First, a close look at the history of a number of mass production industries shows that many evolved from the non-industrial modes we describe (i.e., innovator, community, network exchange). Second, even in the context of mature products, user innovation is frequent and may even be the norm in less affluent societies and social groups. Third,

[1] We theorize on when this might occur and provide examples of product domains in which modes are omitted in the Discussion.

[2] Some individuals – innovators – may need to create and prototype a new product concept in order to use, while others – consumers – may simply need to purchase the existing product, but in both cases, the need or desire to *use* the product drives their actions.

the non-industrial modes we identify were essential to the development and diffusion of a number of high-tech products. We discuss these arguments in detail in the Discussion section.

The next section summarizes previous research on industry creation and the role of users in innovation and commercialization. Section 3 provides a detailed description of the study setting and method. Section 4 presents findings. Section 5 discusses our findings' implications for theory in the area of industry creation and development. Section 6 concludes.

2. INDUSTRY CREATION & THE ROLE OF USERS

The Creation of New Industries

A great deal of economics and management research explores the dynamics and evolution of industries. Economic studies of industry evolution show that many go through life-cycle stages characterized by differences in market growth rates and by dramatic changes in the numbers of producers (Gort et al. 1982, Klepper and Grady 1990). These studies tend to focus on the number of firms in an industry over time and relate that pattern to data on innovative activity, the emergence of dominant designs, and firm survival (Gort and Klepper 1982, Klepper and Grady 1990, Utterback 1994, Agarwal et al. 2002). These studies capture patterns in industry evolution but they do not explain how or why the industry emerged initially. In other words, how do products, product markets, and firms begin?

Organizational studies of industry formation focus on why and how a *collective identity* – an industry grouping – emerges amongst a set of firms operating in a new product arena (see, for example, DiMaggio et al. 1983, Hannan et al. 1992, Aldrich et al. 1994, Rao 1994). This research suggests that defined industries arise through the coordinating activities of formal institutions such as industry associations and standard-setting bodies, or evolve as the number of firms in a population increases. McKendrick and Carroll (2001) examine these possibilities in the context of the disk-array industry and find limited evidence for each of these theoretical arguments. Instead, they suggest that *if* firms operating in a particular area derive their primary identities from other lines of business, the new area will not become a distinct industry code. They offer additional support for their argument in a subsequent paper (McKendrick et al. 2003), providing a potential explanation for why some industries gain external legitimacy and others do not. However, these studies also cannot explain how and why the *first* firms produced a particular product and entered a product market, or how those product markets began.

User Innovation, Community-Based Innovation & User Entrepreneurship

This paper presents evidence suggesting one possible pathway leading to industry emergence: a pathway triggered by the activities of users and their communities. Users have long been acknowledged as a critical source of innovation (von Hippel 1988, Kline et al. 1996). Numerous studies in the last thirty years, of industries ranging from automobiles to scientific equipment to library software systems, show that many important innovations are developed by users and that a large fraction of users also innovate (Knight 1963, von Hippel 1976, von Hippel 1977, Franz 1999, Morrison 2000, Franke et al. 2003, Lüthje et al. 2005, Haring 2007). Users innovate primarily in cases where they need or desire a new product or product feature and have the skills and time to create it.

User innovation is well accepted in the literatures on innovation and the history and sociology of technology. However, it has long been assumed that users who relay product preferences to designers or perhaps even innovate for themselves will *not* engage directly in economic or commercial activity. There are several reasons for this. The "social construction of technology" (SCOT) approach initially endowed *technologies* with "interpretive flexibility" such that consumers had the ability to interpret and use technologies in new ways but did not have the ability to alter those technologies (i.e., innovate). After Mackay and Gillespie (1992) criticized the SCOT approach for not thoroughly exploring the range of activities that users might engage in and for not showing how users could actively *modify* stable technologies, Kline and Pinch (1996) conducted a study of the Model T showing how users can act as "agents of technological change" – that is, as innovators.[3]

Two subsequent studies – Lindsey (1997) on the TRS-80 personal computer and Muñiz Jr. et al (2005) on the Apple Newton PDA – showed that users might adopt multiple identities or roles with respect to a particular technology *when faced with no other choice.* Both studies find evidence that users and user communities engage in the service, sale, and resale of beloved products that are no longer supported commercially. Additional roles for users are less well-understood in this literature. Rosen (1993) and the studies in Oudshoorn and Pinch (2003) argue for expanding and further studying the role of users, particularly how the activities of one set of users influences other sets and how user activities influence industrial production models.

The situation is similar in innovation management research. Many of the studies of user innovation conducted in the first 25 years of this literature focused on innovations made by employees of firms using a particular product or service (see, for example, von Hippel 1988). These users often worked alone or with the resources of their firm at their disposal and relayed their ideas to manufacturers for integration into future products. Hence, their activities were largely confined to innovation. In fact, the early literature assumes that user innovators will *not* assume the role of manufacturer (von Hippel 1988, Chapter 4).

Only during the past ten years has the literature on users been extended to include issues related to user-community formation and user entrepreneurship, thereby illuminating the wide and varied activities of product users. Studies of innovation in several fields have observed that users often work together,

[3] Little is reported on whether and how farmers shared information with one another, worked collaboratively, or sold copies of their innovations, although it can perhaps be assumed that their ideas spread by word of mouth.

sharing resources, knowledge, ideas, and innovative products within user innovation communities (Franke and Shah 2003, von Hippel 2005). From a conceptual standpoint, the individuals who contribute to an innovation community do so voluntarily, share overlapping interests, and tend to be loosely affiliated with one another (Franke and Shah 2003). A few members may remain in the community for extended periods while others contribute briefly or sporadically (Franke and Shah 2003, von Krogh et al. 2003). User communities are characterized by the relatively free flow of information and far less hierarchical control and coordination than seen in firms. These community-centered exchanges allow for rich feedback and the potential to match problems with individuals who possess the ideas and means to solve them. Due to the varied needs and skills of the individuals involved, some user communities are well-equipped to identify and solve a wide range of design problems. Thus, innovative communities have been influential in fields as diverse as astronomy (Ferris 2002, McCray 2004, McCray 2008), automobiles (Franz 2005, Lucsko 2008), blast furnaces (Allen 1983), electronic musical instruments (Jeppesen et al. 2006), open source software (see, for example, Raymond 1999, Lee et al. 2003, von Hippel et al. 2003), personal computers (Freiberger et al. 2000), engines (Nuvolari 2004), and video games (Jeppesen and Molin 2003). Finally, several recent studies have observed that some user-innovators eventually found firms. For example, Shah and Tripsas (2007) found that 84% of juvenile products firms are founded by users. Chatterjee and Fabrizio (2007) and Winston-Smith (2009) observe user entrepreneurship in the medical device industry.

3. METHOD

We develop a framework for understanding the social and economic structures that support the development and diffusion of user innovations. Our framework was developed in stages and draws upon comparative, longitudinal data. The product and its features were the focal unit around which both data collection and analyses were structured. Our data collection and analytic methods include the purposive use of heterogeneous products in our sample, detailed interviews with individuals possessing a variety of perspectives, data triangulation, informant anonymity, and grounded theory building. As a result of these methods we were able to construct and analyze thick, detailed histories of each product and generate a framework that we believe to be internally and externally valid, generalizable (within bounds, please see the discussion), and reliable (Lincoln et al. 1985).

We first compiled detailed innovation and commercialization histories for four product categories using primary-source and archival data. We collected data on the social and economic development around each product over time. Our data collection begins at the time the idea for the product was originally conceived and follows each product through to - and beyond - the time of commercialization and subsequent product market competition. Each of the four products studied were being produced by multiple manufacturers for a decade or more by the time data collection was concluded. We interviewed more than 150 individuals for this study.

We then compared and contrasted these data to develop a framework for understanding the process by which user innovation gives rise to social structures – communities, network exchanges, and industries – that encourage the further development and diffusion of the product. We provide detailed information on the study setting, data collection procedures, and analytic methods below.

Study Setting

This study examines data from four product categories: scanning probe microscopy, windsurfing, skateboarding, and snowboarding. All are relatively recent product categories, making it possible to study their economic and social history via primary data collection methods, including discussions with early innovators and other actors. This resulted in the collection of especially rich and detailed data. All four products were developed largely within the United States and Europe, and are used worldwide.

We chose these four product categories, because their heterogeneous characteristics allow us to conduct a comparative case analysis. Heterogeneity across dimensions allows us to ascertain whether or not – and how –differences along these dimensions influence our findings, thereby allowing us to build a robust and generalizable framework that can ideally provide explanatory power across cases that span these dimensions (Eisenhardt 1989). Comparison between these four products allowed for cross-case comparisons on *four* dimensions: the novelty of their underlying technology base, their physical composition (Baldwin et al. 2000), the people using them (Pinch et al. 1984, von Hippel 1988, Urban et al. 2004), and the institutional structure surrounding the earliest innovators. The technology supporting scanning probe microscopy has its roots in the physical sciences and its developers were awarded a Nobel Prize. The technology behind most sports equipment innovations, on the other hand, was generally well known before it was applied or altered to fit new contexts. Our product categories also differ regarding the number of components: the windsurf board and scanning probe microscope have many components, while the skateboard and snowboard have only a few. The microscope is used primarily by scientists and engineers, while sports equipment is used largely recreationally by a highly heterogeneous group of users. All early innovators were users, however the early innovators in scanning probe microscopy were employees of a large corporate research lab, whereas the early innovators in windsurfing, skateboarding, and snowboarding were hobbyists.

INSERT TABLE 1 HERE

Data Sources: Interviews & Archival Data

We constructed comprehensive development and commercialization histories for each product using primary-source interview data, as well as archival data. We began our data collection efforts by familiarizing ourselves with these products by reading available materials and consulting well-known experts in these fields, such as current designers, current manufacturers, magazine editors, and book authors. These early-stage, "pilot" interviews conferred several benefits: (1) they allowed us to develop an understanding of the product's use and how the product technology functioned, which allowed us to ask more insightful and deeper questions of subsequent interviewees and especially innovators, (2) the provided us with a preliminary history of these products upon which to build, (3) they allowed us to begin identifying the individuals – innovators, developers, entrepreneurs, and product proponents of various sorts - who would be our primary source of data.

