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Peer Production and Cooperation

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1. Introduction and overview

Peer production is the most significant organizational innovation that has emerged from Internet-mediated social practice. Organizationally, it combines three core characteristics: (a) *decentralization of conception and execution* of problems and solutions, (b) *harnessing diverse motivations*, and (c) *separation of governance and management from property and contract*. Functionally, these components make peer production practices highly adept at learning and experimentation, innovation, and adaptation in rapidly changing, persistently uncertain and complex environments. Under high rates of technological innovation, and the high diversity of sources of uncertainty typical of early 21st century global markets, the functional advantages of peer production have made it an effective organizational model in diverse domains. From free software, through Wikipedia to video journalism, peer production plays a more significant role in the information production environment than predicted by standard models at the turn of the millennium.[1]

Free and Open Source Software (FOSS) and Wikipedia are the best known instances of peer production. FOSS is responsible for the development of most of the basic utilities on which the Internet runs. Firms have recognized this, and have adopted FOSS as a strategic option for over a decade, since IBM first announced it would invest one billion dollars in its FOSS strategy and Netscape turned its browser over to the Mozilla Foundation. Most recently, Google's strategic choice to develop Android as FOSS allowed Android to catch up and overtake Apple's iOS as the dominant smartphone operating system. Wikipedia was laughable: a curiosity at best, a theoretical impossibility at worst, for mainstream economic theory of 1999. And yet it is one of the most important knowledge utilities of our time.

Much of the early economic analysis of peer production focused on software (Ghosh 1998; Lerner and Tirole 2002; Besen 2005), but FOSS was understood by some from the start as an aspect of online cooperation generally (Ghosh 1998; Kollock 1999; Moglen 1999), with a strong emphasis on the comparative advantages of peer production as an organizational and institutional model of collaborative innovation and information production (Benkler 2001, 2002; Von Hippel and Von Krogh 2003; Weber 2004). Since then there has been a gradually expanding literature on FOSS and peer production: open collaborative innovation and creation, performed by diverse, decentralized groups organized principally by neither price signals nor organizational hierarchy, harnessing heterogeneous motivations, and governed and managed based on principles other than the residual authority of ownership implemented through contract. Work has largely fallen in the categories of motivation, organization, and effectiveness or value to innovation. Here I will emphasize particularly the lessons for the importance of (a) diversity of human motivation; (b) innovation, experimentation, and tacit knowledge under conditions of uncertainty and change, and (c) transaction and organization costs, in making these

1 For example, Shapiro and Varian 1998 is an excellent example of the best understanding at the time. It characterizes the core dynamics of information and network production as related to high-fixed, low-marginal cost, lock-in, network effects, and the experience good nature of information goods. FOSS or what would become peer production; the role of diverse motivations, these play no role in the book, which uses the threat of Microsoft's Encarta to Britannica as a core instance of the new models of network-based and information production.

decentralized models stable and self-sustaining, effective, and in some cases superior to the traditional models of production: markets, firms (both for-profit and non-profit), and governments.

The implications of peer production are broader than the direct economic impact of the practice. Beyond the magnitude of its effects on innovation and knowledge production in the networked economy and participation in the networked society, the success of peer production and online cooperation has several implications for economics more generally. It requires that we refine our ideas about motivation or incentives; it recalibrates the roles of property and contract, as opposed to commons and social organization, in the growth-critical domains of knowledge-dependent production and innovation; and it requires adaptations to the theory of the firm.

a. Definitions: Peer production distinguished from crowdsourcing, online labor markets, prizes or competitions, and open, collaborative innovation

Peer production is an organizational innovation along three dimensions:

1. Decentralized conception and execution
2. Diverse motivations, including a range of non-monetary motivations, are central.
3. Organization (governance and management) is separated from property and contract
    1. Inputs and outputs mostly governed as open commons or common property regimes
    2. Organizational governance and managerial resource and task definition and allocation utilize combinations of participatory, meritocratic (do-ocracy) and charismatic, rather than proprietary or contractual models

        NB: In firm-hosted peer production, property and contract are often retained, but contract structure is designed to simulated freedom to operate features of the absence of property and contract. The retention of control over platforms does influence the dynamics, capabilities, and potential tensions faced by firm-based peer production.

Section 2 will explain the centrality of these three to the particular advantages of peer production as a an information, innovation, and knowledge production system. For now, take Wikipedia or FOSS as the core examples, where conception and execution (of a feature needing development, or an article that needs writing) are decentralized; where contributors rely on diverse motivations, many (about half in FOSS, all in Wikipedia) non-monetary; where the copyright licenses used make ownership or contract irrelevant to the core organizational question of who does what, when, with what resources and which collaborators, and where task construction generally is collaborative, though in some cases may be merely coordinated/collated. Property and contract play a somewhat larger role in copyleft[2] licenses than non-copyleft licenses, but even in copyleft licenses the property/contract aspects play a minimal baseline set of constraints rather than providing the basis for either signaling or authority to direct and coordinate action.

The phenomenon most often confounded with peer production is crowdsourcing (Howe 2006),

2 A “copyleft” license is one that uses copyright to assure that derivative works made from the work so licensed are themselves available to anyone under the same terms as the original work. It conditions the permission to use the work to create a derivative work (such as by improving or adding functionality to FOSS software), without which it would be illegal for the downstream developer to write that modification or development, on a provision that makes the derivative work (the modification or improvement) available under the same terms as they themselves relied on when they used the original license.

whose clearest instance is Amazon Mechanical Turk (MTurk). MTurk is an online labor market that allows anyone to offer distributed workers monetary rewards in exchange for completing discrete, usually highly granular, tasks for low per-task payment. One common use is image tagging. Visual comprehension is extremely difficult for machines to perform well, and very intuitive for people. "Human computing" is a developing field in computer science that tries to solve machine-hard, human-easy tasks like interpreting visual images by building platforms that harness human beings to perform these tasks in ways that can then be recombined as a solution. For example, ReCAPTCHA, a project developed by Luis van Ahn, uses optically scanned book fragments as gateways to secure services. Because vision is computer-hard, human-easy, requiring human beings to identify and type in the letters in a visually-blurry string of letters is a good mechanism for telling humans from bots on the Net. These "CAPTCHAs" are therefore a good gateway device for services, such as online subscription services, or security questions, to filter out bots—automated scripts programmed to look human to the service they access. ReCAPTCHA uses this feature, and by using scanned books or newspapers as the captcha, harnesses the human beings who need to access the service to clean up digitized archives (Van Ahn 2008).

Crowdsourcing is distinct from peer production because the tasks it involves are highly regimented and pre-specified by the task designer. It comes in two flavors—monetary and non-monetary. MTurk is the most widely used monetary crowdsourcing platform (Horton 2010). Non-monetary crowdsourcing platforms, whose lead innovator has been Van Ahn, use fun, as in Games with A Purpose (GWAP), or necessity, as with ReCAPTCHA, to harness distributed human action to achieve the pre-defined goal. The critical distinction between crowdsourcing and peer production is in the location of conception of tasks and solutions. "Crowdsourcing" would most usefully be applied to instances where cost reduction, rather than distributed exploration of a resource and opportunity space, is the core function of the system. This would properly apply to situations where the task is conceived and defined by a given entity, and then put out to distributed individuals whose actions are limited to performing the pre-concieved task. In this, it harnesses undifferentiated human labor, rather than judgment, creativity, experience, tacit knowledge, or talent. From an organizational perspective, crowdsourcing represents a relatively small innovation. It harnesses thousands of independent contractors to perform tightly specified tasks; but it does not effect governance or ownership, does not restructure innovation, learning, and adaptation for the organization or the task, and does not generally harness any new motivational vectors beyond standard hedonic gains: through payments (MTurk), fun (GWAP), or as a precondition to access desired services (ReCAPTCHA). The task construction itself generally relies on the coordinated output of many contributors; unlike online labor markets or prize systems, no single contribution by itself is a potentially complete, however imperfect, solution to the task or problem addressed. Some citizen science projects, like the Mars Clickworkers that originated the practice, distributed computing, like SETI@Home or Folding@Home, or open government projects that harness citizens to monitor their governments by performing very low-level regimented data input from diverse forms to convert them into computable form, have this characteristic.

