Contrasting Innovation Creation and Commercialization within Open, User and Cumulative Innovation

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Abstract: While industrial innovation was once assumed to be a vertically integrated process, three recent streams of research — open innovation, user innovation and cumulative innovation — have examined how innovation is created outside the boundaries of the firm. However, within these streams are multiple paths by which innovations are created and commercialized. We identify nine distinct innovation modes, which we systematically classify according to the locus of innovation creation and commercialization, and according to their enabling conditions. Finally, we discuss the contribution of our taxonomy and suggest future opportunities for research on the micro-foundations of each of these streams.

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1. Introduction

Until recently, the conceptualization of the modern industrial corporation — whether Dupont, General Motors or IBM — was that its success depended on developing and commercializing its own technological innovations (Chandler, 1977, 1990). However, beginning with von Hippel (1988), innovation researchers have begun to consider a broader range of sources of innovations that might be commercialized by firms. Other researchers, such as Teece (1986) and Chesbrough (2003), have even suggested that firms do not need to commercialize their own innovations. Finally, research on phenomena such as open source and free software (e.g. von Hippel, 2007) has shown that some economically significant technological innovations are both created and diffused entirely outside the control of firms or other for-profit actors.

This view of innovation creation and commercialization as spanning firm boundaries (or outside them entirely) has been concentrated in three major streams of research: user innovation (UI) (von Hippel, 1988, 2005), cumulative innovation (CI) (Scotchmer, 2004; Murray & O'Mahony, 2007) and open innovation (OI) (Chesbrough, 2003, 2006; Laursen & Salter, 2006). When compared to the traditional vertically integrated innovation (VII) model, these three distributed views of innovation also place greater emphasis on cooperation between actors (both individual and corporate) in the creation and commercialization of such innovations.

However, within each of these three streams are multiple distinct innovation modes that differ in the path of knowledge between actors, degree of cooperation, and assumed institutional context. For some key variables, the similarities across streams — as when firms rely on external sources of innovation (part of both UI and OI) — can be greater than the similarities between multiple modes within a given stream.

Here we identify and contrast the multiple innovation modes within open, user and cumulative innovation research. We identify the supply, demand and institutional conditions that are associated with each mode, and develop a general taxonomy of creating and commercializing innovations that includes alternatives both inside and outside the firm. From this, we suggest opportunities for future research within and across the modes.

2. Distributed Perspectives on the Innovation Process

Decades of research has identified how firms develop technical inventions into technological innovations, and then commercialize these innovations through an internal process of R&D, production and distribution. Such research has established both technical and business aspects of the innovation process, as exemplified by the industrial giants of the mid-20th century (Freeman, 1982; Chandler, 1990).

However, beginning with the work of Allen (1983) and von Hippel (1988), researchers have identified anomalies that did not conform to this stylized model of VII. From this early work, considerable research over the intervening two decades has focused on documenting the existence of a more distributed model — in which innovation outside the boundaries of the firm supplements or even supplants the integrated process of innovation commercialization — and also to explain how and why such distributed innovation occurs. (Here we use "distributed innovation" as a metacategory for prior research on innovation that crosses organizational boundaries or take place entirely outside an organization.)

Three distinct and largely disjoint streams of distributed innovation research have emerged: OI, UI and CI (Table 1). Within each stream, there are multiple modes that differ on how a new or improved technology is commercialized. These three major streams link to existing research on innovation creation, but differ from that research in their assumption as to the origins and

commercialization of such innovations. They also differ dramatically with each in both their domain and their underlying assumptions, as will be discussed below.

Insert Table 1 here

2.1. Defining Innovation, Commercialization and Diffusion

As conceptualized by innovation scholars, the industrial innovation process comprises both a technical component (invention) and also the commercialization of that technology (innovation). Schumpeter (1934: 88) concluded that technical inventions "not carried into practice … are economically irrelevant," while Freeman (1982: 7) argued that "inventions … do not necessarily lead to technical *innovations*. In fact the majority do not. An *innovation* in the economic sense is accomplished only with the first *commercial* transaction."

However, innovations can have economic or societal impact even if disseminated through a non-commercial process that Rogers (1995) has labeled the diffusion of innovations; an example of this would be Project GNU of the free/open source software movement, developed without regard to any commercial implications (West & Gallagher, 2006).[1] A definition of innovation that subsumes such cases is given by Roberts (2007: 36): "Innovation is composed of two parts: (1) the generation of an idea or invention, and (2) the conversion of that invention into a business or other useful application."

Different researchers have used different definitions as to which technical changes qualify as an "innovation." Some researchers adopt a relatively narrow technical or economic scope for "innovation," such as those that limit it to discontinuous or radical innovations that are "new to the world." Research in OI, UI and CI generally uses a broad definition of innovation. Consonant

[1] Not all open source software is non-commercial, because a significant fraction of open source software projects are sponsored by firms to help them commercialize their own inventions or those of voluntary contributors (West & O'Mahony, 2008).

with the OI, UI and CI literatures, we adopt the Nelson and Winter (1977: 48) definition that "any nontrivial change in a product or process, if there has been no prior experience, is an innovation."

2.2. Streams of Distributed Innovation Research

Overall, the different literature streams on OI, UI and CI all reject as incomplete the traditional paradigm of the vertically integrated firm, pointing to the prevalence of innovation that relies on multiple sources of knowledge not controlled by a single firm. Originally motivated by one or more anomalies — gaps between the actual practice and the accepted VII model of innovation creation and commercialization — each stream is based on a fundamental rejection of one or more of the premises of that model.

