Peer Production: A Form of Collective Intelligence[*]

Yochai Benkler (ybenkler@law.harvard.edu)
HARVARD UNIVERSITY

Aaron Shaw (aaronshaw@northwestern.edu)
NORTHWESTERN UNIVERSITY

Benjamin Mako Hill (makohill@uw.edu)
UNIVERSITY OF WASHINGTON

INTRODUCTION

Wikipedia has mobilized a collective of millions to produce an enormous, high quality, encyclopedia without traditional forms of hierarchical organization or financial incentives. More than any other twenty-first century collaborative endeavor, Wikipedia has attracted the attention of scholars in the social sciences and law both as an example of what collective intelligence makes possible and as an empirical puzzle. Conventional thinking suggests that effective and successful organizations succeed through hierarchical control and management, but Wikipedia seems to organize collectively without either. Legal and economic common sense dictates that compensation and contracts are necessary for individuals to share the valuable products of their work, yet Wikipedia elicits millions of contributions without payment or ownership. Intuition suggests that hobbyists, volunteers, and rag-tag groups will not be able to create information goods of sufficient quality to undermine professional production, but contributors to Wikipedia have done exactly this. Wikipedia should not work, but it does.

The gaps between conventional wisdom about the organization of knowledge production and the empirical reality of collective intelligence produced in "peer production" projects like Wikipedia have motivated research on fundamental social scientific questions of organization and motivation of collective action, cooperation, and distributed knowledge production. Historically, researchers

[*]Parts of this chapter build upon work published in: Y. Benkler, Peer. "Production and Cooperation" forthcoming in J. M. Bauer & M. Latzer (eds.), *Handbook on the Economics of the Internet*, Cheltenham and Northampton, Edward Elgar.

in diverse fields such as communication, sociology, law, and economics have argued that effective human systems organize people through a combination of hierarchical structures (e.g., bureaucracies), completely distributed coordination mechanisms (e.g., markets), and social institutions of various kinds (e.g., cultural norms). However, the rise of networked systems and online platforms for collective intelligence has upended many of the assumptions and findings from this earlier research. In the process, online collective intelligence systems have generated data sources for the study of social organization and behavior at unprecedented scale and granularity. As a result, social scientific research on collective intelligence continues to grow rapidly.

Wikipedia demonstrates how participants in many collective intelligence systems contribute valuable resources without the hierarchical bureaucracies or strong leadership structures common to state agencies or firms and in the absence of clear financial incentives or rewards. Consistent with this example, foundational social scientific research relevant to understanding collective intelligence has focused on three central concerns: (1) explaining the organization and governance of decentralized projects, (2) understanding the motivation of contributors in the absence of financial incentives or coercive obligations, and (3) evaluating the quality of the products generated through collective intelligence systems.

Much collective intelligence research in the social sciences has focused on peer production projects. Following Benkler (2013), we define peer production as a form of open creation and sharing performed by groups online that: set and execute goals in a decentralized manner; harness a diverse range of participant motivations, particularly non-monetary motivations; and separate governance and management relations from exclusive forms of property and relational contracts (i.e., projects are governed as open commons or common property regimes and organizational governance utilizes combinations of participatory, meritocratic and charismatic, rather than proprietary or contractual, models). Peer production is the most significant organizational innovation that has emerged from Internet-mediated social practice, among the most visible and important examples of collective intelligence, and a central theoretical frame used by social scientists and legal scholars of collective intelligence.

Peer production includes many of the largest and most important collaborative communities on the Internet. The best known instances of the phenomena include collaborative free/libre and open source software (FLOSS), like the GNU/Linux operating system, and free culture projects, like Wikipedia. GNU/Linux is widely used in servers, mobile phones, and embedded systems like televisions. Other FLOSS systems, such as the Apache web server, are core Internet utilities. Through participation in FLOSS development, many of the largest global technology companies have adopted peer production as a core business strategy. Explicitly inspired by FLOSS, Wikipedia has been the subject of several books and over 6,200 academic articles.[1] Wikipedia is among the top

[1] http://scholar.google.com/scholar?q=intitle%3Awikipedia (Accessed July 10, 2013)

six websites in the world with more than half a billion unique viewers each month.[2] The success of FLOSS and Wikipedia has coincided with a variety of peer production projects in an array of industries that includes stock photography, videos, and travel guides. Organizations, both for-profit and non-profit, have found ways to organize their products through peer production to overcome competition from more traditional, market- and firm-based approaches.