Online labor markets are yet a different model of decentralization. ODesk, for example, is a platform that allows computer programmers from around the world to bid on contracts to execute on orders proposed by customers. The innovation is in creating a much more efficient, global market for high quality services, which allows firms to harness distributed talent from around the world. Organizationally, these represent not an innovation, but a significant incremental improvement in the efficiency of markets for skilled labor. They are valuable and important, but not truly novel. Online labor markets adopt some degree of decentralized conception and execution, more the latter than the former, and in this regard are very different from crowdsourcing. They usually result in individual, rather than collaborative or even coordinated production, in the sense that the contracted-for contribution is itself a complete response to the task defined. And they rely on monetary motivations as the sole motivator and generally maintain the nexus between ownership and governance and management, using contract and property to govern inputs, outputs, processes, and role allocation associated with the task.

Prize systems. TopCoder is a platform that enables about one million registered coders to enter competitions for designing the best solutions to problems posed by clients. Innocentive, Kaggle, and other firms provide similar platforms for either general purpose or field-specific competition and prize systems to be deployed to harness creative problem solving effort toward problems posed by firms or governments. Prize systems are similar to online labor markets, but they emphasize decentralization of conception and execution even more forcefully, leaving even the design of the task to be performed to a highly distributed pool of innovative, skilled workers. Because prize systems need not pay for effort or outcome of every participant, unlike online labor markets, they can afford much wider and more diverse experimentation with alternative solution approaches than can online labor markets. This, in turn, allows them to capture extreme value solutions in areas where the problem definition and path of execution are highly uncertain. (Boudreau, Lacetera, and Lakhani 2011). Even more than online labor markets, prize systems engage parallel efforts of competitors, and the ultimate output is generally the output of a single competing person or entity, as opposed to offering even complementarity between solutions offered. I call this task construction *parallel competitive*, as distinguished from *parallel-complementary* task organization models, that allow each discrete contribution to offer a complete solution to the problem, but depend on complementarity between the alternative solutions to attain the best outcome.

	Task conception decentralized	Task execution decentralized	Social motivations significant	Governance/ Management separated from ownership	Task structure
Crowdsourcing	0	1	~	0	Coordination
Online labor markets	~	1	0	0	Individual; Parallel
Prize systems	1	1	~	0	Parallel competitive
Open collaborative innovation	~	~	0	0	Collaboration
Firm-hosted peer-production	1 / ~	1	1	0/~	Collaboration; coordination; parallel complementary
Commons-based peer-production	1	1	1	1	Collaboration; coordination; parallel complementary

Table 1: Peer Production Distinguished from Other Models of Decentralized Production and Innovation
1= characteristic present; 0= characteristic absent; ~=present in some instances or only to a degree

Open collaborative innovation is a set of productive practices that have developed among firms in various complex product and innovation-rich markets for a while, although they have gotten a boost from networked communications (Powell 1990, 1996; Chesborough 2003; Sabel, Gilson, Scott, 2008, 2010). These practices share with peer production the recognition that the smartest and best people to solve any given problem are unlikely to work in a single firm, the firm facing the challenge, and that models of innovation and problem-solving that allow diverse people, from diverse settings, to work collaboratively on the problem will lead to better outcomes than production models that enforce strict boundaries at the edge of the firm and do not allow collaboration based on fit of person to task rather than based on employment contract and ownership of the problem. There are strong overlaps between open collaborative innovation and peer production from policy perspectives, primarily in implications for intellectual property, but this category does not include the separation of ownership from governance and management, or the inclusion of participants who are not part of any of the set of mutually-cooperating firms, or those motivated by non-monetary motivations. A firm facing a complex software development problem could enter into contracts with several of its suppliers and even competitors, adopt open standards at the core of its strategy, and place some of its workers in other firms, and receive those of others in its own, as part of an open collaborative strategy. Or, that same firm could partly develop the software it requires and license it as FOSS and use Sourceforge or GitHub to manage the repository. In the former case, the firm would be engaged in open collaborative innovation. The latter would be the firm engaging peer production.

Peer production itself has, over the past decade, developed into two quite distinct flavors. Commons-based peer production (CBPP), the original model of FOSS and Wikipedia, includes all attributes I ascribed to peer production. Firm-hosted peer production, such as Yelp or TripAdvisor, deviates in a critical way from CBPP, or full peer production, in that the governance and management are based in proprietary claims to exclusion from the site to enforce terms of use with regard to user contributions. These are anchored in firm control over the infrastructure or platform used to host and coordinate the peer production effort. (Fuster Morell 2010). Yelp is a clear example of this approach. The firm depends on its users to select restaurants, businesses, etc. to be reviewed, and depends on them to provide reviews; at the same time, the contributions are governed by terms of use that retain proprietary claims over the database, and outline certain acceptable use constraints as contractual obligations of the users. Task conception (who should be reviewed) is more distributed than in crowdsourcing, and social motivations are salient, as users are not paid for their reviews. These firm-hosted peer production models need to rely on contract terms that simulate the absence of property and contract. Firms do so by retaining and providing to users non-exclusive licenses to all user content, rather than asserting full ownership over it; by making contributions flow into the system without permission, and by limiting their own assertion of contractual and property rights to rare occasions and justifying those rare occasions by reference to shared norms, not merely to firm interest or legal power.

Not all firms that engage with peer production necessarily deviate from commons-based peer production. When IBM participates in Apache (which is not an IBM-hosted or initiated project) development, or even when Google distributes Chromium (a Google project) under a FOSS license, the organization of development, despite the formal ownership of the code, is severed from the firm's ownership. Where the property and contract remain separated from ownership and operation of the site, the fact that a firm owns the site does not make a commons-based peer production enterprise into a firm-hosted peer production enterprise. For example, when peer editors of Wikitravel came to dislike the policies of the site / trademark owner, Internet Brands, they were able to leave, take all the content they had developed, which was under a creative commons license, and start afresh as WikiVoyage. Despite its corporate ownership and the presence of for-profit advertising on the site from 2006 to 2012, the property and contract structure of management and governance maintained the nature of the site as CBPP or full peer production. It is whether contract and property are separated from governance and management, not ownership of the site or the trademark associated with it, that mark a site as firm-hosted peer production or commons-based peer production. In terms of the information quality attributes, a firm-hosted peer-production process will only share the exploration and discovery characteristics of commons-based peer production if it avoids using contract or property to steer and constrain avenues of exploration and experimentation by the peers. In terms of motivational harnessing attributes, firm-based peer production will only replicate the attributes of commons-based peer production if it can authentically and credibly bind itself, or by practice instill trust in the peers whose work it facilitates, that it will not assert its contractual or proprietary authority in ways visibly at odds with management and coordination practices commonly observed in commons-based peer production enterprises, or with normative understanding among the peers about the proper role of the firm with regard to the peer community.

b. How significant is peer production in the actual economy?

Measuring the direct economic significance or impact of peer production is difficult. One approach is to observe adoption of information goods, in various verticals, that are the outputs of peer production. The most obvious cluster of utilities is the Web itself. Netcraft Web survey has been collecting data on web server software adoption since the middle of 1995. At that point, academically-developed and a range of "other" servers were competing for adoption. By March of 1996, Sun Microsystems's and the FOSS project Apache were the main competitors, as Microsoft joined the field. Within a year, Microsoft caught up with and eclipsed Sun, and since then has been the primary competitor to Apache. Nonetheless, Apache never lost its dominance as a share of adopted web server platforms connected to the Net. As of January of 2013, Apache held a 55% market share, Microsoft 17%; nginx, an alternative FOSS platform, 13%; Google's servers for its own machines, 4%; and the remainder was held by platforms bunched as "other." (Netcraft Websurvey 2013). Server side scripting languages are the primary languages used for programming functions on the Web. PHP, an open source language, is used by 78% of websites, while Microsoft's ASP.Net holds the remaining 20%; most of the remaining languages, like Ruby or Python, are also open source. (W3Techs 2013). Web Browser statistics are less clearly in favor of open source. Historically, Microsoft's Internet explorer held over 95% of the market after it squeezed Netscape Navigator out of the market (illegally, according antitrust adjudications in both the U.S. And EU). Netscape then spun out Navigator to a non-profit, the Mozilla foundation, as FOSS. Over time, Firefox gradually captured market share over the 2000s, and in 2008 Google also release Chrome, and at the same time a parallel, FOSS project, Chromium. As of January 2013, competing methods identify IE as either having 55% of the desktop browser market or 31%; and Chrome and Firefox having either 18% and 20%, respectively, or 36% and 22%, respectively. (ZDNET 2013). By a different measure, almost 40% of firms engaged in software development reported spending development time on developing and contributing to FOSS software. (Lerner and Schankerman 2010). Others have suggested that FOSS has higher quality or innovativeness by various measures. Bonnacorsi, A. and Rossi, C. (2003), von Krogh (2003), and Lorenzi and Rossi (2007) considering the adoption patterns and the literature, it appears clear that, at least in software, FOSS is an economically significant organizational and institutional strategy. And software, as an industry, accounts for somewhere between $350B and $400B per year in the United States (on one model, one could combine computer services: NAICS 5415, (245B,) software publishing NAICS 5112 (135B) / Internet publishing 31B NAICS 51913.); Forrester Research suggests 208B in software sales and 188B in IT integration and consulting services). [3]

3 http://www.forrester.com/rb/Research/us_tech_market_outlook_for_2012/q/id/61056/t/2?