The second – and most exciting – stage of our fieldwork involved identifying and interviewing those who had influenced the product's use, development, and diffusion in various ways. We sought out innovators, developers, users, entrepreneurs, product proponents, and critics of the products. We asked all those we interviewed to suggest the names of others who they considered experts or deeply knowledgeable participants in the field. Over time we developed a lengthy and comprehensive list of individuals who had contributed in some way to each product's development and commercialization. The lists became complete as the names suggested in subsequent interviews and/or recounted in the histories, stories, and memories relayed by interviewees overlapped with the names already on the lists. We took two additional measures to ensure that we captured the product's evolution *over time* and *differing perspectives:* (1) we chose to interview individuals involved with the product over long periods of time, as well as individuals who were involved with the product for short periods, and (2) we tried to interview several individuals involved with a product's development at a particular point in history, because different individuals may have perceived the product, its features, and its chances for broad diffusion and/commercial success differently. Over 150 individuals were ultimately interviewed.

Our primary-source data were collected through one-on-one telephone interviews. Interviewees were asked a series of open-ended questions, augmented by follow-up and clarifying questions (Spradley 1979). Interviews ranged in length from 40 minutes to over five hours (across several sessions), with most lasting between 70 and 90 minutes. Interviews were generally conducted by telephone and recorded to facilitate data analysis; a few were conducted in person. Detailed notes were taken during interviews and interviews were also transcribed to facilitate data analysis.

We structured our interviews to determine the local information employed and the specific circumstances, needs, and problem solving methods surrounding development and commercialization activity. In addition to issues related to knowledge and actions, we also sought to collect information related to why individuals took particular actions. We explored issues related to both individual agency and social context, as both influence individual behavior. We examine individual choices and motives in considerable depth and allow for a wide range of possible motives for any particular behavior. An individual may possess multiple motives, motives may differ across individuals, and motives may evolve over time (Jencks et al. 1988, Jensen et al. 1994). We also sought to understand individuals' perceptions of their environment as a social system, because each individual's choices are likely to depend on the surrounding social system and to affect that system as well (Giddens 1984, Coleman 1994). The goals, norms and values, status markers, and social cleavages of social systems were recorded.

Archival data, when available, was used for triangulation (Fine et al. 2000): information collected was verified using a second interview source, published magazine articles, patent applications, old equipment catalogues, or dated photographs, drafts, and sketches. Triangulation improves the internal validity and credibility of the data upon which we build our framework.

In-text quotes relating to specific innovations have been attributed to particular innovators (particularly when previously published materials also document the same story); quotes relating to process, beliefs, and motives are included anonymously in order to respect the privacy of interviewees, many of whom spoke very openly with us about their decisions, experiences (both good and bad), and opinions.

Data Analysis

Because little is known about the emergence of new industries, we analyze our data using an inductive and qualitative methodological approach based on the principles of grounded theory-building (Glaser et al. 1967). This approach avoids layering preconceived theoretical concepts onto a novel social structure and "makes room for the discovery of the unanticipated" (Van Maanen 1998).

The technique involves comparing and contrasting specific findings from our interview notes to construct theoretical categories that serve as the basis for analysis (Strauss 1987, King et al. 1994). The construction of categories is an iterative process intended to create a common meaning that captures the essence of multiple observations (Eisenhardt 1989, Locke 2001). For example, we found a number of instances where individuals were trading copies of innovative equipment for a variety of non-pecuniary benefits. We therefore created a *preliminary* category, "grey market" to describe this process. After a category was named, we examined the data again and looked for other fragments of data (such as interview quotes) that fell within the category in a positive or negative way. If no other instances (positive or negative) appeared, the category was abandoned or revised. For example – and continuing with the same example - we realized that the exchanges of equipment for other benefits were generally occurring amongst individuals who knew one another, were acquaintances, or were introduced via mutual acquaintances. This pattern resembled a network more than a market and we revised both the conceptual underpinnings of the category, as well as the category name, to "network exchange." As data analysis progressed, frequently mentioned categories were refined by adding or altering specific descriptors. The variance inherent in the data and the use of various sources of data enlivened and fed the process of constant comparison and the development of categories. After identifying and refining a number of categories, we tried to understand how the different categories formed a coherent picture.

Few qualitative, inductive studies have attempted to compare data collected in different settings. Guided by an approach used by Barley (1996) and O'Mahoney & Bechky (2006), we made a series of comparisons – as described above - at two levels. First, we identified commonalities and differences among interviewee reports *within* each product area to determine how the social structure around the product evolved over time. Second, we compared and contrasted the social structures and change processes across the four product areas to identify similarities and differences, to understand the purpose of various behaviors and mechanisms, and to understand the motives driving these behaviors. This part of the process was time intensive and involved frequent and lengthy discussion between the study's authors. It was engaging and exciting to see the similarities in various patterns across the product areas as the framework unfolded. The greatest benefit of conducting this comparison was that it allowed the authors to create a highly detailed, nuanced, and broad framework; multiple cases allowed for the construction of both depth and generalization.

We used results from these relatively descriptive analyses to create more generalizable social science concepts. Specifically, we (1) sought to understand how the patterns that emerged though our comparative data analysis compared to existing concepts in the literature, and (2) compared our inductively developed to documented examples of technology development in order to (3) gauge the external validity and generalizability of our framework. This final step led us to alter our preliminary model of *sequential modes* of technology development (from innovation to community to network exchange to industry) to a model that explicitly recognizes that these *modes* can arise in different orders and that not all modes occur in every industry. (We explore this argument in depth in the Discussion). The mode in operation at any given time seems to be largely a function of the motives and resources present rather than a product of technological determinism.

4. FINDINGS

This study documents four modes of social and economic development that user innovations may pass through between product conception to commercialization: innovation, community, network exchange, and industry. Table 2 provides an overview of each mode in the focal industries of scanning probe microscopy, windurfing, skateboarding, and snowboarding. Table 2 also segments the modes based on the key actors involved. For each mode, the identity of actors participating in the social structure, the critical resource requirements, the key characteristics of the social structure, and the product design developments are reported. Table 3 provides a summary of the individual-level motives that triggered or prevented the onset of a transition to a different (usually the next-more-socially-complex) mode. Detailed information on each of these modes and the incentives and disincentives for transitions are reported in the remainder of this section.

INSERT TABLES 2 & 3 HERE

There are several points to remember when reading the figures, tables and corresponding text. First, as explained above, the framework is not meant to be teleological. Though the social structure surrounding a particular product is likely to evolve over time, it is certainly not inevitable. We have found examples in the literature of communities moving forward, backward, and standing still through these modes. We present these examples and their theoretical implications in the Discussion. Second, even when the four modes emerge in the order they are presented, the activities in each mode build upon one another and may overlap as a new mode takes shape. Third, the interactions of different actors and social structures are often tied to one another: for example, innovators become part of a community, network exchange exists within and supported by the community, at least some firms maintain relations with communities, and some user-innovators become entrepreneurs. Indeed, perhaps our most policy-relevant point is that network exchange mechanisms often persist even after an industry forms, and that an industry's firms are some of the most important players in those network exchanges. Fourth, open and shared design and standards are the bedrock upon which communities operate; openness is necessary for products to be developed, modified, and diffused in a collaborative manner.

We begin by describing the factors that trigger evolution from the innovation mode to the community mode.[4]

Community Formation

Community is a notoriously difficult concept to define, but it is critical to understanding the innovative and commercial history of both scientific instruments and sporting equipment. A novel piece of equipment used by only one person cannot underpin a new *sport* (though it could be the basis for a rather eccentric and idiosyncratic pastime). Scientific instruments are different in that a single instrument can make an important contribution. However, for those contributions to count as "discoveries", there must be

[4] We do not describe the user-innovator mode because this mode and the motives for user innovation have been discussed in detail in the prior literature (please see the literature review in Section 2 of this paper). Interested readers might begin with von Hippel (1988).

some community of people vested in the instrument's data, who have some understanding of its inner workings, and accept its measurements as valid.[5]

Though community is difficult to define precisely, its broad contours have been defined (see literature review). We draw from this broad definition and our interviewees' emic understanding and descriptive use of the word community to define the social structure in which they participate. Our sense of "community" is therefore attuned to these questions: How does an activity change from an eccentric pastime to a sport? How do an instrument's results change from data to discovery? These questions are open-ended enough that they do not allow us to rigidly define a community's boundaries. Nor would we want to, because boundaries of innovation communities that are policed too well tend to die off (Kaufman et al. 2005). We prefer to define communities using the tools that actors employ to construct them. Those include: a means for ensuring communication among various members of the community (scientific journals such as *Ultramicroscopy* or *Windsurf*); a means for ensuring the occasional co-presence of members (scientific conferences such as the semi-annual America Physical Society meetings or informal sporting events such as the "First Hawaiian World Cup"); and other informal networks of correspondence and exchange (e.g., sending microscope blueprints and software to another user, showing another skateboard enthusiast how to do a new kind of jump, or creating and mailing newsletters documenting the innovations you created). We also gauge community membership (as do the actors) by looking at who produced the innovative designs and applications the community applauds or depends upon.

Individual-Level Motives for Forming Communities

Because there are plenty of disincentives for inventors to cultivate other users of their technology, not all innovations spawn dedicated communities. Constructing institutions to serve a community is time-consuming and often thankless. Sharing personal innovations with others requires an innovator to relinquish some measure of control over that innovation. New users may, in fact, be more creative with their own innovations, crowding the original inventor out of the limelight.