Although peer production is central to social scientific and legal research on collective intelligence, not all examples of collective intelligence created in online systems are peer production. First, (1) collective intelligence can involve centralized control over goal-setting and execution of tasks. For example, InnoCentive provides a platform for companies to distribute the search for solutions to difficult problems, but the problems themselves are defined within the boundaries of InnoCentive's client firms ("seekers") and solutions are returned to seekers as a complete product created by a single individual or team. Peer production, in contrast, decentralizes both goal setting and execution to networks of individuals or more structured communities (Brabham, 2013). Second, (2) many collective intelligence platforms, such as the ESP Game or Amazon's Mechanical Turk labor market, focus on optimizing systems around a relatively narrow set of motivations and incentives – ludic and financial in ESP and Mechanical Turk respectively. Peer production projects involve a broad range of incentives. Finally, (3) collective intelligence often occurs within firms where participants are bound by the obligation of contracts and in contexts where the resources used or products of collective effort are managed through exclusive property rights. Peer production exists without these structures.

Since the late 1990s when FLOSS first acquired widespread visibility and broad economic relevance, peer production has attracted scholarly attention. The earliest work sought to both explain the surprising success of peer production and to draw distinctions between peer production and traditional models of firm-based production. While many of these first analyses focused on software, the concept of peer production emerged as the most influential attempt to situate FLOSS as an instance of a broader phenomenon of online cooperation (Benkler, 2001, 2002). A series of scholars then adopted the concept of peer production to emphasize the comparative advantages of Internet-based cooperation as a powerful new mode of innovation and information production (e.g., von Hippel and von Krogh, 2003; Weber, 2004).

In the rest of this chapter, we describe the development of the academic literature on peer production and collective intelligence in three areas – organization, motivation, and quality. In each area, we introduce *foundational work* consisting primarily of earlier scholarship that sought to describe peer production and establish its legitimacy. Subsequently, we characterize work, usually more recent, that seeks to pursue *new directions* and to derive more nuanced analytical insights. Because FLOSS and Wikipedia have generated the majority of the peer production research to date,

[2] http://www.alexa.com/siteinfo/wikipedia.org (Accessed June 15, 2013)

we focus on research analyzing those efforts. For each theoretical area, we briefly synthesize both foundational work and new directions and describe some of the challenges for future scholarship. Neither our themes nor our periodization are intended to encompass the complete literature on peer production. Instead, they reflect core areas of research that speak most directly to the literature on collective intelligence and locate peer production within that broader phenomena. We conclude with a discussion of several issues that traverse our themes and implications of peer production scholarship for research on collective intelligence more broadly.

ORGANIZATION

Early scholars of peer production were struck by the apparent absence of formal hierarchies and leadership structures. Indeed, peer production communities perform all of the "classical" organizational functions like coordination, division of labor, recruitment, training, norm creation and enforcement, conflict resolution, and boundary maintenance – but do so in the absence of many of the institutions associated with more traditional organizations. Put in Williamson's (1985) terms, peer production communities thrive despite a relative absence of bureaucratic structure, exclusive property rights, and relational contracts. However, as peer production communities have aged, some have acquired increasingly formal organizational attributes, including bureaucratic rules and routines for interaction and control. The challenge for early peer production research was to elaborate an account of the characteristics that differentiate peer production from traditional organizations. As literature on peer production has matured, more recent work has sought to understand when the organizational mechanisms associated with peer production are more and less effective and how organizational features of communities change over time.

Foundational Work

A diverse and interdisciplinary group of scholars provided initial explanations for how and why peer production communities function. Early organizational analyses of peer production focused on discussions of how peer production compared to modes of organization in firms, states, and markets. Descriptive work also characterized patterns and processes of governance and leadership within some of the most prominent peer production communities.