Software adoption is more widely and consistently measured than other information production sectors. Wikipedia is by far the most successful, largest, and most diverse peer production project. The subject of several books and over 5,000 articles,[4] Wikipedia is among the top 6 to 8 sites in the world, and has become the basic knowledge utility of networked life, alongside Google search. Frischmann, Madison, and Strandburg (2014) collect a series of chapters describing a wider range of peer production practices. Maurer (2010) describes case studies of instances where distributed, non-state, non-market action was able to deliver discrete but meaningful public goods, ranging from nanotech safety standards to a Synthetic DNA anti-terrorism code. Online, in a range of specific product areas, business models that depend on peer production have outcompeted businesses that depend on more traditional, price-cleared or firm-centric models of production. Flickr, Photobucket, and Google Images, all of which are peer production platforms capable of delivering stock photography, have overshadowed Corbis, the primary firm using the traditional model in this field. YouTube, Google video, and Vimeo are all more highly ranked as online video sites than the proprietary models of Hulu, Vevo, or even Netflix (though Netflix, the most widely used among these, is roughly equal to Vimeo). TripAdvisor is more popular than Lonely Planet, Fodor's, or Frommers in travel guides. Yelp, in restaurant reviews. In all, organizations, both for-profit and non-profit, who have found ways of organizing their core production function on a peer production model have thrived in the networked environment, often overcoming competition from more traditional, market- and firm-based models. However, there have been no formal measurements of the relative contribution of peer production to the Internet economy, or efforts to measure performance of firms that have adopted these strategies. The closest efforts we have are de Jong and von Hippel (2009), who seek to assess the level of innovation by user firms, as opposed to producer firms, and von Hippel, de Jong, and Flowers (2010), who use survey methods to elicit innovation among individuals in the U.K. Population generally. This is related, but not direct evidence. For our purposes here, it is perhaps sufficient to accept that peer production has played a significant role over the course of the first twenty years of the commercial Internet, and continues to do so today. The dirth of work suggest that formal measurement of the productivity and contributions of peer production in well-defined studies is an important avenue for future research.

c. Core Economic Questions

Three major questions occupy the literature on the economics of peer production, mostly discussed in the domain of free and open source software. The broad overarching question is that of effectiveness and innovation: what are the conditions for the emergence of sustained peer production, and what are the relative advantages of this networked organizational model over more traditional models: firms, government, and pure market clearance. Two more discrete questions inform that broader question: motivations and governance. For motivations, much of the initial question in economics has been why individuals would volunteer their efforts toward producing a product in which they then claim no exclusion rights, and later this work also focused on why firms would invest in such efforts and adopt its outputs. The forward looking question, however, should be, can we use our knowledge of the microfoundations of diverse motivations to design organizational forms that better harness and direct these diverse motivations. In other words, can we move from mechanism design to

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4 Search in Google Scholar, articles that wikipedia appears in title.

cooperative human systems design. The second question is one of governance and management: how do networks of collaborators organize their affairs once exclusive ownership and formal contract are excluded as the foundation of organizational governance (questions of who gets to make what kinds of decision in the organization) and management (questions of who does what with which resource sets).

2. *Innovation and learning: Why would peer production emerge now, and what are its advantages as a mode of production?*

Peer production (including FOSS) is an organizational innovation. It marks a new organizational form that expands on the more traditional market/hierarchy dichotomy in the study of organizations. (Benkler 2002, 2006, Osterloh et al 2003, Elsner et. al 2009; Baldwin and von Hippel 2010). It is the clearest instance of the rise of networks as an alternative organizational model to markets and hierarchies (Powell 1990). To understand this organizational innovation, in turn, requires an explanation of the advantages that loosely-coupled networks of diversely experienced and motivated individuals have over firms or markets as innovation and knowledge production models.

The basic model is a straight transactions cost model. Production requires the coordination of people (agents), resources, and projects. In a classic perfect market, prices on each of these three components lead to matching. A firm expecting a given price for project P, will be able to determine how much it can afford to pay for agents and resources for the project, which converts resources and agents bought in that market into the output that will be sold at some price *p* in the market. The values of the competing projects, the value of the various people and resources to competing projects, will determine the market-clearing price for any given resource or person, and in turn will decide whether, when, and at what quality the project can be pursued given the market valuation of its output. Coase's new institutional theory of the firm (Coase 1937) posited that for some resources, people, and projects, the cost of managerial allocation plus potential misallocation was lower than the cost of market clearance, leading to the creation of firms, but also limiting their size when managerial costs outweigh price-system costs. Once one understands that social exchange is also a transactional framework widely used for a broad range of goods and services (Benkler 2004 provides a series of NAICS categories that denote market provision of services alongside their commonly used social exchange) (childcare, home healthcare, entertainment, carpooling, being the most intuitively visible services for which social exchange is widely used in modern economies), it is trivial to expand the same analysis to social exchange transactional networks. Where information inputs, whose marginal cost is zero, can be combined with highly distributed low-cost physical capital (computers and communications networks) and human capital that is widely underemployed (TV watching hours, at least), a substantial amount of distributed information production using these widely distributed inputs can effectively compete with market, firm, or state-based transactional models (Benkler 2002).

A simple, elegant model in this vein is Baldwin and von Hippel (2010). Baldwin and Von Hippel posit a two dimensional space made of communications costs and design costs for an innovation. Where communications costs are extremely high (e.g., unique needs of a single farmer) but design costs are very low, the communication necessary for producers to work on the problem will fail, and only single user developers will innovate. Where design costs are high, and communications costs are high, only producer innovators will develop, because the capital cost of innovating will be too high for the user innovator to undertake alone, and the high communication costs will prevent peer production from spreading the design cost among many contributors. Where design costs are extremely high and communications costs extremely low, open collaborative innovation, or peer production, will be dominant, because peer producers can spread the design costs over many developers, at a low communications cost. There are various levels of design cost / communications cost where two or three of the approaches will be sustainable.

The simple transactions cost model can be supplemented with a more specific view of information and learning that explains why distributed innovation, creativity, or problem-solving would have a transactions costs advantage over proprietary and managed systems. A less crisp but more complete explanation requires a clearer model of how organizations learn. Both managerial control and price clearance require formalization of descriptions of resources, people (that is, their diverse capabilities and availabilities for a given project at a given juncture/time), and projects into units capable of transmission through the communications system these organizational models represent. The organizational and transactions costs associated with perfectly defining price, or perfectly defining for managerial assessment and decisionmaking, over every potential resource or person that somewhat diverges from its neighbor in context and time require abstraction, generalization, and standardization of the characteristics of the resources, people, and projects. In that abstraction process, both administrative descriptions and prices are “lossy”: the formalization strips information out of the real world characteristics of the relevant resources and projects. The lost information, in turn, leads systems whose functioning depends on discarding the information to underperform relative to systems able to bring a more refined fit of potential resources and agents to better-defined projects. Complexity and uncertainty make the information problem of matching people, resources, and projects less amenable to managerial or price-based solutions. Complexity (whether described as nonlinear or linear stochastic) and uncertainty (Knightian uncertainty of with unknown probabilities of outcomes or unknown potential outcomes, as opposed to risk, with known probabilities of a known range of outcomes) put pressure on both neoclassical and new institutional models, because the actual properties of resources, people, and projects are highly diverse and interconnected; and the interactions among them are complex, in the sense that small differences in initial conditions or perturbations over time can significantly change the qualities of the interactions and outcomes at the system level. These lead to the known phenomenon of path dependence, both technological and institutional (David 1985; North 1991; Arthur 1994), suggesting that these divergences can persist in the face of systematic observed inefficiency. The fine-grained, diverse qualities of people, projects, and resources, and the relatively significant divergences that can occur because of relatively fine-grained differences in input combinations or local interactions, mean that it is impossible to abstract and generalize the process into communications units available for managerial decision or price clearance without significant loss of information, control, and, ultimately, effectiveness.