Given these disincentives, why do innovation communities form? An example from probe microscopy offers some clues. The first probe microscope, the scanning tunneling microscope, was inspired partly by a multimillion dollar project at IBM to build a supercomputer based on superconducting (rather than traditional semiconducting) logic elements between 1968 and 1983. A crucial prerequisite to building a supercomputer was a reliable process for making thin films of

[5] The relatively well known social construction of technology approaches for analyzing technology development (e.g. Pinch and Bijker 1984, Bijker 1995) developed from the sociology of scientific knowledge (SSK) literature, which stressed that scientific knowledge must be ratified by a small "core set" of interconnected researchers, before being presented and used by larger and more diffuse (in terms of knowledge and the variety of applications for which the knowledge is used) populations (see Collins 1985). This set of interconnected researchers is the equivalent of our community mode.

superconducting materials. The IBM team encountered serious problems with “pinholes” in these thin films, and a colleague, Heini Rohrer, began to look into the problem. Rohrer assigned a new hire, Gerd Binnig, to the task. At almost any other company, Binnig and Rohrer would have simply bought an electron microscope or other commercial instrument and adapted it to this problem, but IBM was large, rich, and used to developing its own instrumentation to deal with problems that no other company would have to face.

Binnig and Rohrer designed an entirely new class of instrument that depended on moving a small, solid probe back and forth over a surface. As it traveled, the probe would record the strength of the “tunneling current” of electrons moving between probe and sample, and these data would be assembled to form an image of the sample – hence, the name “scanning tunneling microscope”. They got this instrument to scan and tunnel simultaneously by early 1982 – at which point the superconducting supercomputer project was coming to an end.

Had the project continued, the STM might have become an instrument without a community – it could have continued on as the standard means by which IBM, and only IBM, checked thin film integrity. To avoid a fate where the instrument was used for only a single purpose, Binnig and Rohrer needed to create a climate of support for the STM within IBM in order to keep working on it. One strategy was to consult IBM’s own materials scientists and surface scientists to see what samples they would like to see STM images of – in effect, building a community of STM consumers. At the same time, Binnig and Rohrer began encouraging their contacts in the academic community to begin building STMs – in effect, stimulating a community of STM builders.

This community grew slowly, largely because the STM was such a complex and difficult technology that it took the first generation of replicators as long to build their instruments as it had taken Binnig and Rohrer to invent the original. Finally, in late 1984, a group of replicators met with Rohrer at a resort in Cancun to figure out why they were having so much trouble. This meeting, in effect, created a community where before there had only been isolated STM builders linked to Binnig and Rohrer but not networked with each other. The Cancun meeting also achieved its participants’ goal, though no one is quite sure how: several of the groups had their STMs running properly within a few months.

Legitimization of Time and Effort Invested in the Technology

This extended anecdote reveals a number of reasons why innovation communities form. First, communities offer legitimization that a particular technology is worth pursuing. At IBM, this legitimization earned managerial support to continue developing the STM. In extreme sports communities, the initial legitimization of an activity comes from convincing other “hip” or “cool” individuals to participate in the sport. Participants in a community activity earn “coolness” and membership in an elite group, whereas participants without a community risk appearing odd and marginal.

Replication & the Transfer of Explicit Knowledge

Second, communities encourage technology replication. For early adopters, replication problems provide a strong incentive to network. Building and using an instrument or a new class of sporting equipment requires enormous amounts of tacit knowledge that can most efficiently be passed on through face-to-face interactions (Nonaka et al. 1995). Different parts of a proto-community may specialize in different kinds of relevant tacit knowledge. For instance, some of the first replicators of the STM knew a great deal about scanning a probe to form micrographs because of their experiences with an earlier technique, the scanning acoustic microscope. Others knew a great deal about ultrahigh vacuum technology and preparation of semiconductor samples. By meeting at Cancun and continuing to interact through their nascent community, these early adopters were able to exchange their tacit knowledge more quickly and develop improvements to the existing technology.

In the case of sports, replication issues often arose as enthusiasts hundreds or thousands of miles apart tried to replicate an innovation and/or a technique which they read about in a newsletter or heard by word-of-mouth. Teaming with other local enthusiasts helped these individuals build and optimize their equipment and learn and improve on their technique.

Desire to Promote Future Innovation & the Discovery of New Applications for the Technology by Increasing Resources

Finally, perhaps the most important reason for forming an innovation community is that the limits of a community's technology – with respect to its use and application in various contexts – are unknown. An instrument like an STM might have been invented with one or two clear uses in mind, and the applications of a surfboard or snowboard might be broadly deducible at the outset, but in practice the most interesting uses of these technologies, and the most interesting trajectories for innovating them, emerge slowly. Binnig and Rohrer, for instance, recognized that they could guess various applications for the STM but didn't have the expertise to explore all those applications in depth. Thus, they encouraged electrochemists to build electrochemical STMs, biophysicists to build biophysical STMs, and surface scientists to build surface science STMs.

Similarly, in the early days of skateboarding, it was unclear what direction the technology would go. Would it be used primarily in drained swimming pools, or in home-built half-pipes, or to travel through and on features of the urban landscape? It's likely that in the 1970s few could have imagined the proliferation of skate parks achieved through extensive community lobbying efforts by a large population of skateboarders – the skateboarding *community* (Brooke 1999).

Enjoyment

Innovators and modifiers may also seek others out and share their knowledge simply because they enjoy the innovation development process and working with others. This pattern emerged in the windsurfing, skateboarding, and snowboarding industries, and in research examining the activities and motives of software, radio, and automobile enthusiasts (Weizenbaum 1976, Gelernter 1998, Ghosh 1998, Haring 2007). In the words of one windsurfing innovator interviewed for this study, "If you did not share… [others] would not be able to keep up with you. To do or experience something new and fantastic or go another step faster isn't much fun when you shout 'Wow! Did you see that!' and nobody is there to hear you" (1999).

Prevention of Third-Party Appropriation

Finally, public exchange and sharing -- purposefully or as a matter of happenstance – prevents a third party from appropriating the technology and removing it from the public domain. Specifically, U.S. patent law allows innovators up to one year to file for a patent after public disclosure. Patent law in other countries is more stringent: public disclosure without prior application for a patent places the technology into the public domain immediately. As a result, by revealing their technology to others, innovators and modifiers who wish to continue working in a community environment, or who want to maintain free access to the innovation, or who want to encourage further improvement and competition, can publicly reveal their ideas to prevent third-party appropriation. Snowboarding innovator Dimitrije Milovich is one example of this. Granted a patent for his snowboard in the early 1970s, Milovich announced that he wouldn't enforce it and encouraged others to build their own boards and improve upon his technology (author interview, 2007). Such actions occur routinely in open-source software as well (O'Mahony 2003).

Community Norms and Organization

Community norms and organization are designed to attract individuals possessing highly heterogeneous sets of knowledge and resources and to make collaboration between individuals as simple as possible. By attracting highly heterogeneous individuals, the community increases its chances of finding solutions for a variety of problems. For example, one individual might identify a problem based on need, but not possess the ability or knowledge to find a solution. If that problem is shared with a diverse group, the chance of finding a solution should increase. Attracting a highly heterogeneous group is difficult and requires establishing norms and practices to support openness and to allow individuals to enter and "try out" the community. We thus observe that communities are open to transient membership and the free sharing of knowledge, such that what might be labeled "free-riding" in other contexts is encouraged, even with individuals who are new to the group and/or have little to offer. Attracting new members also signals to existing and potential members that their efforts are valued by others.

Consolidating communication regarding problems and potential solutions allows a problem to be heard by many, and increases the chance that some will engage in problem solving and find a potential solution.[6] Problem solving efforts by many, accompanied by the sharing of valuable insights discovered along the way, is likely to uncover solutions more rapidly than isolated problem solving activity or purely sequential experimentation (Loch et al. 2001). For example, communities that meet face-to-face generally prefer to have everyone meet together and, before dispersing, announce new creations and challenges to the entire group. When face-to-face meetings are not possible or infrequent, methods emerge to ensure sharing and collaboration. In the early days of the sports studied here, for example, the details of how to build and use a new innovation were mimeographed and sent by postal mail to anyone who expressed an interest. These individuals then engaged in further trial-and-error learning, shared knowledge and resources locally, and then sent improvement ideas and altogether new ideas to the newsletter "editors" to print in the next version. This process codified known knowledge, lowered the costs of knowledge transmission, and conserved individuals' time.

A community's desire to encourage contributions drives its expectations of individual behavior. For example, individuals who act in ways that drive others away (e.g., behaving unpleasantly) may be ostracized or ignored in an effort to stop the behavior. Individuals who choose not to share information may be tolerated, but will likely possess lower status in the community than those who discuss and share ideas openly. At an early and informal windsurfing competition focused on exhibiting new windsurfing tricks and techniques, one participant refused to discuss his ideas and share his equipment modifications with other participants. His behaviors were met with laughter and – as recalled by another participant – "the conversation went on without him." Community members are keenly aware that they cannot force others to share, but they can create a welcoming and energetic environment for those who do share.

The community's *reaction* to problematic behaviors is based on the willingness of individual members to make their views heard, an often emotionally-costly endeavor. As a result, overall reactions may be tempered and only occur in particularly egregious cases, depending on the constitutions of other members. Not surprisingly, it seems that individual communities do develop unique cultures that define

[6] It is important to note that moieties may form within the community. For instance, membership in the probe microscopy community very quickly differentiated between those building ultrahigh vacuum STMs for surface science and those building other kinds of probe microscopes for a wider range of applications. This separation occurs at a cost, in that at least some of the diversity of ideas and resources brought into the community by new members may go untapped or unnoticed. Over time, some groups fragment to the point that even innovative and experienced members using the technology for different uses splinter into subgroups, an event that might slow the diffusion of novel ideas and innovations across the larger community. The ultrahigh vacuum surface science STMers mentioned above, for instance, attempted in the early 1990s to form their own conference series that would have limited interaction with microscopists working on a wider range of tools and applications. They were unsuccessful as a group, but many individual members of this sub-community disengaged with the larger probe microscopy community until funding for "nanotechnology" after 2000 prompted them to reconnect with former peers.

acceptable and unacceptable communication practices. These cultures often reflect the behaviors of a few members who contribute with high frequency and whose contributions are respected.