The streams are similar in that much of the early work has focused on documenting the existence, prevalence and societal impact of the associated phenomenon. However, they differ in their assumptions and core research questions, including the presumed path for creating and commercializing innovation. In addition to differences between streams, there are also important differences between the modes within each stream (Table 2).

Insert Table 2 here

Here, we outline the basic premises for each of these three major streams, as well as the distinct innovation modes within each of the streams.

Open innovation (OI). Research on OI assumes that firms are often better off commercializing external sources of innovations, and finding external paths for commercializing internally sourced innovation. The core research questions are how and when firms can commercialize the innovations of others and commercialize its valuable innovations through

others. OI is therefore especially concerned with which economic (pecuniary) implications and opportunities are provided by external sources of innovation and commercialization.

Although OI as conceived by Chesbrough (2003) is like UI in examining the extra-organizational sources of innovation, both the research motivation and the presumed motivation of key actors are considerably different. In OI, profit-maximizing firms seek to find the optimal flows of knowledge into and out of the firm to advance their technology (Chesbrough, 2006). OI is the innovation stream most similar to VII, combining with and supplementing the practices and concepts of the integrated model (Chesbrough, 2006). Unlike UI and CI, some approaches to OI allow for — if not depend on — achieving economies of scale, as when Intel designs standardized microprocessor components that are used as external innovations by systems integrators (West, 2006).

Most research on OI is split between two distinct modes, based on the direction of innovation and knowledge flows (West & Gallagher, 2006; Enkel et al., 2009). Since Chesbrough (2003), most research has focused on the outside-in (*OI-inbound*) approach for firms to access external innovations to reduce cost or increase opportunity. For example, Laursen and Salter (2006) found that internal innovation and the search for external innovations were direct substitutes, while the depth of external search was greatest earliest in the product life cycle. Neyer et al. (2009) considered the social integration processes used by medium-sized firms to incorporate external innovations.

A much smaller body of research has considered how firms — consistent with Teece (1986) — use intellectual property (IP) protection to market their innovations for commercialization by others (*OI-outbound*). A rare example is the study of Lichtenthaler (2009: 326), which concluded that "higher transaction rates in the markets for technology strengthen the positive effects of

[outbound] open innovation strategies." Conversely, Fabrizio (2006) used patent data to conclude that university efforts to monetize scientific discoveries — an OI practice consonant with Chesbrough (2003) — also slowed the cumulative production processes of open science.

Some research considers both modes, often by examining both sides of the dyadic exchange between buyers and sellers of innovation. An example is when Christensen (2006) looks at the choices made by consumer electronics makers in response a radical innovation in amplifiers: including the choice of vertical integration or OI-inbound for sourcing the new technology, and the decision whether to utilize OI-outbound for some or all of their revenues.

User innovation (UI). Research on UI assumes that users have the knowledge and motivation to create innovations that solve needs unmet by existing producers. The core research questions focus on tools, processes and policies to enable such innovation, both to unleash the potentially innovative ideas they have, and to find a way for those ideas to be diffused to others.

UI is different from VII, OI and CI in that it primarily focuses on the users of technology (individual, community and corporate) rather than the producers. Instead of the monetary profit presumed by most firm centric research, UI examines how users benefit from using their new or improved products and service. Studies of UI are thus predicated on the assumption that users will satisfy their own needs, if enabled by various design and policy choices. One such choice is the modularity of product design and, in particular, the provision of "user toolkits" to facilitate user experimentation and innovation (von Hippel & Katz, 2002; Franke & von Hippel, 2003; Jeppesen, 2005). Other choices include firm policies to encourage and solicit such innovation (von Hippel, 1988), and government IP policies that enable experimentation (von Hippel, 2005).

With this stream, four modes correspond to distinct paths for commercialization or other forms of diffusion. In the first path (*UI-input*), firms solicit user innovations as input for new or

improved commercial products, whether through user suggestions or fully elaborated prototypes (Franke & Piller, 2004; Lüthje & Herstatt, 2004; Jeppesen & Frederiksen, 2006). An example is 3M, a classical VII firm, which successfully generates new product ideas by identifying lead users in target and other markets, thereby greatly outperforming traditional innovation projects (Lilien et al., 2002). Producers can moreover outsource a part of the innovation process to users by providing toolkits for innovation. For example, Nestle FoodServices' toolkit enables custom food design by restaurants with direct prototyping and testing based on learning-by-doing — instead of the traditional approach of continuous and imperfect "translation" between users' recipes and Nestle's prototypes (von Hippel & Katz, 2002).

In another mode (*UI-self*), users may utilize the tools and alternatives to meet their needs but not seek to commercialize or otherwise disseminate those innovations. This might include traditional user-innovators that innovate to solve their own needs by making incremental improvements (cf. Hollander, 1965; Bogers, 2009). For example, Lüthje (2004) reports that the majority of innovators among outdoor sports enthusiasts does not transfer the innovative ideas to producers, and apparently do not share within a community. Moreover, Bogers et al. (forthcoming) identify users as post-implementation adapters, which include cases of users (mostly firms) that adapt (or re-invent) a producer's innovation after it has been implemented (cf. von Hippel & Tyre, 1995; Pisano, 1996). UI-self also takes place when users are given the tools to alter a product based on their specific needs, as in the case of "embedded toolkits" in which users can adapt a product to their needs while they are using it (Steiner et al., 2009).