Note that “knowledge” and “learning” in the presence of complexity and uncertainty refers to more than a classic notion of innovation, such as creating a new way of doing something that was impossible to do before. Importantly, it also includes problem-solving, or iterative improvement in how something is done given persistent absence of complete knowledge about the problem and the solution that comes with complexity and uncertainty. If creating the WWW or writable web software like Wiki was “innovation” on a commons-based model, Wikipedia's organizational innovation is in problem-solving more than innovation: how to maintain quality contributions together with potentially limitless expansion, a problem that scarcity absolved Britannica from solving. User generated content similarly solves for serving more diverse tastes than a more centralized system can; user-created restaurant or hotel accommodations solve a complexity in implementation problem with highly diverse sites to review and tastes of people who may want to use the places reviewed. In each case, the peer approach allowed the organizations to explore a space of highly diverse interests and tastes that was too costly for more traditional organizations to explore.

In this model, a critical part of the advantage of peer production incorporates the importance of incontractible knowledge: either because it is tacit knowledge, or because the number and diversity of people with knowledge that needs to be brought to bear on an implementation problem is too great to contract for. Tacit knowledge is knowledge people possess, but in a form that they cannot communicate. Once you learn how to ride a bicycle, you know how to do so. Yet if you were to sit down and write a detailed memorandum, your reader would not know how to ride a bicycle. It is increasingly clear that tacit knowledge is critical in actual human systems. And peer production allows people to deploy their tacit knowledge directly, without losing much of it in the effort to translate it into the communicable form (an effort as futile as teaching how to ride a bike by writing a memo) necessary for decision making through prices or managerial hierarchies. Where knowledge is explicit, but highly distributed in forms that need to be collated to be effective, the barrier is a simple transactions costs problem. A system that allows agents to explore their environment for problems and solutions, experiment, learn, and iterate on solutions and their refinement without requiring intermediate formalizations to permit and fund the process will have an advantage over a system that does require those formalizations; and that advantage will grow as the uncertainty of what path to follow, who is best situated to follow it, and what class of solution approaches are most promising becomes less clearly defined.

Consider the original, single-person version of user innovation as originally developed by von Hippel (e.g.., von Hippel 1988). There, von Hippel showed how in diverse settings, lead users were able to identify new uses that required an innovation, the limitations of existing devices or systems to address these uses, and were able to experiment with diverse solutions until they hit on an innovation that solved a problem that producers did not even know existed. Examples of this distributed search for problems and solutions range as wide as the first heart lung machines, developed by physicians that had reached the boundary of innovation in surgical techniques that required that improvement, or self-moving irrigation systems developed by lead farmers. In both cases, the diversity of practices in medicine, and the divergence of practices and needs of local farming, create a knowledge gap between emerging needs and the companies that would ultimately stabilize the solution. That vacuum was filled by innovative users, who applied themselves to the problem, solved the basic innovation outlines, and freely shared their innovations. Only once the practice had reached a level of crystallization that could be transmitted to a firm, did firms enter and ultimately improve on the original design. But the diversity and complexity of problems, resources, and experiments at solutions was driven by decentralized actors that were not operating within either price or managerial structures for the production of the innovations they developed. Von Hippel documented this phenomenon repeatedly for users exploring problem and solution spaces, while firms generalize and standardize, you might say "productize," a solution developed by one of these many and diverse individuals.

Peer production more generally, in particular when it relies on commons—that is, on symmetrical access privileges (with or without use rules) to the resource without transaction—allows (a) diverse people, irrespective of organizational affiliation or property/contract nexus to a given resource or project; (b) dynamically to assess and reassess the available resources, projects, and potential collaborators, and (c) to self assign to projects and collaborations. By leaving all these elements of the organization of a project to self-organization dynamics, peer production overcomes the lossiness of markets and bureaucracies, whether firm or governmental. It does so, of course, at the expense of incurring new kinds of coordination and self-organization costs Where the physical capital requirements of a project are either very low, or capable of fulfillment by utilizing pre-existing distributed capital endowments, where the project is susceptible to modularization for incremental production pursued by diverse participants, and where the diversity gain from harnessing a wide range of experience, talent, insight, and creativity in innovation, quality, speed, or precision of connecting outputs to demand is high, peer production can emerge and outperform markets and hierarchies (Benkler 2002, 2004).

The effectiveness of the distributed search and experimentation model was increased dramatically when the cost of communication and “material” dropped, so that diverse individuals could share problem definitions, potential solutions, and experimental models. (Baldwin and von Hippel 2010.) The first person to identify a need or problem worth solving may not be the best to offer a tentative solution, or the best to identify the incremental improvement on that tentative solution to move the solution to a usable stage. This collaboration then substantially increased the scale and scope of problems and solutions that communities of users could approach. (Raymond 1998; Benkler 2002; Von Hippel (2005); Baldwin and Von Hippel 2010). An early version that connected the benefits of this approach specifically to the complexity of software projects was Besen (2005 (2001 working paper)).

To model the importance of learning under uncertainty to organizational models, we can map the organizational approaches described here along three dimensions. These are: (a) the degree of uncertainty in the project space, (b) the degree to which the human knowledge input important, as well as the degree to which it is formalizable, explicit, and routine as opposed to tacit, intuitive, or creative, and (c) the degree of capital concentration required to execute the project. The more uncertain, as opposed to routine, the problem and solution space is, and the more tacit, creative, intuitive, or knowledge-intensive the human dimensions, the harder it is to define the required human, material, and

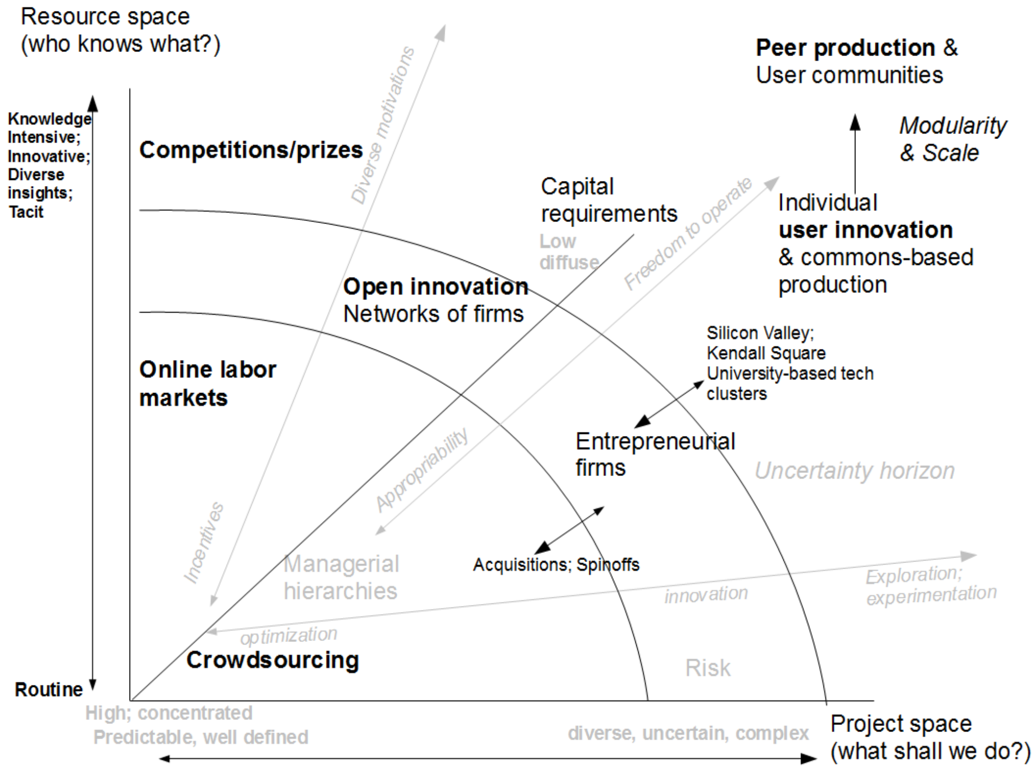

Illustration 1: Organizational models as a function of uncertainty, knowledge, and capital