Not surprisingly, a high volume of transient members (even well behaved transient members) can tax the time and patience of a smaller number of core community members.[7] Hence, norms and structures are established to make communication easier and to ensure that existing knowledge is communicated to new members in a low-cost way (from the perspective of core members). Today, this means searchable on-line listservs, online FAQs, clear instruction to new members to check existing sources prior to posting questions on listservs, and norms to be adhered to when asking questions and mandates to contribute new findings and product features back to the community. This often requires altering the communication structure such that not all communication occurs at the same time and place. Formally establishing separate discussion forums –at conferences, local meetings, in newsletters or magazine, or online – allows members to access and discuss the information in which they are most interested.[8]

It is through the emergence of such distinctions that the community mode transitions to the network structure mode. The innovation community starts as an array of technology replicators and modifiers who are tied to the original innovator but not to each other. Replicators copy others' creations, while modifiers advance an innovation with incremental modifications to existing designs. Ties develop among replicators and modifiers in an innovation community. It may be unclear initially which community members are most skilled, which are most likely to remain over time, and who in the community are allied with whom. Over time, the answers to such questions become clearer and individuals create various roles for themselves within the community. Particular practitioners will be identified as "model members" from whom newcomers should seek advice or guidance. Newcomers will then form relationships with model practitioners rather than the original innovator.[9] Model practitioners (or their close associates) may even set up a system for trading with newcomers so that both newcomer and core member benefit from the exchange. In some communities, this may be the point at which model practitioners establish (or form alliances with) new firms to broker the entry of newcomers. In such cases, communities will move

[7] The reason for this is simple: the time and efforts of even the most dedicated and enthusiastic community members is limited and the questions of individuals just beginning to familiarize themselves with the technology can take considerable time and effort.

[8] For example, today's online communities often have only two list-servs: one for those actively engaged in developing the product, the other for users. We see this frequently in open source software communities, which often use two primary mailing lists into which participants self-select based on their familiarity and interactions with the software code. Conversations about code improvements and extensions occur on a developer list. Conversations about configuring or using the software code occur on a user list. At the same time, having just two separate lists prevents fracturing of the communication flow and helps the community balance its goals of using member knowledge to solve problems and conserving individuals' time and effort.

[9] Based on our observations, the original innovator is more likely to focus on developing her innovation and attracting more individuals to the product than on cementing her role or status in the community, which is already well-acknowledged.

directly to the industry mode. In other cases, more informal trading between core members and newcomers (and among core members) may go on for some time, and perhaps indefinitely. This kind of community has, in our terminology, entered the network exchange mode.

INSERT TABLE 4 HERE

Network Exchange

Individual-Level Motives for Forming Network Exchanges

Network exchange is not a way-station on the path to commercialization, because not all innovations are eventually commercialized. Especially in the life sciences, there are famous examples where the "moral economy" of the (often academic) community privileges bartering for biological materials (fruit flies, transgenic mice, etc.) in lieu of, or even as a way to resist, commercialization (Kohler 1994, Murray 2009). We argue that the existence of network exchange will encourage some innovation community members to form dedicated firms, but only when (1) they can persuade the rest of the community to accept a commercial product *or* (2) they can use commercialization to bring in a large number of new, sympathetic community members and consumers.

By "network exchange" we mean the introduction of mechanisms for *trading* innovations for some token – perhaps money, but also materials, personnel, ideas, the use of ideas protected by intellectual property, etc. In this mode, trades are carried out either by individuals, informal organizations, or as a sideline activity by organizations that are primarily focused on some other task. As a sideline activity, network exchange is sometimes frowned upon as a distraction. For instance, when one of the leading designers of probe microscopes in the 1980s, Calvin Quate of Stanford, found out that one of his students was selling STM kits from his garage, Quate was displeased. As another student remembers, "Basically Dr. Quate said, 'Graduate students work, eat, and sleep, and most of the time they go hungry.' You can't have a company and be a graduate student at the same time', so [student's name removed] had to finish up [his dissertation], graduate, and move on" (author interview, 2001).

Existing communities may also resist or be reluctant to welcome customers who buy equipment through network exchange. Many innovation communities start with a core of members who are accomplished builders of the relevant technology; building therefore becomes a credential for membership in the innovation community (Haring 2007). The quality of a newcomer's home-built microscope or windsurfing board, and the degree to which it incorporates new ideas that the rest of the community can use, establishes his or her reputation within the community. If, suddenly, newcomers can trade money, materials, etc., for a microscope or a board, the community loses an important metric for sorting skilled from unskilled practitioners.

Despite these disincentives, network exchanges do form. One reason is that network exchange customers are often buying *time* as much as they are buying technology. In a fast-moving innovation community, individuals may see advantages to gaining early membership, even if their membership is not yet fully credentialed. Often, such individuals are not opposed to the criterion of building, and in fact will build the relevant technology as soon as they can. Several of the customers of the Quate student mentioned above, for instance, bought his microscopes so they could learn to use the technology while they were building their own, more sophisticated, models. And, of course, a number of new members find that they want to *use* the new technology, but lack the time, inclination, skills, and/or talent to build one on their own. Thus, even as they buy or trade equipment from others, they often have respect for those with the ability to design and/or build the equipment.[10]

One important reason that innovation communities may be willing to accept new members who enter through network exchange is that artifacts traded through network exchange tend to be open-ended and unfinished. A microscope or surfboard made in one's spare time for someone else is unlikely to have all the bells and whistles of either an artifact made for oneself or one marketed commercially. Thus, network exchange tends to produce kits (to be assembled by the customer) or critical subassemblies (to be augmented by the customer). For instance, while Quate's student sold STM hardware, customers had to build the electronics themselves. An earlier STM bartered among IBM employees, the so-called Blue Box, supplied the electronics but not the hardware.

As a result, individuals who enter innovation communities through network exchange still have to learn many of the skills involved in building the relevant technology. The open-ended nature of kits allows newcomers to tweak them with their own innovations and thereby allows for the possibility that their efforts will benefit the community as a whole.[11] For instance, in the late 1980s, IBM Research attempted to propagate STM within the organization by making a batch-produced STM kit available at no cost to any IBM research group that wanted one. These instruments were usually entrusted to postdocs who needed to prove to managers that they had experimental "hands" or skills. Thus, some postdocs were relieved to find that the batch-produced STMs were essentially unusable without substantial modification

[10] In fact, this may be an interesting way to think about communities/network exchanges vs. commercial markets: in communities and network exchange the exchanges seem to occur with *respect* towards the innovators, modifiers, and builders – "purchasers" often know who the innovators are and what their contributions are and respect the innovativeness of their ideas and the talent required to build a copy of the product (also possibly because the knowledge is still tacit in these modes and getting a copy is a favor of sorts from the producer to the consumer). In the industry/commercial mode, the exchange is more transactional: when customers are attracted to brands, they are buying bragging rights, not earning them. Knowledge is also more explicit at this stage.

[11] Kristen Haring (2007) notes that the amateur radio community was able to absorb the emergence of pre-packaged ham radio kits so long as the kit electronics consisted of discrete components – kit builders still had to learn what each of the components did. It was only when kits started to incorporate integrated circuits – essentially black boxes that hid functionality – that large numbers of hams became disgruntled.

and allowed for significant tweaking – tweaking that would show off a postdoc's ability to implement his or her own ideas, and which could, in turn, be shared with the rest of the STM community.

Status

Why did IBM make batch-produced STMs available? In this particular case, the company was likely trying to stimulate production of journal articles based on STM research to generate favorable publicity. More generally, though, makers of kits traded through network exchange hoped to enhance their status through the propagation of their innovations. If a surfboard maker can get a large number of people to ride his boards, the surfing community will be more likely to view his boards as well-made and aesthetically pleasing. In the context of science, Latour and Woolgar (1986) identified a "cycle of credit" whereby those who write outstanding articles get cited, which makes it easier to get funding, which allows them to buy equipment, which generates data for articles, which get them cited further. For an instrument builder, having a design adopted by colleagues is equivalent to being cited – it is the kind of recognition that gains them influence in the innovation community, which they can use to attract new talent to their labs, bringing new ideas that make the lab group even more influential, etc.

Attracting new talent is important because no one can tell *a priori* what the most interesting uses and designs of a new scientific instrument or sporting equipment will be. Creative ideas about how best to build and apply such technologies may come from people who do not have the skills or resources to build a technology themselves. Not everyone has the knowledge or the machine shop to construct a windsurfing board, for instance, but if given the equipment, they may come up with new tricks or provide feedback that improves the design. Builders who supply boards through network exchange ensure access to "customer" feedback, allowing them to further improve their boards. Similarly, not every scientific discipline values, or trains its members in, building instruments. Yet members of these disciplines have expertise about particular materials that can be explored with a new instrument, thereby establishing an important new application for the technology. If offered an instrument, these "customers" can provide feedback on how to make the instrument more user-friendly or flexible – feedback that may end up in the next generation of designs.

One effect of *commercialization* is that cash becomes the dominant token of exchange for innovations. However, network exchange rarely disappears completely, and start-up companies are among the biggest participants in vestigial post-commercialization network exchanges. Start-up firms – especially those founded as "copycat" firms who lack ties to existing innovators, communities, and network exchanges - often find they cannot buy the legitimacy they need (e.g., for instruments, scientific credibility; for extreme sports, a reputation for coolness gained by generating novel equipment or techniques), so they barter for it. A well-known example is sponsorship deals, where an athletic equipment manufacturer induces a high-profile innovator or athlete to use a company's gear to improve its reputation with potential customers. Such deals happen surprisingly often with scientific instruments as well. Manufacturers will offer deals to high-profile scientists who have some association with a rival firm. Similarly, probe microscope companies sometimes sell a microscope cheaply (or with shortened waiting times for instrument delivery) to customers who will include the firm's employees as co-authors on papers published with data the microscope generates.

Network Exchange Norms and Organization

As described above, network exchanges form largely as a combination of two factors: a desire by individuals – we call them kitters – to use an innovation without investing large amounts of time and effort building it for themselves, and a desire by some community members to increase their own status and prestige by providing knowledge and resources to kitters.