Moreover, users may freely reveal their innovations without regards to commercialization prospects (*UI-share*), whether out of altruism, reciprocity, or in hopes of accelerating their own problem-solving efforts (Shah, 2006; von Hippel & von Krogh, 2006). It has also been argued

that sharing their innovations (both design and outputs) with others can be economically beneficial for users (Harhoff et al., 2003; Baldwin & von Hippel, 2009), while a large user community may attract producers to enter the newly defined niche (Baldwin et al., 2006). Based on a common interest in creating and disseminating innovations, individuals and firms may form a self-identified innovation community (West & Lakhani, 2008). Sharing among users occurs in information goods, such as open source software (e.g. Lakhani & von Hippel, 2003), as well as in physical goods, such as sports-related products (e.g. Franke & Shah, 2003). Users can share innovations both *horizontally*, thus operating independently of any sponsoring firm (von Hippel, 2007), and *vertically*, with upstream producers (de Jong & von Hippel, 2009).

Most recently, Shah and Tripsas (2007) identified another path for direct commercialization (*UI-startup*), in which users — typically after engaging in a collective creative activity within a user community to identify a need and refine its solution — become user-entrepreneurs to serve heterogeneous niche markets in industries with low entry barriers. An example from their study is the Baby Jogger Company, established by a user-entrepreneur who invented the jogging stroller to be able to roll his son along with him while jogging, while Yahoo! is also given as an example of a firm founded by user-entrepreneurs. Shah and Tripsas (2007) distinguish two types of user entrepreneurs. End-user entrepreneurs use a product in their daily life — similar to UI-self and UI-share (with the subsequent commercialization being the key difference). Professional-user entrepreneurs are embedded in an organization and use a product in their professional life; their commercialization path is to develop a spin-off in a completely different industry — matching the OI-outbound spin-off pattern identified by Chesbrough (2003, 2006).

Cumulative innovation (CI). Research on CI assumes that unmonetized knowledge spillovers between rivals play a crucial role in advancing technological progress and thus in

improving societal welfare. The central research questions focus on documenting the value of such flows and evaluating alternative IP policies that encourage or impede these flows. Such research often (implicitly or explicitly) has implications for IP policy, with a particular emphasis on patent regimes. The earliest CI research focused on rivalrous firms seeking to increase revenues and profits through technological innovation, normally when that technology is immature or otherwise not fully commercialized.

The initial focus of CI research considered cases where various parties successively refine a single technology until the improved technology is widely used by a range of producers (Allen, 1983; Nuvolari, 2004). The other pattern of CI is when firms build upon a common, ever-increasing pool of enabling science, as in biopharmaceutical drug discovery (Murray & O'Mahony, 2007; Scotchmer, 2004). Within CI, a significant body of research models the impact of IP protection regimes upon incentives for initial and subsequent innovators (e.g. Scotchmer, 1991; Bessen, 2004).[2]

Two modes of CI research share a common perspective on the existence (and societal benefits) of interfirm spillovers, but they differ on the degree of cooperation manifest in these spillovers. In some cases, CI is fueled by explicit cooperation and intentional knowledge sharing between firms and other researchers (*CI-share*), including those linked to the norms of open science (David, 2002; Murray & O'Mahony, 2007). Firms may also share knowledge when the innovation is complementary rather than core to their primary business, as in Nuvolari's (2004) study of pumping engines. In other cases, direct competitors build upon each other's knowledge spillovers to advance the state of the art (*CI-rival*). This may occur when efforts to build barriers

[2] While this research has been variously described as "collective invention" or "cumulative innovation," both categories consider the cumulative process of incremental innovation with contributions by rivalrous (or semi-rivalrous) inventors. Here we use the most recent term.

through IP prove unsuccessful (e.g. Allen, 1983). Alternately, consistent with von Hippel and von Krogh's (2006) typology of free revealing, firms may resign themselves to spillovers after concluding that such knowledge is not cost-effective to protect.[3]

3. Characteristics of Distributed Innovation Modes

While the different streams of distributed innovation research have overlapping critiques of the integrated innovation process, they differ significantly in their enabling assumptions about the sources, incentives and success criteria for creating and diffusing innovations. Here we contrast how the streams differ in terms of the locus of innovation creation, paths to commercialization, and the enabling assumptions (and thus domain boundaries) under which they can occur.

3.1. Locus of Innovation Creation

In the earlier paradigm of the VII firm, all knowledge is internalized and controlled by the firm, which is more efficient due to failure of markets and the inability to appropriate benefits of innovation (cf. Chandler, 1977, 1990; Teece, 1986). In contrast, the OI, UI and CI streams focus on innovation that combines knowledge created at different loci, across multiple stakeholders in a value network (von Hippel, 2005; Chesbrough, 2006; Murray & O'Mahony, 2007). Figure 1 gives a representation of the most commonly discussed flows in these three streams.

Insert Figure 1 here

Distributed loci of innovation creation. While the focal firm can have an internal innovation process (as in VII), the distributed innovation streams particularly emphasize one or

[3] Although UI research has generally been characterized as cooperative and collaborative, some researchers have identified examples of rivalrous UI. For example, as argued by Baldwin and von Hippel (2009), the incentive to freely reveal decreases if the users compete with one another, which can for example happen in the case of competing firms or competing sportspeople (Franke & Shah, 2003; Baldwin et al., 2006).

more of the external stakeholders in the firm's value network as a main source of innovation. More generally, research in the area of OI-inbound argues that there can be several sources of external innovation and thus knowledge inflows. In fact, it generally considers the widest possible variety of external sources of innovation — including customers, suppliers, competitors and complementors — to be of potential value for the firm (Chesbrough & Rosenbloom, 2002; Laursen & Salter, 2006; Poetz & Schreier, 2009). For example, P&G is very successful at "crowdsourcing" (as a general type of OI-inbound) by drawing on any of these sources — thereby enabling that a large part of their new products originate from the outside — while innovation intermediaries like InnoCentive tap into any type of actor, as long as it has the relevant knowledge to solve a particular innovation problem (Lakhani et al., 2007; Howe, 2008).