knowledge resources necessary, as well as to define the best project to pursue. As uncertainty and creativity, tacit knowledge, intuition increase, the benefits of managerial control and explicit pricing decrease relative to their costs. As uncertainty increases along these two dimensions, so too do the advantages of peer production specifically, and more generally of open innovation strategies, over proprietary, closed models that limit the range of actors and resources in order to improve appropriability. The third dimension, the degree to which the capital costs of execution are high and concentrated (the steam engine, the assembly plant), as opposed to low (writing a song) or susceptible to fulfillment by aggregating diffuse capital (personal computers already distributed in the population), creates an efficient limit on the more open, diverse strategies. Aggregating, managing, and renewing an expensive and concentrated capital base will tend to favor managerial hierarchies, either state or market-based necessary, and will place a limit on the degree to which a project can embrace freedom to operate by diverse actors over appropriability of the project outputs. To the extent that capital formation does not present a barrier, we see strategies migrate toward the more exploratory and less price-mediate. In the part of the map where projects and resources and human knowledge necessary are relatively routine and well understood, and capital concentrated, hierarchical managerial firms are at their best. This is also the space where crowdsourcing can lower the cost associated with production (although it depends on distributed capital necessary for participation—that is, computers in the hands of the crowd harnessed), but only where problem spaces and human inputs can be defined in advance with some precision. Online labor markets still require sufficient certainty on the problem definition to assure payment for labor, but greater uncertainty of who can do the job and a higher degree of diversity in capabilities; it also permits for applying labor to less modular problems.

As we move out from the origin, the organizational models trade off clear, well-understood monetary incentives for a need to harness more diverse motivations. In particular, because the required skills and combinations are increasingly uncertain, the required effort becomes increasingly incontractible: you do not know who to contract with; what to contract them to do; or how to measure what they have done. Here, intrinsic and non-monetary motivations that do not require crisp contracting and monitoring become critical. Moreover, as the project and human space becomes more uncertain, appropriability becomes less certain, and its expected value is overshadowed by the expected learning and exploration benefits of freedom to operate in the resource and problem space; similarly, well-managed optimization of such an uncertain project and human scape becomes futile and wide open exploration and experimentation become more important. As we move out to a band with less certain but still well-understood risk-reward tradeoffs, we see two types of solutions. Where the question of "what is worth doing" is very risky, we see entrepreneurial firms using the market to raise risk capital and deploy, failing or succeeding with little global systemic cost. Where the project space is better understood, but the talent pool is uncertain, we see networks of firms embracing open innovation and collaboration as a mechanism to reach across firm boundaries to apply diverse talent to a range of problems, but retaining managability and appropriability by keeping the set of actors well-defined, in well-managed, usually long-term contractual relationships, applied to what are more clearly defined problems than those where we see peer production at its more effective. The particular advantage of user innovation, competitions/prizes, and peer production lies outside these relatively well-understood boundaries of routine or even well-understood risky development. Similarly, the classic literature on the tradeoff between basic academic science and applied commercial science (Nelson 1959), and the role of universities alongside pharamaceuticals and entrepreneurial firms in biotechnology (Powell 1996) is easy to locate on the map to orient it toward already well-known phenomena.

The broad openness of the model to contributions from anyone, with freedom to operate without having to translate one's ideas or initiatives into someone else's decision over purse strings or authority structures, enables rapid and diverse exploration and experimentation in a highly uncertain scape: where neither the relevant insights and knowledge that human beings possess is well understood, nor the range of plausible projects well defined. Because competitions and prizes still require a "client", a payor who defines the goal, and because the competitors in a prize system usually seek the prize, and hence seek to maintain some level of control or appropriability, these systems will tend to be be single person or managed group entrants, and are therefore closer to the origin than peer production. Fully distributed search and experimentation that characterizes user innovation and peer production varies based on the scale of the problem and the modularity of the project. As the scale, complexity, or novelty of the problem grows, identifying solutions individually becomes less likely. As long as the solution or project aimed at solution retains its decomposability into modules, these larger scale projects will draw user communities and peer production rather than depending solely on individual distributed innovation or commons-based production. The ability to harness a more diverse set of eyes to look at the problem gives these collaborative projects their advantage over distributed, purely parallel search.

Before turning to the question of motivation, it is worthwhile noting the development of evolutionary models to explain the organizational distinctness of FOSS specifically, and peer production more generally *(e.g.,* Elsner et al 2009). Landini (2012) offers an evolutionary game theoretic model that complements the new institutionalist model of Benkler and Baldwin and von Hippel. In addition to the technological effects driving decentralization of capital, reduction of communications cost, and modularization making peer production more efficient and feasible, Landini develops a model of two alternative stable equlibria based on bi-directional causality—where the shape of rights can cause the type of technological development path chosen as well as vice versa. Thus, closed-proprietary and non-modular, relatively high-labor-cost production is stable given proprietary control, because of its superior rent-extraction properties (whether efficient in context of not), and open, modular, low-incremental-labor cost contributions are similarly stable because of their cost, learning, and efficiency advantages. Landini's model explains well the observed relative stability of software projects—those that start open, remain open, and those that start closed, remain closed—rather than convergence on one model or another. It integrates the cost of peer production, in terms of its rent-extraction properties, to those who choose it as a development path, into a stable equilibrium model that makes no claim to superior welfare or innovation properties.

In conclusion to this part, the primary organizational innovation of peer production is that it represents the confluence of technological, organizational and institutional innovations that permit diverse individuals who would not have been able to communicate and coordinate in advance to explore collaboratively an opportunity space made of resources, problems, people, and potential solutions, self-assign and harness their tacit, creative, or otherwise hard-to-communicate knowledge or facility to identify or contribute to defining a problem or solution, and they can do so relying on diverse, often non-monetary motivations that do not incur the limitations imposed by the need to formalize and standardize their insights, efforts, or experimental successes for transmission into formalized channels of markets or hierarchies.

3. The problem of diverse motivations and the success of peer production

Given complexity, uncertainty, and the pervasiveness of tacit knowledge, a core advantage of peer production is its capacity to enable action without requiring translation into a system of formalized carrots and sticks. A system better able to engage self-motivated action will be better able to attract this kind of decentralized, non-price, non-command mediated discovery of projects, resources, and solutions. (Osterloh et al 2002). This perspective would suggest that the critical questions of motivations is how to design for diverse interdependent motivations; that is, monetary and non-monetary, intrinsic and extrinsic motivations that are subject to crowding out. While there has been some work on this problem, to which I will return later in this section, the core initial question that most work in economics focused on was whether it was feasible to collapse the diverse motivations apparently exhibited in peer production back to relatively well-defined models of self-interest.

Early work by Ghosh (1998) and an early canonical statement by Lerner and Tirole, based on case studies of FOSS projects, asserted that FOSS developers are motivated by several motivations that can mostly be assimilated into standard models of economic motivation. These included: (1) the use value of the software to the contributing developer, (2) hedonic pleasure from the coding involved, (3) enhanced employment prospects from reputation gains or human capital accumulated, and (4) social status gains within the community of peers (Ghosh 1998, Lerner & Tirole 2000; Lakhani & Von Hippel 2002; Von Krogh 2003). Early non-economists added more diverse motivational considerations. Kollock emphasized reciprocity, reputation, a sense of efficacy, and collective identity (Kollock 1999), and Benkler emphasized that the combination of material and social-psychological, extrinsic and intrinsic gains makes interdependence of motivations, or crowding out, an important constraint on the organization of peer production. (Benkler 2002, 2004).