Early scholarship on the organization of peer production emphasized theoretical distinctions between peer production, bureaucracy, and transaction cost explanations of firms and markets. Specifically, Benkler (2002; 2004; 2006) focused on the role of non-exclusive property regimes and more permeable organizational boundaries (i.e., organization without relational contracts) to explain how peer production arrived at more efficient equilibria for the production of particular classes of informational goods. Peer production could, Benkler argued, outperform traditional organizational forms under conditions of widespread access to networked communications technologies, a

multitude of motivations driving contributions, and non-rival information capable of being broken down into granular, modular, and easy-to-integrate pieces. Other foundational accounts attended to the emergence of informal hierarchies and governance arrangements within communities (Moglen, 1999; Weber, 2004). This earliest work relied on case study examples and descriptive characterizations of how these arrangements were lightweight compared to traditional bureaucratic practices within organizations historically tasked with the production of information goods. At the extreme, peer production communities were treated as a new category of "leaderless" social systems relying on informal norms such as reciprocity and fairness to solve complex problems *without* organizations.

Much of the earliest empirical research inductively sought to describe the structure and organization of FLOSS communities (e.g., von Krogh et al., 2003; Kelty, 2008) by, for example, characterizing contributions across FLOSS projects through reference to a core and a periphery of participants (e.g., Lakhani, 2006). Other work focused on describing the interactions between formal organizations and FLOSS communities in a variety of contexts (e.g., O'Mahony and Bechky, 2008; West and O'Mahony, 2005; Spaeth et al., 2010). In their review article, Crowston et al. (2010) provide a detailed overview of the scholarly literature on FLOSS organization and practice focusing on work that we characterize as foundational.

A large body of descriptive work has also sought to characterize organizational dimensions of Wikipedia and the practices of its contributors. A series of qualitative accounts examined the norms of participation and consensus among Wikipedians (e.g., Bryant et al., 2005; Forte and Bruckman, 2008; Pentzold, 2011). Reagle (2010) provided the most influential book-length scholarly description of Wikipedia and its processes. Another influential approach employed data-mining to build inductive, quantitative descriptions of Wikipedia's organization (Ortega, 2009; Priedhorsky et al., 2007; Viegas et al., 2007; Yasseri et al., 2012). A growing body of related research has characterized Wikipedia's governance systems (e.g., Butler et al., 2008; Konieczny, 2009); the emergence of leadership within the Wikipedia community (Forte et al., 2009; Zhu et al., 2011, 2012); mechanisms through which new community members are incorporated and socialized (Antin et al., 2012; Antin and Cheshire, 2010; Halfaker et al., 2011); as well as the ways in which bureaucratic decisions like promotions are made (Burke and Kraut, 2008; Leskovec et al., 2010).

Although they are a relative minority, foundational scholarly descriptions of organizational elements of peer production communities other than FLOSS and Wikipedia have emphasized similar concerns. For example, analyses of Slashdot's system of distributed moderation provided an early illustration of how recommendation and filtering constituted an informal mode of governance and supported a division of labor on the site (Lampe and Resnick, 2004; Lampe et al., 2007). This research built on earlier work showing that contributors to bulletin boards, newsgroups, forums, and related systems adopted durable "social roles" through their patterns of contribution (e.g., Fisher

et al., 2006) – an approach that was subsequently applied to Wikipedia (Welser et al., 2011; McDonald et al., 2011).

New Directions

More recent work on organizational aspects of peer production has begun to question the "stylized facts" that prevailed in earlier research. Examples of this work compare across projects and routines to understand the relationship between organizational attributes of communities and their outputs. Other work engages in interventions and field experiments to test and improve organizational operations in peer production communities. Many of the best examples of this newer wave of work have incorporated collections of peer production communities into their analysis to build broader, "industry-level" understandings of the phenomena. Some of these studies also articulate connections between peer production research and theories from a range of other organizational fields including academic studies of firms, states, political parties, social movement organizations, and civic associations.

Although some of the earliest theories of the organization of peer production celebrated the phenomena as non-hierarchical, more recent work has questioned both the putative lack of hierarchy and its purported benefits (e.g., Kreiss et al., 2011). In empirical work, several studies have underscored how feedback loops of attention and cumulative advantage can perpetuate starkly unequal distributions of influence and hierarchy (Hindman, 2008; Wu et al., 2009). Scholars have gone as far as to propose that hierarchy may even contribute to peer production success (Healy and Schussman, 2003) and a series of empirical studies have documented gate-keeping behavior in peer production and suggested that it may benefit projects (Keegan and Gergle, 2010; Shaw, 2012). Several studies have looked at wikis and shown that governance and hierarchies tend to become more pronounced as peer production projects mature (Loubser, 2010; Shaw and Hill, 2014). O'Mahony and Ferraro (2007) argued that FLOSS projects can depend and reflect existing firm-based hierarchies. Although this body of scholarship does not refute the idea that peer production is less hierarchical than alternative forms of organization or that it uses novel governance structures, it suggests a different model of peer production than the stylized anti-hierarchies depicted in earlier work.