Suppliers. Among the various actors in a firm's value network, suppliers are particularly acknowledged by OI research to play an increasingly important role in the innovation process (Chesbrough, 2003), as also exemplified by the embeddedness of specialized technology suppliers in the open innovation system during the transformation to digital technology in sound amplification (Christensen et al., 2005). More generally, there is evidence of important differences in terms of learning and innovation processes for suppliers vis-à-vis users (Pisano, 1996; Jensen et al., 2007; von Hippel & Tyre, 1995). The role of suppliers as the sources of innovation was highlighted in even earlier research, when von Hippel (1988) concluded that suppliers will supply innovation if they can appropriate the benefits from selling material or components that are complementary to the innovation (see also VanderWerf, 1990). Suppliers of external innovations are usually organizations, but firms can also cultivate individual suppliers who — in contrast to user-innovators — may be seeking financial or other rewards (von Hippel, 1988; West & Gallagher, 2006).

Science. The sources of external innovations, especially in OI-inbound, can also be non-profit entities, including universities and government laboratories (West et al., 2006). Prior research has established the importance of external science as a complement to a firm's innovation processes in general (e.g. Cohen & Levinthal, 1990; Etzkowitz & Leydesdorff, 2000; Laursen & Salter, 2004) and university-industry collaboration in particular (e.g. Lee, 1996; Perkmann & Walsh, 2008). Firms can draw upon the knowledge spillovers inherent in the process of open science (which has parallels to UI-share and CI-share), which emphasizes openness in enabling the cumulative process of scientific discovery (David, 1998, 2002). However, since the Bayh-Dole Act, American universities have sought to monetize those spillovers, potentially delaying the cumulative innovation discovery process of open science (Fabrizio, 2006).

Users. Users are considered to be an increasingly important external source of innovation, by both OI-inbound and UI-input. However, these external stakeholders may also innovate independently of the firm, which may include collaborative efforts to collectively produce innovations — as clearly shown by the research of von Hippel (2005, 2007) and others. Empirical research in this area has mostly shown that individual users (UI-self) and user communities (UI-share) innovate by cumulatively building on their local knowledge and expertise (Franke & Shah, 2003; Lakhani & von Hippel, 2003; Lüthje, 2004; Lüthje et al., 2005). In addition, intermediate users and other organizational users may also act as a source of innovations (Bogers, 2009; de Jong & von Hippel, 2009). The role of user-innovators is often important for a focal firm because (as shown by UI-share and UI-startup) users innovate independently from producers (Shah & Tripsas, 2007; von Hippel, 2007), while (via UI-input) they can also assist to a producer-innovator (Lilien et al., 2002; von Hippel & Katz, 2002;

Jeppesen & Frederiksen, 2006). In OI-inbound, users can help firms complete their product offering by providing missing pieces of the whole product solution (West & Gallagher, 2006)

Rivals. A firm's competitors can also be an important source of innovation, which is the central argument of CI-rival (Allen, 1983), also supported by CI-share (Nuvolari, 2004) and OI-inbound (Chesbrough, 2006). This viewpoint has parallels to research on inter-firm collaboration as well (e.g. Mowery et al., 1996; Hagedoorn, 2002). Next to formal collaboration, such knowledge sharing might also take place through informal channels (Allen, 1977; von Hippel, 1987; Schrader, 1991). Given the weak property rights associated with knowledge (cf. Arrow, 1962; Liebeskind, 1996), knowledge "leakage" might be unintentional (as in CI-rival), although it might also be disclosed to rivals on a voluntary basis (as in CI-share). Lhuillery (2006) finds that R&D intensive and collaborative firms in high-tech sectors are more likely to engage in knowledge "leakage" or disclosure. Moreover, knowledge might be disclosed not only to competitors but to public laboratories as well (cf. OI-outbound).

3.2. Paths for Commercializing or Diffusing Innovations

The research streams of OI, UI and CI — as well as the innovation modes within them — differ not only in their assumptions of the locus of innovation creation, but also in the relevant commercialization or diffusion paths (cf. Table 2). More precisely, the integrated innovation stream and the various modes of distributed innovation streams differ along two dimensions: the locus of innovation creation and the locus of innovation commercialization — as defined by whether that creation or commercialization happens inside or outside the focal firm (Figure 2).

Insert Figure 2 here

We thus distinguish the two parts of the innovation process, namely the conception of a new technology or invention and the commercialization of that invention (Schumpeter, 1934;

Freeman, 1982). In the latter category, we also include non-commercial diffusion of inventions as they often have an economic impact (Rogers, 1995; Roberts, 2007). The figure additionally makes a distinction between inside (internal) or outside (external) creation and commercialization, referring to whether the creation and/or commercialization are performed by a focal firm in the value network or by some other external stakeholder (cf. Figure 1).

Created inside, commercialized inside. This includes the traditional VII model, which is based on internally developing new ideas, developing those ideas into new technologies, and commercializing them as products to their customers. Thus, both the creation and the commercialization is entirely internalized and controlled by the focal firm (cf. Chandler, 1977, 1990; Teece, 1986). Examples of this would be Dupont's research into organic chemistry in the 1920s and 1930s, that both discovered and developed high-volume manufacturing processes for products such as cellulose, Freon, Teflon, acrylic plastics (Lucite), and lacquer-based automotive paints (Chandler, 1990: 183-187).