Much of the work on individual motivation then moved to focus on surveys. The most influential survey work included the European FLOSS study headed by Rishab Ghosh (Ghosh et. al 2002), the Boston Consulting Group Hacker Survey (Lakhani et. al (2002); Lakhani & Wolf (2005)), and the U.S. FLOSS study by Paul David and Joseph Shapiro (David & Shapiro 2008). Lakhani et al emphasized the self-reported motivations of intellectual stimulation, or hedonic gain, and skills building (Lakhani et. al 2002), while Ghosh et al found reciprocity as the core motivation, alongside skills development (Ghosh et. al 2002). Despite their differences in emphasis, all these early surveys supported the claim that motivations were diverse and heterogenous, and that they included all the hypothesized motivations, as well as a significant number of contributors who earned a living directly or indirectly from writing free and open source software. The breakdown of self-reported motivations was roughly similar even where the responses were segmented between students and hobbyists as compared to salaried contributors (Hars & Ou 2002). Belenzon and Schankerman (2008), using contributions to differently-licensed projects, supported the finding that contributors are heterogeneous in their motivational profiles, but argued that contributors self-sorted among projects, such that those who were more responsive to extrinsic motivations, primarily reputation and employment opportunities, tended to contribute more to larger and more corporate-sponsored projects. An excellent recent formal literature review on the literature on motivations in FOSS covers these and other sources. Von Krogh et al (2012). Note, that there is a separate and significant literature on why *organizations*, firms and governments in particular, choose to adopt open source software. Schweik & English 2012; Lerner and Schankerman 2010). Schweik and English in particular offer a richly detailed analysis, using the Institutional Analysis and Development framework developed by Elinor Ostrom to explain the advantages of adopting peer produced outputs to governments, companies, and individuals. These focus on the rate of innovation and the capacity to collaborate with other firms, as well as the avoidance of dependence on sole-source providers. Another major organizational advantage is that participating in a peer production enterprise can permit the firm to develop inhouse expertise in a tacit-knowledge rich innovation system; it increases the absorptive capacity of the firm. Lakhani and King 2011).

The diversity of motivational drivers (experience by each individual) and motivational profiles (the mix of motivational drivers that characterize a given individual; or one's baseline taste for prosociality, which is heterogeneous among individual contributors) find support in more recent work on Wikipedia as well, work that combines full observational data on behavior in Wikipedia with experimental observations of Wikipedians in lab experiments. Hill et al. (2013), observing all Wikipedia barnstars (a social recognition system whereby every Wikipedian can give every other Wikipedian a symbolic reward for making valuable contributions) find that about half of all barnstar recipients are social signalers—individuals who exhibit their rewards publicly—and half are not. They found that the “signalers” edited significantly more than the “non-signalers” after receiving an award. Combining observational data on the full contribution history of 850 Wikipedians with the performance of these individuals in a battery of lab experimental games with social signaling measures partly based on the barnstar observational data from Hill et al (2013), Algan et al. (2013) show that while a taste for reciprocity as measured by contributions to public goods games and trustworthy behavior in the trust game predicts increased contributions in the real world of Wikipedia, a taste for reciprocity as measured in anonymous experimental settings does not explain contributions of the group of highest contributors. A taste for social signaling does predict levels of contributions, but these high-contributing social signalers do not exhibit particularly prosocial behavior in the abstracted setting of the lab. These lab experiments do, however, exclude pure altruism as a significant motive.

The growing evidence that individuals themselves are driven by diverse motivations, and that individuals are different from each other in the mix of motivational drivers that characterize them makes the problem of designing a well-functioning peer production system more complex. Trying to develop the equivalent of mechanism design for a population of individuals who have diverse motivations within each agent, and are diverse between agents is complex. This difficulty is compounded substantially by the fact that the effects of any given design intervention focused on a given motivational driver (most commonly, material rewards and punishments) are non-separable from their effects on the prosocial motivational drivers. Experimental and observational data has exhaustively documented that the effects of explicit material rewards and punishments, the standard economic incentives tools, are not separable from the effects of these interventions on social-motivational vectors (major reviews are Bowles and Polania-Reyes 2013; Bowles and Hwang 2008; Frey and Jegen 2001; Frey 1997). Adding a monetary reward to an activity may undermine the sum of motivations across the target population, if it reduces the magnitude of prosocial motivations to perform the act more than it increases the magnitude of self-interested monetary incentives to perform it in a sufficient proportion of the population in which the activity is sought to be increased. Positive (negative) monetary rewards (punishments) can (a) drive the total sum of motivations for any given individual in the opposite direction, and (b) lead to substitution in the population of agents from individuals driven by prosocial motivations to individuals driven by monetary motivations. Managing the tension, first between explicit, direct material rewards and prosocial motivations, and second, among diverse prosocial rewards, is a critical design challenge of peer production systems. FOSS in particular has shown that, with the appropriate normative framing, it is possible to combine both paid and unpaid contributions without causing crowding out Alexy & Leitner (2010). Nonetheless, managing this tension is hardly a trivial achievement, and there are no good studies of successful integration of material rewards and prosocial rewards in other areas of peer production. Most prominently, Wikipedia does not combine material and social rewards, and sites, like Weblogs Inc., that have tried to improve on peer production systems precisely by offering material rewards to top contributors have failed. Beyond mechanism design, the diversity of motivational profiles and the potential for complex interactions between the design of the system and the social behavior it elicits has been translated into calls for evidence-based social design in computer science (Kraut and Resnick 2011) or more generally to cooperative human system design (Benkler 2010, 2011).

In addition to effecting levels of cooperation statically, it is possible, though not yet empirically investigated, that pro-social, cooperative preferences are endogenous to cooperative practices. That is, that participating in cooperative practices can have long-term feedback effects on levels of cooperation by participants in similar practices. If true, whether one succeeds in achieving cooperative dynamics in the short term can influence whether the task becomes harder or easier over time, as participants internalize virtues and values associated with the cooperative or non-cooperative model. With habituation and practice, internalized habitual compliance with norms and practices (encapsulated in the term “virtues”) may lead people to adopt a more, or less, cooperative stance in context based on their interpretation of the appropriate social practice, its rightness, and its coherence with their own self-understanding of how to live their lives well. That is, through practice coupled with a set of normative commitments, people's preferences over discrete elements of a cooperative utility function—their taste for fairness, reciprocity, or altruism/generosity—will be endogenous to the degree of cooperativeness of the practice they undertake. This would be an economists' characterization of what in virtue ethics would be understood as the development of virtues through self-conscious practice. See Benkler & Nissenbaum (2006); Von Krogh et. al (2012). Practice, in other words, can shift the proclivity to cooperate, at least in what is seen as a situationally appropriate context, of participating individuals, and make the work or the organizational framework easier.

In Part 4 below I discuss the observed patterns of governance in peer production enterprises. Here, it is important to note that the governance mechanisms and technical platforms of peer production can play a motivational role in eliciting sustained levels of prosocial contributions, in addition to providing integration and coordination. These include:

1. *Communication*. Unlike the standard game-theoretical assumption of no communications best response systems; a critical design focus of cooperative human systems is to assure extensive communications. Communications systematically improve cooperation in experimental set-ups (Sally 1995); human, unstructured exchanges, rather than canned messages, are important (Putterman 2009); and face to face, or more humanized exchanges, are important too. Low cost communication has been a pervasive feature of economic models of peer production (Baldwin and von Hippel 2010) , and the persistent role of open and continuous communications has been core feature of anthropological and sociological descriptions of peer production (Coleman 2006; Kelty 2008; Reagle 2010).

2. *Fun*. A repeated finding in surveys of FOSS developers is that fun, and a sense of self-efficacy, or the ability to do something well under one's own direction, are important motivators. Lakhani & von Hippel (2003); Lakhani and Wolf (2005); van Ahn (2008). While fun is not a prosocial motivation, it is a fuzzy, intrinsic motivation that will drive behavior without requiring that it be formalized into price or command allocation mechanisms.

3. *Normative framing and norm setting*. How a situation is framed normatively effects the set of motivations most salient to an interaction. Framing cannot, in the long term, be an exercise in manipulation, because participants learn when the framing is inauthentic. Rather, the normative framing of an interaction must be authentic and sustained in order to permit the relevant motivations to develop and become fixed in the interaction. Both Kelty and Coleman make normative negotiation and self-creation central to their accounts of FOSS (Colman 2006; Kelty 2008), and Reagle (2010) locates normative negotiation at the heart of Wikipedia governance. Moreover, in the case of FOSS, normative framing has been described as permitting mixture of monetary and non-monetary rewards, as long as monetary rewards are separated from governance of the project. Alexy & Leitner (2010). A less explicit model involves behavioral patterning of horms. In particular, social network analysis has shown that people pattern even basic behaviors, like overeating, on observed near nodes. (Christakis and Fowler 2007). Setting standards for “normal” behavior can lead to prosocial behavior when that behavior is perceived as normal.