Although enormous variation in organizational form exists among peer production projects, until recently, very few studies had systematically compared across communities. An important step toward such cross-organizational comparisons has been the creation of large data sets drawn from many communities. The FLOSSmole project has helped facilitate recent comparative scholarship by assembling and publishing a series of cross-project datasets in the area of software, including a widely used dataset from the FLOSS hosting website SourceForge (Howison et al., 2006). The most in-depth comparative study of FLOSS is Schweik and English (2012), who build on the work of Ostrom (1990) to compare characteristics of FLOSS projects' organization, resources, governance, and

context, using the FLOSSmole dataset of SourceForge projects. These comparative studies have not only revealed that large, collaborative projects are extraordinarily rare, but also that many projects generating widely downloaded FLOSS resources are, in fact, neither collaboratively produced nor peer production at all but rather the products of firms or individuals working alone.

Similar cross-organization studies in other areas of peer production, or studies comparing across different *types* of peer production, have remained challenging and rare. One difficulty with comparative work across organizations, in general, is designing research capable of supporting inferences into the causes of organizational success and failure. Historically, failed attempts to build organizations never enter into research datasets or attract scholarly attention. Two studies of peer production capturing these failures are Kittur and Kraut (2010) who use a dataset of 7,000 peer production wikis from the hosting firm Wikia, and Shaw and Hill (2014) who use an updated version of this dataset with ten times as many wikis. Others have tried to look across wikis by considering variation in sub-organizations within Wikipedia (Ransbotham and Kane, 2011; Wang et al., 2012; Zhu et al., 2011). Fuster Morell (2010) describes a comparative case study of several hundred peer production projects active in Catalonia. Despite these exceptions, there exist very few publicly available "industry-level" comparative datasets for types of peer production projects outside of FLOSS.

Another exciting path forward in organizational research in peer production lies in the use of field experiments and organizational interventions. Using a series of examples from peer production, Kraut and Resnick (2012) draw on experimental results to form principles of community design. Other examples include Halfaker et al. (2013b), who report experiments by the Wikimedia Foundation to alter the organizational structure around participation and work by Luther et al. (2013), who analyze the impact of a new system intended to support peer produced animations through more effective allocation of leaders' time and effort. By structuring design changes as experiments, these studies make credible causal claims about the relationship of organizational structure and project outcomes that previous work struggled to establish. By intervening in real communities, these efforts achieve a level of external validity that lab-based experiments cannot.

Organizational analysis of peer production remains a critical area for future work as an increasing number of organizations perform their activities in computer-mediated environments using the tools, techniques, and resources of peer production. As a result, a science of the mechanisms, procedures, and techniques necessary for the effective production of networked informational resources is increasingly important in various spheres of activity. Through challenging stylized conceptions of peer production organization, through comparative work, and through causal inference, future peer production research can continue to deepen and extend foundational insights. Future work can also begin to address questions of whether, how, and why peer production systems have transformed some existing organizational fields more profoundly than others. An empirically-informed understanding of when and where organizational practices drawn from peer production provide

efficient and equitable means to produce, disseminate, and access information can provide social impact beyond the insights available through the study of any individual community.

MOTIVATION

A second quality of peer production that challenged conventional economic theories of motivation and cooperation was the absence of clear extrinsic incentives like monetary rewards. Traditional economic explanations of behavior rely on the assumption of a fundamentally self-interested actor mobilized through financial or other incentives. In seeking to explain how peer production projects attract highly skilled contributors without money, much of the literature on peer production has focused on questions of participant motivation. In the earliest work on motivation in the context of FLOSS, an important goal was simply explaining how a system abandoning financial incentives could mobilize participants to freely share their code and effort. Even as it became apparent that peer production attracted contributors motivated by diverse, non-monetary factors, work in economics was focused on whether it was feasible to collapse these motivations into relatively well-defined models of self-interest. A newer wave of work has stepped back from this approach and sought to explain how multiple motivational "vectors" figure in the creation of common pool resources online (Benkler, 2012) – an approach that underscores a core advantage of peer production in its capacity to enable action without requiring translation into a system of formalized, extrinsic, carrots and sticks. Systems better able to engage self-motivated action will be better able to attract the kind of decentralized discovery of projects, resources, and solutions that are neither mediated by prices nor command-and-control hierarchies of obligation (Osterloh et al., 2002).