Created outside, commercialized inside. The clearest example of a focal firm commercializing an externally created innovation is OI-inbound, which deals with how firms can access external innovations to reduce cost or increase opportunity (Chesbrough, 2003; Almirall & Casadesus-Masanell, 2010). For example, Laursen and Salter (2006) explore to what extent UK manufacturing firms rely on external knowledge — such as from suppliers, customers, competitors and universities — for their internally commercialized innovations. OI-inbound considers any external expert as a possible locus of innovation creation (Chesbrough, 2003; Lakhani et al., 2007), while UI-input specifically identifies user communities as valuable sources of innovative knowledge (Dahlander & Wallin, 2006; Jeppesen & Frederiksen, 2006; West & Lakhani, 2008). During product development, firms can also solicit innovations from lead users

or through innovation toolkits — getting the original idea or even prototypes from users — but they subsequently commercialize those innovations internally (cf. Bogers et al., forthcoming). Thus, although UI generally rejects the VII paradigm, user innovations may end up being commercialized through processes that are partly or largely vertically integrated — as in the case of 3M or Nestlé (Lilien et al., 2002; von Hippel & Katz, 2002). Even in cases where user-innovators launch a firm that relies on user innovations (UI-startup), the end result may be a self-sustaining firm that practices VII to a degree similar to other established firms, as when Josephine Cochrane founded what became the dishwasher manufacturer KitchenAid or when mother Julie Aigner-Clark founded the Baby Einstein Company, later bought by the Walt Disney Company (Shah & Tripsas, 2007).

Created outside, commercialized outside. Considerable OI, UI and CI research has established that innovation is created outside of a focal firm, and many of these innovations are commercialized (or otherwise diffused) outside the firm as well. In particular, the UI-share mode assumes that no focal firm is required to diffuse (or use) an innovation and that there is often no commercialization at all.[4] Consequently, the research on UI-share tends to focus on the non-commercial diffusion of innovations by users. This might be spread directly to peers via word of mouth, as when users of stressed-skin panels freely revealed their innovations to other builders instead of keeping them proprietary, thus providing a cheap diffusion mechanism (Slaughter, 1993; von Hippel, 2005). Or it may be diffused to other users via communities, as with the new musical timbres created by users of a computer-controlled music synthesizer (Jeppesen & Frederiksen, 2006). More generally, in UI-share, users can join communities to develop and

[4] UI-self is not included in Figure 2 because it emphasizes efforts by user-innovators to improve their own situation without trying to help others, and thus does not entail any commercialization or diffusion.

freely reveal their innovations, as for example also shown in studies of software and sport-related products (Franke & Shah, 2003; Baldwin et al., 2006; von Hippel, 2007).

Created inside, commercialized outside. While research on distributed innovation often examines getting external knowledge into the firm, a much smaller amount of research considers the case in which the focal firm internally develops an innovation that is commercialized externally (cf. Chesbrough et al., 2006; Enkel et al., 2009; van de Vrande et al., 2009). However, as an important exception, research in the OI-outbound mode investigates which mechanisms a firm can deploy to externally commercialize an internally developed technology when there is a misfit between the technology and the firm's commercialization capabilities or its business model. Chesbrough's (2003) research on efforts to commercialize its PARC discoveries would fit into this category, as when Xerox licensed technologies to spin-off companies including Documentum, Komag and SynOptics.

Created and commercialized at or across firm boundaries. Not all innovation creation or commercialization fits neatly into a simple inside/outside classification. For example, the concept of "co-creation" (Prahalad & Ramaswamy, 2004) is an extension of UI-input or OI-inbound that involves joint development of an innovation *at* the boundary of a firm, i.e. between a firm's employees and external stakeholders such as users (e.g. Neyer et al., 2009). Some forms of CI-share also involve the cooperative solution of key innovation problems. For example, West & Gallagher (2006) classify as UI-input the "pooled R&D" model of firm cooperation in open source development, because the member firms are able to build upon the common technology with their own products; however, the joint development of a shared platform by multiple firms could also be classified as CI-share. If the shared technology is also available as a separate product — as with the Eclipse open source development environment — then the

commercialization is also taking place jointly at the boundary between multiple firms. In other cases, innovation is created or commercialized *across* firm boundaries. The best example of this is the CI-rival mode, as individual firms use industry spillovers as input to their VII creation and commercialization efforts. Allen's (1983) example of iron and steel makers is representative of this pattern. This simultaneous multiple invention or commercialization effort is often accelerated by the processes of open science (cf. David, 2002), as can be found in biomedical research (e.g. Murray & O'Mahony, 2007).

3.3. Boundary Conditions

The different modes of distributed innovation assume different preconditions for when such innovation takes place — across both streams and modes. Table 3 gives an overview of the supply, demand and institutional preconditions for these various modes.

Insert Table 3 here

Industry maturity. Vertical integration is often the direct and indirect outgrowth of industry maturation. As the rate of change slows and opportunities for technological differentiation decrease, firms seek competitive advantage through control their value chain or other complementary assets (Teece, 1986). Eventually, mergers, exits and other sources of consolidation give firms the scale (often by creating oligopolies) necessary to perform their own R&D (Allen, 1983; Utterback & Suárez, 1993).