At its core, network exchange involves the exchange of kits for something of value to the kit-maker. Because this exchange occurs largely between individuals, what is actually exchanged and how it is exchanged may differ, but there are several norms that appear important across contexts. The first is trust in and knowledge of one's exchange partners: Both parties need to feel that their investments of time and effort in learning or teaching will be reciprocated. Because the kit is incomplete – and returning the kit is generally not an option (especially when non-pecuniary goods have been exchanged for kits) – the kitter needs to be satisfied that a kit has the necessary components and directions and that it has been assembled to the best of the kit maker's abilities (acknowledging that a kit is not a complete and perfect product). Trust is also important for kit-producers – especially those bartering their kits for non-pecuniary goods or services (e.g., a chemical sample, an invitation to speak at another university, or goodwill to be repaid at some later date) – who need to feel secure that they will benefit from the exchange.

The second is a willingness on the part of the kit maker to continue communicating after the kit has been exchanged; in essence, what is being exchanged is often a kit *plus* an implicit or explicit promise of further assistance. Because the kit is incomplete and kitters are likely to be using and modifying the kit for different purposes, questions and problems will arise. The kitter is likely to direct many questions to the kit provider, who – in order to promote a reputation as a kit maker of choice and increase their status within the community – will have to field questions, assist, and perhaps introduce the kitter to other knowledgeable community members. In this way, the kit producer might also be seen as spanning the boundary between those who want to enter the community and those who are already active, well-known participants within the community. In the scientific community, this spanning is often arranged through sabbatical or postdoctoral stints by newcomers in the labs of established innovators, and/or through collaborations between newcomers and established innovators that benefit both and can last for years or even decades. Identifying which newcomers are worth collaborating with, though, is a distraction that may be devolved to firms in the industry mode.[12]

Industry

Individual Level Motives for Commercialization

One unfortunate feature of debates about firm formation (and the commercialization of academic research) is that entrepreneurs are often depicted as coldly rational profit-seekers. In fact, we find that individual motives for founding companies are as complex and varied as the individuals themselves. Those motives may have less do with profit than with securing the individual's position within the innovation community (or within their home institution) or within another social group (e.g., family, colleagues). Even when profit is a strong motive, it is often because individuals attach some meaning to profit beyond the coldly economic. As Keynes (1953) pointed out:

> *"Businessmen play a mixed game of skill and chance, the average results of which to the players are not known by those who take a hand. If human nature felt no temptation to take a chance, no satisfaction (profit apart) in constructing a factory, a railway, a mine or a farm, there might not be much investment as a result of cold calculation… Enterprise only pretends to itself to be mainly motivated by the statement in its own prospectus"* (Keynes 1953, p. 150).

Let us start, however, with a discussion of why individuals may *not* have incentive to engage in commercialization. Both extreme sports and academic research communities hold ambivalent attitudes toward commercialization. In extreme sports, this may be expressed as disapproval for "selling out" – a betrayal of the countercultural and innovation-focused orientation that brought many members to the community in the first place. Commercialization can bring unwanted standardization, and with it a loss of craftsmanship in both the design and use of equipment. This can be a perceived problem with commercial scientific instruments as well, because some functionality is often removed to accommodate an "average user."

A particularly striking example is from skateboarding. An early skateboard manufacturer wanted to promote skateboarding as a mass market sport and held a competition. The judges asked competitors to demonstrate a number of relatively tame maneuvers such as skateboarding in figure-8s and doing handstands while riding the skateboard. A group of innovative teenage skateboarders, often referred to as the "Z-Boys", were so dismayed that the firm and its judges were imposing a specific way of skateboarding, that they left the competition to show off their unusual tricks and aerial maneuvers in a neighboring parking lot. Similarly, at one early commercially-sponsored windsurfing competition, avid windsurfers refused to sail around a race course and moved to the next beach to demonstrate free-style aerial acrobatic maneuvers. This tension between standardization and creativity, individuality and

[12] At one point in the mid 1980s, one prominent probe microscopist had so many newcomers visiting his lab that he instituted a new rule: you could either visit his lab for an afternoon or for six months, but nothing in between.

commercialization, exists to this day in snowboarding. For example, Lindsey Jacobellis competed for the U.S. Team at the 2006 Olympic Games in Turin. She was in the lead by a large margin to win the gold medal, but "she slipped to the silver… because she fell while trying to attempt a hot-dog move late during a race… As a result, Jacobellis became the poster child for critics of snowboard cross who claim the sport cares more about style, even at the risk of losing (Brewer 2010)."

Firm founders may also be tagged as less interested in their sport/science than in running a company, or unable to put in the time to hone their sport/science due to the distractions of managing a firm.[13] Founders of instrument companies face the additional suspicion that they may let commercial interests distort their science. Certainly, there are founders of probe microscopy firms whose colleagues regard their conference presentations as inappropriate "advertisements" for their companies, and whose research is seen as skewed to preserve the validity of their patents, even in the face of contradictory evidence.

The Accidental Entrepreneur

Nevertheless, firms do get formed. One partial explanation may be that innovation communities inherently promote firm formation, because the constant trading and sharing in such communities is only a small step from market behavior. In our data sets, many innovators and modifiers provided free prototypes for months before realizing that such production was costly in terms of time and materials. In time, they began charging for their prototypes, initially at cost and, later, for a profit -- often with the hopes of trading their day jobs for a sport-centric lifestyle. This pattern – of "accidental" entrepreneurship (Shah and Tripsas 2007) – was observed many times across innovations in the windsurfing, skateboarding, and snowboarding industries.

The case of "the Hawaiians" illustrates how innovation, fun, and competition combined with small-scale production for most users-turned-manufacturers. The Hawaiians were a group of seven men in their early 20s living in Kailua, Hawaii, in the 1970s. Five of the seven shared a house and all seven windsurfed daily off a nearby beach. When high winds, wave conditions, and unique use patterns challenged the existing equipment., the Hawaiians adapted their equipment and shared their designs freely with other enthusiasts. Some people who saw or heard about the Hawaiians' innovative equipment asked to buy copies. The Hawaiians initially made handmade copies at home – first offering them for free or at cost and later selling them for a profit – and later opened a small store. Eventually, their brand became one of the most popular in the windsurfing industry and they were well-known as makers of exceptionally high-quality equipment. As one windsurfing innovator told us:

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[13] This attitude is paralleled among science popularizers, who are sometimes stigmatized as inferior scientists due to their popular work – the so-called "Sagan Effect." It should be noted that not every popularizer is subject to this effect – rather, scientists strategically popularize when it will help them gain legitimation, and cast aspersions on popularization when it will help them discredit their rivals. See Shermer (2002).

Our model was we build it for ourselves. I didn't want this stuff to break when I was out sailing in 15-foot waves or from Molokai to Oahu when you can't see land in either direction… Built to last and the people who used our stuff understood" (author interview, 1999).

Learning & Self-Actualization

At the same time, innovation communities attract (or create) members with a constant desire to extend their skill sets.[14] This desire might arise from psychological need or as a way for individuals to prove themselves to (and remain central to) their communities. For some individuals, one way to satisfy this desire is to learn how to found and run a business. We have interviewed a number of firm founders who, after several years learning the skills necessary to participate in their innovation community, wanted to test themselves again by learning to run a business. We would hypothesize that this desire might be stronger in communities with a diverse membership. In strongly interdisciplinary research communities, for instance, established innovators who welcome newcomers must teach themselves the knowledge sets associated with the new arrivals. Entrepreneurship may then be seen as simply one among many knowledge sets to be learned. This would be an interesting question for a large sample study.

Lifestyle & Enjoyment

Another feature of innovation communities that may spur firm formation is that membership in the community is largely by choice. Indeed, for extreme-sports enthusiasts, membership is an avocation – if they didn't enjoy being part of the community there would be few reasons to participate. Even among scientists, an innovation community's members, particularly prior to commercialization, tend to be people with a high degree of research autonomy. (Early members of the probe microscopy community still refer to that period as the most exciting time in their careers.) Individuals may found firms to spend more time engaged in and promoting a product they feel passionate about, and possibly to spend more time with like-minded enthusiasts and converting the uninitiated into enthusiasts.

Disgruntlement with Current Career

One greatly underappreciated motivation for firm formation is career dissatisfaction. In one very prominent case in probe microscopy, an entrepreneur founded a microscope manufacturing company largely out of dissatisfaction with his academic colleagues and a desire to make enough profit to demonstrate that his was the superior intellect. More generally, companies that spin off from an innovation community are often "lifestyle firms" founded out of a passion for the technology or the community, and managed more with an eye to community needs than to orthodox business practice. "Lifestyle firm" is in no way a pejorative – firms that incorporate a tight feedback with their innovation

[14] Bailyn and Lynch (1983) examine a group of MIT engineering graduates and find that one-third engage in extensive engineering and tinkering activities to create additional challenge for themselves, as they do not find adequate challenge or autonomy in their day jobs.

community have the potential to dramatically outperform firms run on more orthodox lines, at least in the short- to medium-term. Certainly, that was the case with the commercialization of probe microscopy.

Institutional or Social Encouragement

Community members' "day jobs" can motivate firm formation in other ways. For instance, some may belong to institutions that encourage entrepreneurship. The individual may therefore see founding a firm as a way to satisfy pressures from both the innovation community and their institution. For example, one prominent probe microscope manufacturer in the 1990s was founded by students and postdocs at Stanford (with the help of Cal Quate, their Stanford mentor), where a long and successful history of entrepreneurship made founding a company the local norm. In other cases, innovation community members may bring skills and resources from their vocation to their avocation. Kristen Haring notes that 40% of ham radio enthusiasts had careers in electronics, many at large firms where they had access to mainframe computers (Haring 2007). Thus, when the personal computer community arose in the '70s, radio hams provided many of the personnel both for early computing lifestyle firms and for the institutions supporting that community (e.g., computing magazines like *Byte* and *Kilobaud* were direct spin-offs from ham magazines like *73* and *CQ*).