4. *Reciprocity, reputation, transparency*. Reciprocity has long been understood as a central mechanism for sustained cooperation. Bowles and Gintis (2002, 2011). Over time, evolutionary biology in particular has shown that looser and looser definitions of indirect and network reciprocity

can sustain cooperation in a population of strangers, Nowak 2006. The surveys of FOSS programmers have long placed reciprocity at the heart of FOSS practices (Ghosh 2002.) Algan et al 2013 show that a behaviorally-measured proclivity for reciprocity indeed predicts a substantial amount of contributing behavior among Wikipedians. As the set of people who engage in reciprocity increases, reputation mechanisms that enable some persistence of identity across contexts, and a level of transparency regarding past behavior of participants can all improve levels of contribution.

5. *Fairness*. Extensive experimental and observational work has documented the importance of perceived fairness of outcomes, intentions, and processes to maintaining levels of prosociality. (Fehr and Schmidt 2001). Repeated studies of FOSS and Wikipedia emphasize the suspicion of power (There is No Cabal TINC), and continuous negotiation of assuring that the processes, outcomes and intentions of participants and leaders in particular are accepted by participants as fair. (Colman 2006; Kelty 2008; Reagle 2010).

6. *Empathy and solidarity.* Cooperative systems perform better when they emphasize other-regarding motivational vectors. In particular, systems that allow an agent to see and interact with, or take the perspective of other individuals improve cooperation. They effectively include an argument in each agent's utility function that takes the payoffs of the other into account (albeit, mostly discounted). Moreover, ingroup bias, or solidarity, is a distinct motivational driver that triggers higher degrees of contributions to public goods and cooperative games where present. Measures to develop collective identity, sometimes as simple as naming a team or wearing a uniform, can significantly affect contribution levels (Haslam 2001). The clearest instance of ingroup-outgroup solidarity used in FOSS relates to the long-standing conflict particularly among those FOSS developers who associate more with the more political interpretation of FOSS development, that is the “Free Software” movement as distinct from “Open Source” development.

To conclude, peer production and FOSS development successfully elicit contributions based on diverse prosocial motivations. Because elicitation of prosocial motivations is a central part of their organizational advantage over firms, governments, and markets, a central challenge of peer production enterprises is the design of systems that elicit prosocial motivations in the presence of within-agent diversity of motivations, across-agent diverse motivational profiles, and the non-separability of motivational vectors. There exists early work, both theoretical and empirical, separating out and documenting the different motivational vectors, the different profiles, and the effects of discrete interventions on these different motivations. But this work is in early stages of development and offers a rich area of future research into cooperative human systems design.

4. Governance in Peer Production Communities: diverse redundant mechanisms

Governance of peer production must (a) provide freedom to operate for an open class of agents, who may have something to contribute to the common project; (b) elicit prosocial motivations; and (c) permit coordination and steerage of the collective output without undermining prosocial motivations. The first requirement flows from the advantages of peer production as an innovation and learning process, discussed in Section 2. If the advantage is the capacity to permit diverse individuals, with diverse perspectives, insights, capabilities, and opportunities to define, experiment with, and act on a collective project without seeking permission or preclearance, then the governance structure must assure freedom to operate, and must avoid techniques that constrain in the absence of clearance by a manager or property owner. The second requirement flows from the fact that the informational and diversity advantages of self-motivation and self-monitoring require a system that can elicit intrinsic motivations in order to harness that effort without necessitating monitoring and explicit reward/punishment structures. The third requirement comes from the potential tension between the definition of governance as that set of organizational and institutional mechanisms that allow groups to coordinate their actions, combined with the recognition that the two most-widely used models, hierarchical authority and price signals, can have a negative impact on prosocial motivations and therefore undermine the second desideratum of peer production governance design.

a. Freedom To Operate: Commons-Based Production

The core benefit of peer production systems is their capacity to elicit self-directed action from diverse sources of human talent, experience, tacit knowledge, opportunity and availability, productive interactions, etc., and to bring these to bear on a wide and diversely-defined set of projects using a diverse set of materials and knowledge resources. In order for that core advantage to be operative, actors within the action arena must have freedom to operate with resources in that arena on projects. It is precisely the lack of need of actors to seek permission or await direction before acting that allows peer production to avoid the information and diversity losses associated with price-cleared and hierarchical systems.

The major institutional form available to create this kind of freedom to operate in contemporary market economies are commons. These commons are not the more widely-known common property regimes that were the subject of study in the Ostrom school of commons studies. Commons property regimes are available only to constrained and pre-defined groups of users, under well-understood use and access limitations. Rather, these are open commons: roads, highways, and major shipping channels, common carrier telecommunications networks and WiFi radio systems, and most importantly the public domain in information, knowledge, and culture (See Benkler 2013). The core institutional feature of such commons is the fact that anyone can use the resource on symmetrical terms, without requiring permission from any single property owner or administrator. This is precisely the institutional framework that allows access to and use of resources in the distributed, self-directed form typical of peer production.

Most resources that are the subject of peer production and FOSS are created under a default regime of property: they are granted copyright automatically, as soon as they are fixed. The commons institutional framework therefore needs to be constructed from within the background property system. This "reconstructed commons" (Reichmann and Uhlir 2003; Madison, Strandberg and Frischman 2010) are techniques, some based in contract theories, others in property, that allow the default owners to license the materials on terms that functionally replicate the freedom to operate characteristic of commons. This was the great institutional innovation that Richard Stallman, the father of free software, created. The two major families of such licenses are the software related licenses that flow out of the FOSS communities, and the Creative Commons licenses, developed by a nonprofit to permit the commons-licensing of non-software copyrightable materials.

The primary division within the various commons licensing frameworks is between those that permit use of the resources in the commons for any purpose, including reappropriation, and those that seek to limit uses of the resources, primarily either to limit the uses to noncommercial uses (observed mostly in Creative Commons licensing, and rarely in FOSS licensing) or to require those who make derivative works from the commons-licensed materials to license their own derivations on the same open terms as they themselves received access to the materials, what is often called "copyleft." There has been some attention within economics to this choice (Lerner and Tirole 2004), suggesting a tradeoff between the breadth of for profit firms and profit-seeking individuals who can be brought in to work on a project (larger with the less-restricted license) and the motivation-preserving effects of an assurance that one's work will not be reappropriated by another to produce materials that a present contributor will not be able to build on in the future. Many of the major projects are subject to copyleft, such as Wikipedia or Linux. Other major projects such as Apache or the academic literature project PloS, are not. Whether one or the other systematically translates into more creative, productive, or stable peer production efforts requires further empirical investigation, but no clear answer to that question presently exists.

b. Governance without property or contract: diversity of constraint and affordance

Peer production and FOSS enterprises are left with the question of how to govern their practices while abjuring exclusive control through property and contract in the absence of other sources of legally-binding formal authority. Studies of FOSS projects (Coleman 2006; O'Mahoney and Ferraro 2007; Kelty 2008) and Wikipedia (Reagle 2010; for a review see Fuster Morell 2011) identify a series of shared characteristics of the internal, norms-based governance structures that peer production enterprises have in fact developed to deal with these competing goals under the institutional and motivational constraints characteristic of peer production. Contrary to early work in economics that suggested the potential of a reassertion of hierarchy (Weber 2004), or focused on the increasing prevalence of firm-adopted FOSS, what the work in sociology, anthropology, and management studies suggest is that the complexity of governance without property and contract is solved not by reemergence of hierarchy, but by the utilization of flexible, overlapping, indeterminate systems of negotiating difference and permitting parallel inconsistencies to co-exist until a settlement behavior or outcome emerges. This system is less determinate; its lines of authority or determination are less clear, its components share a role as nonexclusive mechanisms for dispute resolution and the targeting of action, and it preserves freedom of action to the participants for much longer than would likely be thought efficient under either of the more traditional systems. It permits for prolonged experimentation and debate, rather than reaching closure earlier. Its elements are:

1. *Meritocracy.* Individuals gain partial local authority over particular subareas of the shared enterprise based on their contributions to it, the perceived quality of those contributions. This is viewed most crisply in the high visibility role of charismatic founders of projects, but then is replicated in nested forms throughout the collaborative networks as individuals who make significant contributions to particular projects within clusters of contributors receive greater meritocratic deference.