Access to knowledge. There are important differences across the research streams with respect to access to relevant knowledge for successful innovation. Murray and O'Mahony (2007) argue that access is one of the conditions for knowledge accumulation in the area of CI. This is similar to much UI research, although access to external knowledge is not relevant if the required knowledge is locally available (Lüthje et al., 2005). In UI-self, users use their local sticky

knowledge to meet their heterogeneous needs — and they innovate if the costs of producing the innovation are low enough (Bogers et al., forthcoming) — while UI-share moreover depends on a users' decision to (freely) reveal the innovation (Harhoff et al., 2003) — if the costs of distribution are low enough (von Hippel, 2007; Baldwin & von Hippel, 2009). In CI-share, such conditions might have to be more formally institutionalized, for example through cross-licensing or patent pools (e.g. Shapiro, 2001), while CI-rival relies on involuntary spillovers. In UI-input, sticky knowledge moreover implies that firms need to build platforms to access users' knowledge and innovations, based on experimentation and learning-by-doing (von Hippel & Katz, 2002; Dahlander & Wallin, 2006; Jeppesen & Frederiksen, 2006). OI-inbound, on the other hand, does not rely on any given pool of knowledge, but relies on the fact that there are enough expert stakeholders available, with an innovation that fits the firm's business model.

Markets for innovation. In the case of OI-outbound, the innovation is locally available in the focal firm, so that successful commercialization does not depend on access to knowledge but mostly on a market need for the innovation (Chesbrough, 2003). The markets for innovation, more generally, are an important (institutional) condition for various modes of distributed innovation. Weak markets for innovation may prompt VII (cf. Teece, 1986), while strong markets allow OI-inbound to thrive. Market dynamics also play a role in UI and CI, as the general need for creating a non-existing technology is what gives rise to innovation creation by users and rivals, respectively. More specifically, when a user's need are not met by any product on the market, the incentive to create a new innovation increases, as in UI-self, while an innovation is more likely to be diffused if the market of users (and producers) is non-rivalrous, as in UI-share (cf. Harhoff et al., 2003; von Hippel, 2007; Baldwin & von Hippel, 2009). In the case of UI-startup, there are moreover several conditions that need to be met before a user-

innovator decides to commercialize the innovation. Shah and Tripsas (2007) propose that UI-startup will be more prevalent in markets with small-scale niches and high demand variety, while turbulent markets with new products and uncertain, ambiguous and evolving needs also make it more likely.

Appropriability and IP. An important difference across research streams is how appropriability regimes — specifically the strength of IP rights — might foster or hamper distributed innovation. CI relies on a weak IP regime, in order to facilitate knowledge spillovers, whether voluntary (CI-share) or involuntary (CI-rival). In contrast, OI (especially OI-outbound) thrives on the basis of strong IP protection (e.g. licensing), and may be difficult to achieve in, for example, developing countries where *de jure* IP laws are not enforceable, creating weak *de facto* appropriability. Conversely, UI generally assumes weak appropriation (if not appropriability) of intellectual property rights (IPRs), based on the free revealing of users (UI-share), either to other users or to other stakeholders, such as producers (von Hippel, 2007; Baldwin & von Hippel, 2009; de Jong & von Hippel, 2009). Thus, differences in the strength of appropriability correspond to important differences across the modes of distributed innovation research.

Community size. Another condition is the size of the population of firms creating or commercializing innovations. CI relies on a large enough population of innovation creators, while OI can only take place when there are enough buyers or sellers. This is to some extent different for UI, which may require only a few users with strong needs and useful knowledge. In UI-self, there is moreover just a single user-innovator, which innovates whenever the benefits exceed the costs of innovating — mostly based on expected benefits and costs of knowledge transfer (von Hippel, 2005; Baldwin & von Hippel, 2009; Bogers et al., forthcoming). However, a minimum effective network size is relevant to innovation in user communities (UI-share) and

to innovation in a community of competitors (CI-share or CI-rival). Similarly, UI-startup typically depends on collective creative efforts in user communities (Shah & Tripsas, 2007).

4. Discussion

4.1. Contribution

We believe this paper makes three primary contributions.

First, it identifies and contrasts different innovation modes within each of the open, user and cumulative innovation streams of research — differences that in the latter two cases have been downplayed, if not ignored, in the past. By demarking these differences within the streams, as well as identifying the similarities across modes in different streams (most notably OI-inbound and UI-input), future research can more precisely apply, develop and extend this increasingly influential research.

Second, the paper contrasts the demand, supply and institutional conditions that apply to each mode of innovation. We show how these conditions are shaped by issues as industry maturity, knowledge access, markets for innovation, appropriability regimes, and community size. This offers a theory-based rubric for bounding the domain for each mode's normative recommendations and causal predictions, as well as implications for policymakers seeking to stimulate the incidence of a specific mode. Such greater theoretical precision would support calls (e.g. Bogers et al., forthcoming) for an increased focus on the micro-foundations and causal relationships that enable innovation creation and commercialization across the modes.

Third, it demonstrates the importance of broadening the conceptualization of just where innovation and inventions can be found, but also the path by which they get commercialized. Research since von Hippel (1988) has emphasized sources of innovation created outside the firm, while more recent research on CI (e.g. Scotchmer, 2004) and co-creation (Neyer et al., 2009) has

considered creating innovations at the boundary (or jointly across the boundary) of a given firm. However, innovation modes that share a common source for creation (e.g. UI-input and UI-startup) have important differences due to different paths for commercialization.

With the notable exception of OI-outbound research inspired by Chesbrough (2003), little research has considered the converse case, of creating innovations within the firm but commercializing them outside the firm. Similarly, the emphasis on commercialization paths entirely outside the firm has considered non-commercial motivations such as open science and free software, but such voluntary activities also have the potential to advance the firm's pecuniary interests by providing complementary goods and services (Jeppesen & Frederiksen, 2006; West & Gallagher, 2006). Together, we believe this suggests a more general model of commercialization, by fully relaxing the commercialization paths assumed by vertical integration (and even the OI, UI and CI critiques) to include all possible sources and outlets for innovation.