Low Opportunity Costs and Low Risk

The opportunity cost for members to start firms is often quite low. First, many fledgling firms can be formed in an individual's spare time. If the firm fails, the individual has employment through his current occupation, and if it succeeds, the individual has an extra source of income and/or can choose to devote all his time to the firm or sell the firm. A professional surfer or skater who starts a company to sell a line of boards can always resume a full-time pro career if the line is not profitable. Starting a company is in some sense *less* risky than remaining a pro athlete, given that physical athletic skills decline faster over time than entrepreneurial skills. Tenured professors who start a company to make microscopes also enjoy considerable job security. Even if their company fails, it will likely generate enough intellectual property that they can sell it to another firm. (Indeed, this appears to be the standard business model in the biotech industry). There is also some indication that professors use start-up companies as a form of bridge or alternative employment for former members of their lab groups. In probe microscopy, prominent academic groups affiliated with a start-up company would frequently send their former students and postdocs to work at the start-up for a summer, a few years, or permanently. In at least one case, a professor started a probe microscopy company partly because he ran into an unemployed former postdoc on campus. The company would enhance the professor's standing in the probe microscopy community while providing jobs for the postdoc and other former affiliates.

A second reason opportunity costs are low is that even if a firm fails, most founders will still be known as experts in the field and can find employment in the field as trainers, consultants, or in support services.

Finally, because investments have already been made in innovation and prototype production methods have already been developed, it is possible to start a firm with relatively little investment beyond materials and marketing (whose costs may be low for individuals already well known and respected within the community) – making starting a firm a relatively low-risk endeavor for many.

Industrial Norms and Organization

There is an extensive literature examining and describing the methods by which firms interact with other firms (competitors, suppliers, and buyers) and institutions. The vast majority of this literature focuses on behaviors driven by profit-seeking and competition between profit-seeking firms. However, there are documented examples of *cooperative* behavior between profit-seeking firms or between firms and other institutions – such as standard-setting bodies, R&D consortia, and engagement in a variety of anti-competitive practices (collusion) as well. We will simply outline the basic norms by which firms and consumers interact, as our interest is in this topic and these concepts and their meanings are well-described in the literature.

When firms and consumers interact, they tend to do so through arms-length transactions, although some types of relationships may be far more customized (e.g., consulting). Money usually changes hands, with legally enforceable contracts being used when the exchange of the good or service for money is temporally disconnected. The product or service is generally expected to work when the exchange is made, with return and warranty provisions in place to protect the consumer's interests, at least in the short-term (from a month to several years). It is in this mode of development that production and consumption are at their furthest distance apart, with firms acting as producers and consumers focusing on consumption, and with little overlap between these activities. In fact, mechanisms such as market research and advertising – intended to help firms produce products that consumers desire and influence consumers to want the products firms offer, respectively – have been devised to bridge this gap with mixed success (Rothwell et al. 1974, Cooper 1979, 1995)[15]. Market research efforts often fail or lead to products that fall short of expectations; and while advertising often works, it can influence consumers to purchase items that they might not otherwise want or desire.

Another outcome of profit-seeking commercial activity is cost minimization. For example, production costs can be minimized through mass production or assembly-line type methods, while warranty costs can

[15] A large number of papers in management and organization theory have examined the processes and structures that support innovation within firms (see, for example, Griffin et al. 1993, Brown and Eisenhardt 1995, Fleming 2002, Urban and Hauser 2004, Taylor 2010).

be minimized by prohibiting users from tinkering (and perhaps breaking the product) by “black-boxing” its technology. The desire to sell a homogenous product leads to a need to homogenize the *use* of a product such that consumers want similar things. This leads to advertising and instructions about the “correct” way to use a product and often a desire to squelch innovation by users. We discussed the desire of sports equipment producers to promote “one-design” equipment and set techniques in the previous subsection. Similarly, Franz (1999) suggests that U.S. automobile producers tried to gain the upper hand over user-innovators by introducing the one-piece auto-body in the 1950s, and Noble (1977) suggests that producers in the 1950s and later actively engaged in convincing consumers that modern industry would provide science and technology to benefit average Americans – implicitly influencing the average citizen to allow producers to provide for them, rather than engaging in innovation, production, and replication for their personal use and enjoyment.

Another industry mode departure from the practices of community and network exchange modes is the use of intellectual property to exclude others from using a firm’s ideas. Although a product’s design may be relatively open (in that users and other firms can see it), intellectual property limits others’ abilities to work from that design without paying for it. While intellectual property may not directly limit users’ ability to innovate, it does so indirectly by limiting their ability to diffuse the innovation once it is created and build upon one another’s work. Not all firms engage in these strategies. Some firms promote the ideals of open design and tinkering, though these are often firms founded by innovators or users-turned-entrepreneurs with a commitment to innovation and/or community as well as to profit. However, some user-founded firms grow and expand considerably, and may adopt common industry practices as they grow (this is an area where future research would be useful). Future research might examine differences between the goals, strategies, and outcomes created by user-founded versus other types of firms.

5. DISCUSSION

Summary of Key Findings

We build a framework for understanding industry emergence and development based on data from probe microscopy and three sports. We identify four modes of social, economic, and technological development around each product - innovator, community, network exchange, and industry – and describe the individual motivations and social structures that define each mode. The proposed framework (1) fills a gap in the literature, (2) is largely endogenous in that the activities in each mode present incentives and disincentives for moving to another mode of industry development, and (3) the framework exhibits some degree of internal consistency in that firms and markets arise naturally from the social and economic activities that occurred in earlier modes. This paper contributes four key findings to the literature. First, motives for innovation and entrepreneurship are multiple and heterogeneous. Second, the impact of users extends well beyond consumption and innovation. Third, we uncover four social structures that exist to support product innovation, diffusion, and commercialization. Fourth, open, cooperative social structures for innovation creation and diffusion can give rise to proprietary structures. Moreover, open and proprietary structures can coexist.

Limitations & Generalizability

We took care to base our comparison on two vastly different sets of products – scanning probe microscopy and extreme sports – following the notion that common facets across such dissimilar sets of products and settings should lead to relatively robust results. Nevertheless, this study has several limitations. The use of in-depth, qualitative data offers the opportunity for insight and theory development in underexplored areas. However, such theory may be idiosyncratic and not generalizable to the entire population of industries seeded by user innovations (Eisenhardt 1989). We identify and discuss below two factors that might limit the generalizability of our results: the nature of the product being developed and the enthusiasm and commitment of individuals.

Scanning probe microscopy and extreme sports are product areas in which products can be modified and reconfigured in various ways and where new features can generally be built without encroaching on or destroying the functionality of existing features. This is in contrast to products such as pharmaceutical or chemical compounds where a slight change to the structure or use environment might render the product useless. Whether or not this framework applies to non-cumulative product domains is a matter for further research.

In the cases described here, innovators and modifiers were usually enthusiastic about the product they were developing and demonstrated what appears to be a high degree of dedication and commitment to the field. As a result, their efforts formed strong and seemingly effective communities and encouraged the widespread diffusion of products. Innovators and modifiers working on other products may demonstrate lower levels of commitment, either due to the relative personal importance of the product, the opportunity costs of their time, or the constraints placed on them by other institutional structures (note our earlier anecdote about the Quate student admonished for founding an STM firm). As a result, communities may not be as strong, may lack informal leadership, or may just have looser structures. Alternatively, innovators and modifiers in other product domains may be equally committed but possess different individual characteristics and motivations. These differences may stem from individual differences or differences in the institutional environments that shaped their preferences (for example, individuals with academic versus commercial backgrounds may have vastly different approaches towards intellectual property and commercialization, see Murray 2009).

Overall, we believe our basic framework can be generalized and extended to a diverse array of product domains and national/cultural contexts. We welcome future work to extend and refine the framework.

Multiple and Heterogeneous Motives for Innovation and Entrepreneurship

Theory generally assumes that financial motives on the part of firms, or a combination of status and financial motives on the part of academic scientists, drive innovative and entrepreneurial activity. Here we see evidence that a wide variety of motives propel users to engage in a wide variety of activities supporting innovation and entrepreneurship. An individual's relationship to the task and the social structure in which she is embedded are likely to influence and shape her motives (Giddens 1984, Coleman 1994). For example, an individual employed within a firm might be cued to respond largely to financial incentives, while scientists strive to increase their status. Relatively constrained innovation environments may have their benefits with respect to efficiencies and coordination gained by funneling thought, effort, and resources into narrow channels, but they may also constrain individuals. The result may be decreased productivity, increased turnover, or various methods of job crafting through which individuals alter the design and social environments of their work tasks, and hence the meaning of and identity derived from their work (Hackman et al. 1980, Wrzesniewski et al. 2001). The wide variety of motives supported by the community suggests that communities may be a particularly robust social structure for supporting innovative and entrepreneurial activity, one capable of spawning innovations and firms with a wide variety of goals and characteristics.

By building a framework that provides individuals with a means to become knowledgeable about an innovation, and by recognizing multiple motives for their efforts, we depart from existing explanations for entrepreneurial activity that rely on risk-taking, personality, or other exogenous factors for which little empirical support exists (Thornton 1999).

The Impact of Users

Until recently, the role of users was focused primarily on consumption and innovation, with firms being necessary to support user activity. As we've seen, users are capable of driving significant change *without* firm participation or support. This may be a boon for economic and social progress and deserves further investigation. For example, non-profit electric vehicle associations dedicated to helping individuals refit their automobiles with electric batteries have long existed in many cities across the United States, even when established automakers were unwilling or unable to produce electric vehicles for mass consumption.

Most studies of innovation in management, economics, and sociology focus on the industry mode, when firms can use their leverage to constrain user innovation and the bulk of consumers may be uninterested in innovating. Based on past research, one might argue that our focus on users and non-industrial modes of technological development gives too much weight to a negligible source of innovations. We offer three main reasons why this is not the case and why our model has general applications.