2. *Leadership as coordination, not control*. Those who emerge in the meritocratic process as leaders, in turn, serve a role as coordinators of that bit of the network, rather than as hierarchically-superior sources of task allocation. Dahlander & O'Mahony (2008), for example, using GNOME data (a graphical user interface to Linux), show that progression in networked collaboration involves not a move "up" a hierarchy that involves greater authority over other individuals (who continue to self-assign to tasks) but a move "to the center" of a network of contributions, where those who move to the center begin their rise in lateral authority through contributions and quality, but then (a) increase their efforts after their increase in authority, and (b) shift their role toward spending more time on coordination of contributions and efforts.

3. *Organizational Formalization*. Several of the larger projects, such as Apache or Wikipedia, have developed more traditional organizational models to manage some of the governance functions. These foundations, however, do not exercise formal rights to manage the workflow, and have limited roles in the management of the work itself, and conflicts among the peer contributors, as opposed to managing the infrastructure of the projects. (Fuster Morell 2010).

4. *Norms*. Wikipedia is the clearest and earliest example of the extensive use of written norms as a governance mechanism, with internal community enforcement; but the definition of norms and the use of transparent records of prior disagreement have been a central part of peer production communities in FOSS as elsewhere. (Coleman 2006; Kelty 2008).

5. *Transparency.* Decisions, disagreements, etc. are almost entirely transacted in media that keep public open records of the interactions. This radical transparency underwrites the procedures that depend on continued debate, communication, and voting, and allows for the creation of a degree of trust that the shared enterprise is not being hijacked by any subset of participants.

6. *Rough consensus and nondeterminative voting*. The Internet Engineering Task Force famously relied on "rough consensus and running code." (Clark 1991). The "running code" part of the definition goes to a shared sense of common purpose that has measurably or defined "better"/"worse" outcomes, and that appeal to that outcome is critical. This shared understanding of the possibility of better/worse is foundational to the meritocratic aspect of governance. The "rough consensus" aspect is an important voting rule that mediates two competing risks: first, is the risk that full consensus will create veto points, the second is the risk that strict majoritarian voting will lead to (a) disaffection by repeated minorities and (b) weakened discourse or communication over what the "right answer" is, that is, whether the "code" is running, which is harder to achieve in nonfunctional settings, such as Wikipedia. As a result, projects range from very structured majoritarian voting (see Debian model in O'Mahoney and Ferraro 2007) to the very fuzzy nonbinding straw polls used in Wikipedia (Reagle 2010); but in all events the results of voting are not really the binding decision. Instead, as described below, there are redundant governance paths and even after a vote substantial play remains for resistance, avoidance, and continued negotiation of the proper projects, resources, and outcomes.

7. *Humor, mockery, irreverence*. Coleman first focused on TINC (There is no cabal) as a core feature of these systems of governance. (Coleman 2006). This feature is important in preserving the looseness of coupling between decisions and action. It serves as a social mechanism to constrain the capacity of majorities, or charismatic leaders, or formal organizational organs like the foundations created to manage the platform from overreaching.

8. *Charismatic leadership*. Some of the projects remain importantly influenced by their founders: Linus Torvalds in Linux; Jimmy Wales in Wikipedia. Some projects use these "benevolent dictators for life" as last resort Gordian Knot breakers; but they can only perform that function relatively rarely, and with appropriate humility and publicly performed reluctance. Founder-leaders range in power from those who carry a title but whose role is rare and minimal (Drupal) to quite substantial (Linux kernel), with intermediate models of the quite legalistic Debian that has formal constraints on leadership.

9. *Redundancy of governance pathways*. Perhaps the most remarkable aspect of governance in peer production enterprises is that it is rarely definitive. In FOSS, for example, the fact that most projects over the past five years have come to be version-controlled by Git means that even where there

is a centralized foundation or leader who maintains the official version, every version is hosted independently by every developer, and forking is technically easier than it was until the mid-2000s, when most projects used centralized depositories. In Wikipedia, a central overarching rule is "Ignore All Rules." It is foundational to the process that every individual see themselves as having the freedom to act against the rules, or against the decisions of others; Wikipedia Administrators can apply their administration powers in ways that contradict those of others who have acted on the same matter.

These characteristics of the governance of peer production systems contribute both to the freedom to operate and to the maintenance of intrinsic motivations. They make determinative exclusions of paths of exploration and experimentation rare and difficult to achieve. They provide substantial room for peers to maintain a sense of self-efficacy even when their actions are rejected, or when the process points to a direction of action that one or some peers have not chosen. They allow for mixed motivations to co-exist, and they provide the mechanism for normative framing, establishment of the bounds of fairness, transparency and reciprocity, and social signaling of actions and contributions. Together, these jointly solve the problem of coordination and motivation that is commonly seen as the task of governance systems.

The flexibility of governance mechanisms replicates within the range of peer production practices the tradeoffs discussed in Part 2 between hierarchical systems and decentralized networked systems. That is, the extent to which the governance mechanisms are flexible, redundant, and nondeterminative trades off freedom to operate for manageability, intrinsic self-direction for extrinsic control over actions within the project, and unstructured exploration for a more directed search of predictable enhancements or developments. In Linux distributions, for example, we see for-profit firm-based distributions, like Red Hat or Novell, and non-profit foundation distributions, like Ubuntu, developing to serve the needs of companies or unsophisticated users, respectively, by replacing some flexibility with a more managed, directed approach focusing on assuring the availability of particular features and a predictable release cycle, or the integration with proprietary platforms. By contrast, the standard-setting cutting edge distribution, Debian, retains its highly flexible governance mechanism. There is relatively little new empirical work that critically assesses the internal governance structures of peer production enterprises, and as that work develops we will be able to refine our understanding of the extent to which the fully flexible, decentralized governance model prevails, and the extent to which hybrids that trade off flexibility and the networked form for various flavors of hierarchy and structure that improve survival and effectiveness (Benkler, Hill, and Shaw 2013).

Despite the potential limitations of fully flexible governance mechanisms, the extent to which nondeterminative governance systems are in fact observed in successful peer production enterprises in the wild provides support for the theoretical claim that the particular advantage of these systems is the freedom to operate they offer. The governance system's diversity and redundancy is clearly exhibiting the success of costly systems for the maintenance of diversity and divergent behavior well beyond what one might expect in a relatively predictable and well-behaved environment, where the efficiency costs would not be outweighed by the exploration and experimentation benefits.

5. Conclusion

Peer production and FOSS represent a new mode of production. Its defining characteristics include (a) *decentralization of conception and execution* of problems and solutions, (b) *diverse motivations*, and (c) *separation of governance from property and contract*. These characteristics make peer production practices adept at learning and experimentation, innovation, and adaptation in rapidly changing, persistently uncertain and complex environments.

The core advantage of peer production is its capacity to harness diversely motivated and capable individuals in the context of persistent uncertainty and complexity. The freedom to operate that marks peer production, and the full organizational permeability of the practices, allow anyone with a potential to contribute to self-assign, experiment with resources, projects, and collaborations, and test the improvement produced in these experiments. This freedom to operate is purchased at the cost of rent extraction or appropriability. It is most effective when the cost of experimentation are relatively low, or susceptible to collaborative investment of small or pre-existing increments of capital, physical and human; when communication costs are low; and when the work can be performed with high modularity. These characteristics, all present in Internet-mediated production, explain the relatively high salience of these practices in the networked environment. Coupled with the high uncertainty and complexity introduced by a global, rapidly innovating effective market, the advantages of peer production are at their clearest.

Peer production successfully harnesses diverse, and primarily intrinsic and self-policed motivations. This is important because it avoids the necessarily lossy (and costly in terms of transactions cots) process of formalization of information about individual capabilities and opportunities into prices or information packets susceptible to managerial decision making. Particularly where tacit knowledge or high diversity of experience and perspective are important, the lossiness of markets and hierarchies is pronounced, and the advantages of intrinsically motivated action clearest.

In order to preserve the relatively loose organization and freedom to operate, while permitting coordination and collaboration without triggering the dysfunctions of motivation crowding out or interdependence of motivations, peer production processes avoid the authority of property and contract. They implement instead overlapping, incomplete systems of governance, adapted dynamically to the particular instances of potential conflict or practical decision making faced by the enterprise. These mechanisms are diverse, and their successful implementation depends on communication and recursive adaptation of practice to context.

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