4.2. Suggestions for Future Research

Beyond enabling the more precise application of existing innovation modes, this taxonomy suggests opportunities to consider research that combines multiple modes. For example, Chesbrough (2006) suggests that the optimal firm strategy is to combine the VII, OI-inbound and OI-outbound innovation modes. Von Hippel (2005) has advocated that firms practicing UI-input integrate such efforts with UI-share, while Shah and Tripsas (2007) argue that UI-self and UI-share may lead to UI-startup if other alternatives are blocked. However, there is no theoretical reason to assume that combinations of modes are limited to a single stream. For example, despite very distinct assumptions about motivations and conditions, the use of OI (both OI-inbound and OI-outbound) is likely linked to the process of open science (cf. UI-share and CI-share).

Research can moreover consider the existing and potential overlaps between multiple modes. Do the differences between UI-input and OI-inbound extend beyond the former's presumption of a user "scratching a personal itch"[5] and the latter's emphasis on pecuniary motivations? Which one most accurately predicts the outcomes of external innovation processes such as user-generated content or crowdsourcing? Do either help explain the related (and taxonomically adjacent) phenomenon of innovation co-creation?

The overlap between multiple related innovation modes also offers the opportunity to further investigate the degree to which supply, demand or institutional conditions are predictors of the likelihood of the various modes. For example, as less restrictive IP policies have been argued to be essential antecedents to CI-rival (Scotchmer, 2004) and UI-share (von Hippel, 2005), a quasi-experiment or cross-sectional comparison would be expected to show lower incidence of these modes in countries with stronger IP policies. This raises even more possible empirical questions: Are other innovation modes (e.g. OI-inbound, UI-input) more likely, and will overall innovation increase or decrease? Also, is the incidence of some modes positively (or negatively) correlated to each other? Similarly, research in developing countries where distribution channels provide high entry barriers would be expected to encourage innovative startups to use OI-outbound (cf. Teece, 1986), while weak IP institutions could render that approach impractical.

Other research can consider whether the innovation is core or complementary to the focal firm's business. As noted above, firms have consciously managed efforts by external innovators to provide (and non-commercially diffuse) complementary goods, whether by non-profit innovation communities or ecosystems of for-profit firms (cf. Vanhaverbeke, 2006; West &

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[5] The exact, oft-quoted axiom of user innovation in open source software by Raymond (2001: 32) is: "Every good work of software starts by scratching a developer's personal itch."

Lakhani, 2008). Is there a theoretical reason why this external sourcing has been less often identified for core innovations, or is this another possible (and perhaps already extant) mode of external innovation?

Finally, a systematic taxonomy offers the advantage of suggesting as-yet unidentified modes of innovation. Not surprisingly, many of the most novel opportunities for research (and practice) are at the boundaries of the internal and external alternatives. Recently, researchers (and managers) have been excited by co-creation of innovation, but what about co-commercialization? Are there opportunities to methodically combine the best of external and internal diffusion efforts for externally (or internally) created innovations? Are there preconditions, key variables or best practices that generalize beyond a particular case? What role do boundary spanners play in bridging the internal and external divide — whether employees working in open source projects (Henkel, 2009) or consultants acting as innovation intermediaries (Sawhney et al., 2003)? Are there aspects of boundary spanning from creation that generalize to commercialization?

Along these lines, we believe our work is complementary to (and could be integrated with) that of Baldwin and von Hippel (2009), who mathematically model how the locus of innovation creation will depend on the relative magnitude of communication and design costs. For their category of "open collaborative innovators," they use open source software as an exemplar, but West and O'Mahony (2008) note important differences in the collaboration model depending on whether the open source sponsors have commercial or non-commercial motivations (i.e. corresponding to the inside/outside commercialization bifurcation of Figure 2). Thus, we believe that a similar opportunity exists to rigorously model the conditions for commercialization, as well as the choice of different paths linking innovation creation to commercialization.

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6. Tables and Figures

Research Stream	Key Premise	Seminal Authors
Vertical integration (VII)	Firms need to control the creation and commercialization of their innovations	Chandler (1977, 1990)
Open innovation (OI)	Firms often do better with external creation or commercialization	Chesbrough (2003, 2006)
User innovation (UI)	Users often know best how to create innovations	Von Hippel (1988, 2005)
Cumulative innovation (CI)	Innovation often depends on rival firms building upon each other's work	Allen (1983), Scotchmer (2004)

Table 1: Key streams of innovation research

Research Stream	Innovation Mode	Designator	Commercialization Path
Vertical integration (VII)	Vertically integrated innovation	VII	The firm commercializes own innovations
Open innovation (OI)	Outside-in	OI-inbound	The firm commercializes others' innovations
	Inside-out	OI-outbound	Others commercialize the firm's innovations
User innovation (UI)	Lead users	UI-input	By producers
	User self-help	UI-self	Enhances own utility, but not diffused
	User sharing	UI-share	Non-commercial diffusion
	User entrepreneurship	UI-startup	Self commercialization
Cumulative innovation (CI)	Cooperative	CI-share	Innovators share knowledge
	Rivalrous	CI-rival	Knowledge leaks between competitors