First, even mass-production industries (where user innovation might seem severely constrained) evolved from the pre-industrial modes, and the non-firm actors present in earlier modes can remain important sources of innovation in a mature industry. The history of automotive technology provides an instructive example. The first cars were built by user-tinkerers such as Karl Benz. Although these tinkerers quickly formed firms to market to consumers, the difficulties and challenges they encountered in automotive engineering provided the incentive to create localized *innovation communities* in places like Stuttgart or Detroit, where modifiers - whether hobbyists, independent entrepreneurs, or employees of existing firms – could share and develop ideas jointly. Eventually, early firms were able to sell to consumers, though early cars were so unreliable that consumers, forced to continually rebuild them, formed additional communities to share work-arounds. By 1903, rural users were modifying cars to run washing machines, butter churns, grinders, water pumps, etc. Small firms arose to sell *kits* to help users implement these modifications. Such kitter firms only faded in the 1930s when automobiles became an increasingly stable and reliable product with a generally accepted feature set. Users continued tinkering, however, and a hot-rodding community arose that continuously innovated in automotive design and provided feedback with the original equipment manufacturers. Indeed, for much of the 20th century, Detroit's new lines were filled with innovations trickled *up* from the hot rod community (Lucsko 2008).

Second, in the context of mature products, the prevalence of user innovation may only appear trivial if one limits analysis to affluent, Western consumer societies where consumers possess disposable income and products and services are increasingly cheap. However, when considering less affluent nations and less affluent segments of society, the prevalence of user innovation, even among mature products, is striking. As David Edgerton (2007) has argued, a great deal of innovation occurs in adapting new technologies to fit with older ones, and in prolonging the life of technologies when it is not feasible to replace them. To return to automotive history, one need think only of the user innovation required to keep Havana's fleet of classic American cars running when neither spare parts nor replacement cars are readily available.

Finally, if Havana's taxis represent the mature, low-tech end of the user innovation spectrum, the non-industrial modes we identify are essential to emerging high-tech products. The diffusion of transistor technology in the 1950s, for instance, closely resembled our community and network exchange modes. The original innovators' firm, Bell Labs, was compelled by law to share their technology, thereby creating a community of interested individuals in other firms who set up new trade journals and conferences to share their discoveries along the rocky road to a transistor industry (Choi 2007). The lasting influence of network exchange mechanisms helps explain why the firms responsible for important microelectronics innovations such as the CMOS transistor (RCA, IBM, Fairchild Semiconductor) were not the ones (e.g., Intel) that most successfully commercialized them (Bassett 2002). More recently, the entire biotech industry arose from, and requires the continued existence of, network exchange processes. Many new biotech firms arise from user innovations within the academic molecular biology discipline, which operates on norms of network exchange (Smith Hughes 2001).

Patterns in Industry Emergence

It's not surprising that industries develop in a variety of ways, though establishing a framework to describe and categorize these pathways has proven to be an elusive and difficult goal – a goal made more elusive by the lack of empirical data on the early stages of new industries. We hope these data and this framework are a step in the right direction.

Our framework is strongly grounded in the detailed data we collected. In assessing our framework, we took the liberty of comparing these data to data and stories about the development of *other* industries and/or product categories that we have read about or been exposed to through discussions. Two additional features of the framework quickly became apparent: (1) modes can appear in almost any order; and (2) modes can be omitted, yielding relatively consistent effects on the eventual structure of the industry (assuming that the industry mode emerges in the product category). Future work might explore these patterns in greater detail.

Modes Can Occur in Various Orders

A product may move through various modes in almost any order depending on the motives and actions of individuals involved with the product. Table 5 provides examples. For example, network exchange is often an endpoint for scientific equipment because the technology is complex and expensive and the market small. There are also cases where a key actor or set of actors drops out of the social structure and incentives arise for the social structure to transition to a mode with less distance between producers and consumers. For example, imagine a situation where the social structure is in the industry mode, but a dominant firm in ceases production. The firms' former customers may begin developing and sharing their own technology modifications, continuing innovation through community and network exchange processes. (This was the case with the TRS-80 (Lindsay 1997) and Apple Newton (Muñiz Jr. and Schau 2005)).

INSERT TABLE 5 HERE

The Effects of Omitting a Mode on Industry Structure

What happens when actors' motives or technology characteristics result in either the community or network exchange mode being omitted on the path from innovation to industry formation (see Table 5)? We offer some predictions here. The community mode might be omitted if an innovator chooses not to share his or her idea with others. An innovator hoping to reap proprietary benefit might act in this way, as might an innovator who doesn't realize that his or her innovation might be attractive to others. If the innovator patents his or her innovation and subsequently manages to generate consumer interest, a monopolistic industry structure might result. Something similar to this happened in the early years of the windsurfing industry at a time when only a handful of people practiced the sport: Hoyle Schweizer and Jim Drake of Windsurfing International took out and actively enforced a patent on the windsurfer. Product diffusion was slow and there was relatively little experimentation with respect to equipment or technique. It was only when wind and wave conditions led "the Hawaiians" to create the subfield of "high performance windsurfing" – with its own equipment and techniques, and a culture of widespread experimentation and sharing – that interest in the sport in the United States was revived. This example suggests that (1) omitting the community mode might result in slower diffusion and adoption, a smaller initial market, and less excitement and enthusiasm for a product early in its development *unless* firms engage in significant marketing efforts and/or the use-benefit is very clear (the case of magnetic resonance imaging is a good example of the latter. See (Kevles 1997)); and (2) less design experimentation may result in weaker product design and/or fewer or more limited uses for the product.

INSERT TABLE 6 HERE

In contrast, omitting the network exchange mode is likely to have little impact on the commercial structure of a developing industry and little (negative) impact on technology development. Omitting the network exchange phase *may* be an indication that an industry's innovators and modifiers face high opportunity costs on their time and do not wish to commercialize their work and/or engage in exchange transactions. As a result, an industry's first firms may be established by community members or outsiders who are not innovators or modifiers (i.e., are lower-status community members) but who see commercial potential in the product. This may also occur when government regulation or the strategic use of existing patents by extant firms creates barriers to entry that make network exchange too costly.

There are also a number of reasons why a set of firms – an industry – may *not* form in spite of a strong community and strong network exchange mechanisms around a product. First, there may be little mass market consumer interest in the product and/or it may be difficult to extract sufficiently high rents from a small group of consumers. (This is often the case for scientific instruments, where four or five lab groups around the world might saturate demand.). Second, the product may be straightforward to assemble and build. Third, incumbent firms in an existing industry may adopt the novel product concepts and integrate them into existing products. Fourth, the product may be non-rival (consumption by one individual does not reduce the amount available to others), non-excludable (freely available to all), and easy to replicate (e.g., digital goods). Finally, the product may be illegal or face significant barriers to adoption.

Coexistence: Open and Proprietary Structures

A key contribution of this paper is the idea that various social exchange structures for innovation development and commercialization can and do exist, even within the same product category. Moreover, these social exchange structures can coexist temporally, creating a rich and diverse set of environments in which individuals with various skills, resources, and motives can contribute to and shape a field's future. The fact that open (innovator, network exchange) and proprietary (industry) social exchange structures *coexist* does not mean that they do not influence one another; not only can advances from one structure diffuse to the other, but the existence of one structure might advance or limit progress in the other (Lindsey2010). On the side of advancing progress, we are observing more and more examples of communities and firms working jointly – that is, we are seeing more example of cooperation across social structures. IBM's involvement in Linux is a prime example. Other examples exist in software and electronic music (Dahlander et al. 2005, Jeppesen and Frederiksen 2006). However, the effects of this may not be altogether positive. Based on the results of a simulation, Torrance and Tomlinson (Torrance et al. 2009) suggest that a system where patent protection *and* the use of a commons for sharing both exist will lead to *lower* rates of innovation, productivity, and social utility as compared to a pure commons-based system – and roughly equivalent rates compared to a system based purely on patent protection. Examining scientific patent and paper *pairs*, Murray and Stern (2007) suggest that patents limit further innovation and work by others in the scientific area. Murray (2009) documents the tension and upheaval in a scientific field when patenting – and requests to license in order to use – a technology begin. Why these effects? Heller and Eisenberg (1998) explicate one mechanism that might halt progress when property rights are highly distributed. Namely, when property rights owners must agree or share their rights to make effective use of the property, they may be unable to reach a compromise allowing those rights to be used to their potential -- creating a system-wide failure. Certainly, more research is needed in these areas: macro research on innovation rates, as well as micro-level research on the effects of collaboration on firms and communities.

6. CONCLUSION

We inductively derive a framework for understanding the social and economic processes that lead to the development of new industries seeded by user innovations. User innovation is well accepted in the literatures on innovation and the history and sociology of technology. However, it has long been assumed that users do *not* engage directly in economic or commercial activity. This paper finds that users become entrepreneurs in the microscopy and sports equipment fields, and provides additional evidence and theorizing to extend the known scope of activities that users engage in, vividly illustrating the significant impact that users can have. We identify and describe various social structures that can support product development and diffusion and – in the process – we show that profit is only one among several motivations for undertaking innovation, diffusion, and commercialization activities.