Table 2: Distinct innovation modes within open, user and cumulative innovation

Mode	Supply Conditions (Creation)	Demand Conditions (Commercialization)	Institutional Conditions
VII	Firms having scale to do internal R&D	Large homogeneous markets	Weak markets for innovation
OI-inbound	Availability of external knowledge	Fit with focal firm's business model	Strong markets for innovation
OI-outbound	Firms having valuable technology	1) Broad need for technology; or 2) specialized need outside the firm	Strong IP regime
UI-input	Ability to innovate and transfer sticky knowledge through platforms (toolkits)	Sufficient number of other users with similar needs	Transferability and modularity of knowledge and property rights
UI-self	Low-cost production of innovation	Heterogeneous need, particular to small number of users	User needs unmet by incumbent producers (imperfect markets)
UI-share	Low-cost distribution of innovation	Identifiable pool of similarly situated and non-rivalrous users	Weak appropriability of IP
UI-startup	Entrepreneurial user spots unmet need	Large enough to support small scale entry, too small to attract incumbents	Immature markets
CI-share	Multiple firms with scale to perform some R&D, but lacking scale to internalize all R&D	Multiple firms with overlapping needs	Incentives aligned to jointly benefit from industry advance
CI-rival	Multiple firms with scale to perform some R&D		IP impractical to enforce

Table 3: Preconditions for distributed innovation

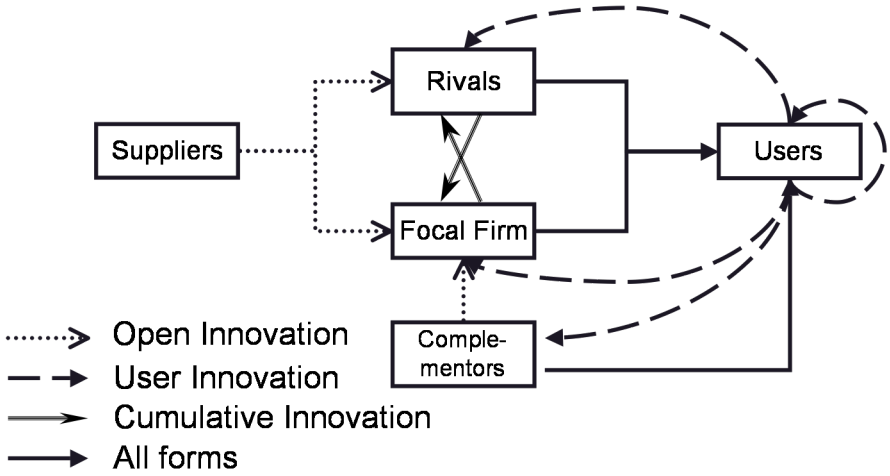

Figure 1: Innovation flows in the value network

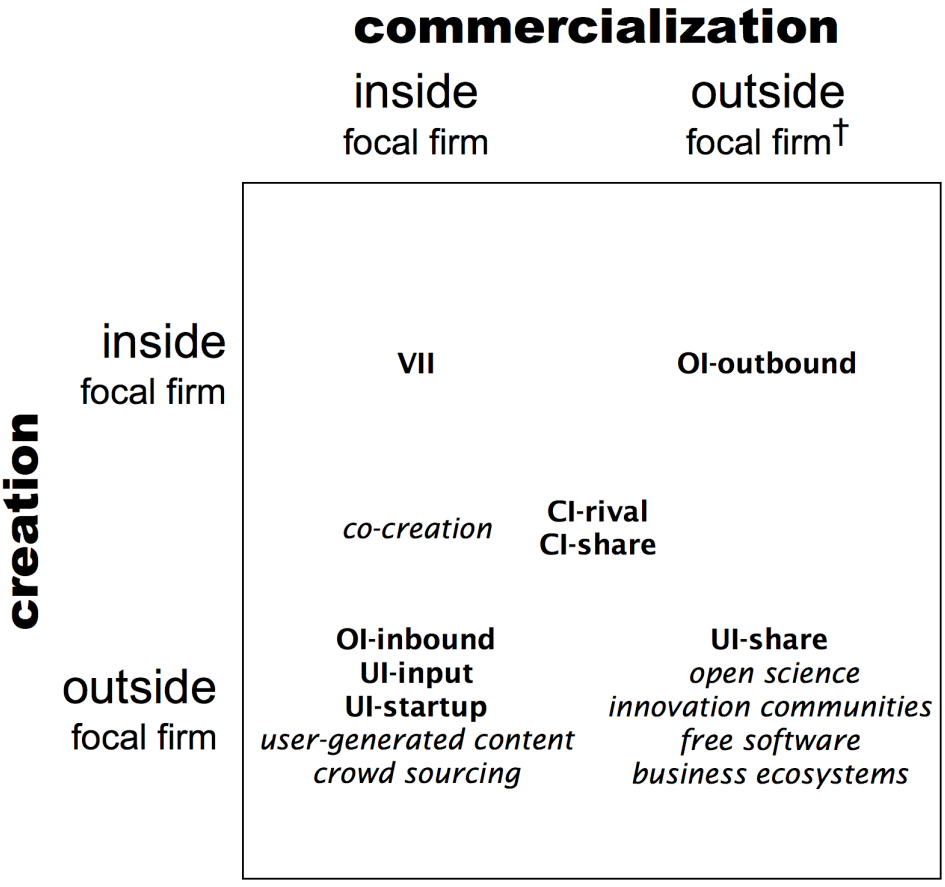

Figure 2: Locus of innovation creation and commercialization

Legend: † Includes non-commercial diffusion of innovations
Bold Innovation mode (UI-self not shown)
Italic Distributed innovation phenomenon