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TABLES & FIGURES

Table 1: Study Setting

Product Category	Scanning Probe Microscopes	Sports Equipment: Windsurfing, Skateboarding, Snowboarding
Knowledge Base of Users	Formal education and graduate training in the sciences or engineering	Highly varied
Affiliations of User	Users situated in academic and corporate labs	End-users not situated in a firm or academic institution, i.e., hobbyists, tinkerers
Product Structure Examined	Baseline technology spawned many variant microscope designs and features	57 key equipment innovations that are part of the windsurf board, skateboard, and snowboard. Innovations encompass first-of-type creations and the development of subsequent key product features

Table 2: Overview of Social Structures Supporting Innovation Development & Diffusion

Mode	Innovation	Community	Network Exchange	Industry
Focal Set of Actors	User innovators	Modifiers: Users willing to build existing designs for themselves and/or modify designs incrementally	Kitters: Users seeking to use pre-made equipment or kits, often supplied by user innovators or modifiers at low cost	Entrepreneurs: Individuals who explicitly found businesses aimed at commercialization the product or service Consumers Supporting professionals and associations: e.g. industry trade groups, industry journals, service providers
Critical Resources Required	Ideas: Understanding of new product needs and how to satisfy these needs	Communication infrastructure Time and resources for additional experimentation: time is often provided by users and modifiers (i.e., use of their own time). Resources – ideas, equipment, knowledge of techniques - often provided by the community and/or other members of the users or modifiers immediate environment	Social legitimacy: for users purchasing kits rather than taking the time to build products (as others will observe and potentially question their activities) Amateurs able to access innovative equipment	Business know-how Operational know-how Formalization of business processes/production, use
Key Characteristics of the Social Structure	Technology shared in small groups, not shared, or introduced to familiar people only	Cooperation/sharing Competition between individuals based on jockeying for social position as someone who contributed a key insight or idea Very open, loose affiliations with the community Subgroups of users form over time within the community. Most communities attempt to maintain communication between these groups such that everyone benefits from novel ideas	Acknowledged experts Experts trading knowledge in order to expand the community	Profit-driven competition: appropriability and intellectual property protection become important Firms become knowledge providers for mass market users Relationships between firms and community characterized by symbiosis or tension: largely based on a firm's orientation towards IP and standardization
Product Design Developments	Experimental Trial and error Very early prototypes High levels of tacit knowledge with respect to both building and using the innovation	Technology shown to work and is improved Technology shown to be replicable Multiple key designs and uses being identified (i.e., innovation in applications) Build-your- own mentality	Multiple key designs and uses continue to be identified Begin to see actors making efforts to make tacit knowledge easier to diffuse, i.e. through the creation of kits	Focus on ease of use Focus on product standardization by many firms, i.e. well-defined functionality

Table 3: Motives & Actions Supporting the Emergence of Different Social Structures

	Innovation	Community	Network Exchange	Industry
Motives Supporting the Emergence of This Mode	• Need or desire for a product, service, or feature	• Need to attract a variety of experts to develop technology further - Need for ideas and skills - Need for resources - For innovators within firms or universities especially, the institution may want to halt the individual's activities without demotivating the innovator. This may be the impetus to share the innovation openly within a community - Belief that if they don't share, the technology may decline (as happened with field ion microscopy). This is a particularly important factor when an innovator does not have resources (time, ideas, component parts) necessary to develop the technology further • Increase legitimacy of the product in eyes of outsiders and/or individuals that have control over the time of innovators and modifiers • Enjoyment derived from working with others • Replication and knowledge transfer • Prevention of third party appropriation	• Network exchanges formed as individuals who wish to use – but wish to spend less time and effort learning about and building – the product hear about the product and join the community. • Existing community members begin to provide kits to satisfy these individuals (occasionally, entrepreneurially motivated individuals do this as well) in exchange for status as experts within the community or as part of a continued effort to broaden the field	• Realization of mass market profit potential • Availability of people with relevant skills and interest in engaging in commercialization activities; often enabled by: exchange - Learning & Self-Actualization - Lifestyle & Enjoyment - Institutional or Social Encouragement - Low Opportunity Costs - Low Risk - Disgruntlement
Actions Supporting the Emergence of This Mode	• Need to attract a variety of experts to invest time and resources to innovate	• Public revealing of innovation (and how to replicate it) by innovators in journal articles, magazines, etc • Creation of conferences, competitions or contests to promote the fledgling technology, encourage heterogeneous uses, and provide a venue for information to be shared • Creation of communication networks to share knowledge	Product features and capabilities have stabilized to the point where individuals can focus on applying the technology to applications/settings/contexts in which they are interested. • Individuals begin to request to purchase technology or particularly difficult to make component parts	• Investment by entrepreneurs or diversifying firms in creating a product that is easy to use, reliable, durable, and produces replicable results

Table 4: Mechanisms That Promote Contribution

	Innovation	Community	Network Exchange	Industry
Mechanisms that Promote Contribution	**Selective Revealing:** Sharing generally occurs only with individuals who the innovator seeks out and/or knows. - Some of these individuals may have been sought out for their expertise - Some of these individuals may be technology users sought out because of their ability to provide use-related feedback and/or encouragement **Importance of tacit knowledge** requires individuals who hear about innovation and want to use it to quickly get to know and get information with inventors. Personal contact and value of knowledge shared by inventors, generally ensures reciprocal exchange by individuals who develop the technology further	**Sharing of non-rival goods** is relatively low cost, but does require time and effort. As a result of the low costs of sharing, not everyone who benefits from the knowledge and advice of others in the community need contribute; the contributions of just a few of the many individuals welcomed into the community can make it worthwhile for others to contribute **Informal vetting by existing members** based on pre-existing social relationships and/or community interactions **Socialization** Socialization mechanisms generally require little effort on the part of existing community members - New members *observe* rich and frequent exchange of information, often creating a situation where they – for a short time – either feel they *want* to contribute something or feel *obligated* to do so - In situations where products of outcomes are observable (e.g. physical products, journal articles), others will ask questions regarding how something was accomplished, creating a situation where information *should be* shared	**Exchange of rival** goods requires considerable time, effort, and/or resources. As a result, individuals are likely to be more careful with whom they exchange - Some resources may be shared, but most are intentionally exchanged (e.g. for coauthorship, advice and knowledge, accumulation of goodwill, introduction to new networks, e.g. for post-docs, for additional knowledge) **Exchange with known individuals** - Community participation increases number of potential trusted exchange partners	**Direct, reciprocal exchange:** for example, goods exchanged for money. As a result, exchange can occur between the firm and any party with any problems (e.g. product functionality or quality) becoming the responsibility of the firm to resolve, if the firm wants to maintain its reputation - Events that cause damage to the firm's reputation and affect a community member will likely be quickly broadcast throughout the community - Events that affect a non-community member may take longer to come to light - Newcomers are not personally connected to the community, may continue to have very few ties to the community after purchase of the product

Table 5: Examples of Products that Remain in One Mode or Transition Between Modes

Initial Mode	Subsequent Mode	Examples
Innovation	*remains in* Innovation	Ideas that are highly customized or idiosyncratic to a particular individual or context, e.g. "jet propelled ignition system" designed by an amateur gliding enthusiast (Franke and Shah 2003)
Innovation	Community	Sports; scanning probe microscope, ham radio (Haring 2007); hot rods
Innovation	Network Exchange	Monoclonal antibodies
Innovation	Industry	Magnetic resonance imaging (Kevles 1997)
Community	*remains in* Community	Hot air ballooning from the late 1700s to mid-1900s (Holmes 2008)
Community	Network Exchange	Sports; scanning probe miscroscopes; personal computer (Freiberger and Swaine 2000)
Community	Industry	Some open source software (e.g. Linux commercialized by Red Hat)
Network Exchange	Community	Drosophila (fruit flies) (Kohler 1994)
Network Exchange	*remains in* Network Exchange	Model-T (Franz 2005); work arounds for medical devices
Network Exchange	Industry	Sports; scanning probe microscopes
Industry	Community	High end audio systems (Downes 2009); TRS-80 (Lindsay 1997); Apple Newton (Muñiz Jr. and Schau 2005); Cisco making previously proprietary drivers open source; Sun Microsystems founding of multiple open source communities seeded with code kernals developed in-house; companies trying to seed communities (i.e. Nokia building open source software platforms for smartphones)
Industry	Network Exchange	TRS-80 (Lindsay 1997); Apple Newton (Muñiz Jr. and Schau 2005)
Industry	*remains in* Industry	Jet engine (Scranton 2007) [1]

Notes:

- The above examples provide examples of cases where a particular product transitioned from being supported by one social structure to another (some products – like atomic force microscopy, windsurfing, skateboarding, and snowboarding equipment - transition through multiple modes).
- There are also cases where a product transitions from the community, network exchange, or industry mode to the innovation mode. We believe these to be rare. One example is the case of tile production tools. University of Pennsylvania archeologist Henry Chapman Mercer believed that American society was being ravaged by industrialism and began an effort to reintroduce the art of making custom tiles. He set up a facility to do so in 1898 and made several tool innovations.
- It is also possible for a new product to be developed in a social structure that exists to support an existing product. Take for example the fact that many early ham radio operators were employed in the electronics industry (Haring 2007). They used the knowledge, skills, and tools they had developed in electronics – and in some cases the resources provided by their employers - to benefit their tinkering in the domain of ham radio. Savvy innovators across product categories may engage in such tactics as a means for garnering resources.

[1] Such products are likely to utilize the resources of an industrial and/or corporate structure that is already in place to support an existing product.

Table 6: Impact of Omitting a Developmental Mode on Industry Structure

Mode Omitted	Potential Impact on Industry Structure[a]
Community	Monopoly structure if innovator takes out a patent Slower diffusion and adoption Smaller market, less excitement and enthusiasm early on unless firms engage in significant marketing efforts or use benefit is very clear to potential users Less design experimentation with the result being a potentially weaker product design and/or fewer or more limited uses for the product
Network Exchange	Little impact, especially if community phase robust
Industry	Firms may not form, or only a few firms may form, for several reasons: • Little mass market consumer interest in the product and/or an inability to extract sufficiently high rents from a small group of consumers (in this case, the product will likely remain in the network exchange mode) • Product is straightforward to assemble • Product is non-rival (consumption by one individual does not reduce the amount available to others), non-excludable (freely available to all), and easy to replicate (e.g. digital goods)[b c] • Product is illegal or there exist significant barrier to adoption (communities are often instrumental in removing such barriers)

[a] Assumes product seeded with a user innovation

[b] Note that knowledge satisfies all these criteria and hence a community – at least some of whose members will build the product for themselves (as the knowledge required for understanding the design and building the product is largely non-rival, non-excludable – except in cases where IP is created and stringently enforced, and easy to replicate – although it may take effort to use or enact that knowledge) - will almost always co-exist with the industry

[c] In such instances firms may form to provide various types of support services around the product (e.g. consulting, testing and certification of the product, t aching and training)

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