Foundational Work

The earliest research on motivation in peer production by Ghosh (1998) and Lerner and Tirole (2002) used case studies of FLOSS projects to assert that developers were motivated by motivations which could be easily assimilated into standard economic models. Frequently cited motivations in foundational work included: the use value of the software to the contributing developer, the hedonic pleasure of building software, the increased human capital, reputation, or employment prospects, and social status within a community of peers (Ghosh, 1998; Lerner and Tirole, 2002; von Hippel and von Krogh, 2003; von Krogh, 2003). Other early accounts analyzing examples of peer production beyond FLOSS suggested additional motivations. For example, Kollock (1999) emphasized reciprocity, reputation, a sense of efficacy, and collective identity as salient social psychological drivers of contribution to online communities and forums. Early studies of Wikipedia contributors suggested that Wikipedians edited in response to a variety of motives, many of which were social psychological in character (Beenen et al., 2004; Forte and Bruckman, 2008; Nov, 2007; Rafaeli and Ariel, 2008; Panciera et al., 2009). In studies of peer-to-peer file sharing networks and on-

line information sharing communities, Cheshire (2007) and Cheshire and Antin (2008) emphasized social psychological motivation and demonstrated that peer feedback could provide a mechanism of activating reputational concerns and encouraging additional contributions. Benkler (2002, 2006) argued that the combination of many incentives created a potentially fragile interdependence of motivations in peer production. In anthropological accounts of FLOSS, Coleman suggested that political ideologies of freedom play an important role in FLOSS production (Coleman, 2012; Coleman and Hill, 2004). von Krogh et al. (2012) provide a comprehensive recent survey of work characterizing motivations in open source software.

Much of the scholarship on individual motivation in FLOSS, Wikipedia, and other communities has relied on surveys. Some of the most influential survey research on FLOSS are studies by Rishab Ghosh and colleagues (e.g., Ghosh and Prakash, 2000; Ghosh et al., 2002; Ghosh, 2005), the Boston Consulting Group Hacker Survey (Lakhani and Wolf, 2005), and the US FLOSS study (David and Shapiro, 2008). Lakhani and Wolf (2005) emphasized the self-reported motivations of intellectual stimulation, hedonic gain, and skills building, while Ghosh et al. (2002) found reciprocity and skills development as the core motivation – a finding supported even among contributors who earned a living from their work on FLOSS (Hars and Ou, 2002). Ghosh and colleagues at the UN University in Maastricht also collaborated with the Wikimedia Foundation to conduct an early survey of Wikipedia editors and readers (Glott et al., 2010) – a study repeated several times – finding that Wikipedia contributors likewise identified many different reasons for participation. Surveys from remixing communities have suggested a similarly diverse range (Yew, 2009). Despite their differences in emphasis, scope, and genre, all of these surveys support the claim that motivations in peer production are diverse and heterogeneous.

A related body of early observational research into motivations of peer production participants underscored their self-selection into particular social roles within projects and communities (Fisher et al., 2006). For example, Shah (2006) found that developers motivated by use value contributed more to what she called "gated" source communities, while developers who were primarily motivated by fun or pleasure contributed primarily to more purely peer production-based projects. Using contributions to differently-licensed FLOSS projects, Belenzon and Schankerman (2008) found that contributors are heterogeneous in their motivational profiles, but also argued that contributors self-sorted among projects. For example, contributors who were more responsive to extrinsic motivations like reputation and employment tended to contribute more to larger corporate-sponsored projects. Studies of free culture communities including Slashdot and Wikipedia suggest comparable findings: participant behavior patterns reflect the sorts of editorial and coordination tasks necessary to produce relevant news and encyclopedic content (Lampe et al., 2007, 2010; Welser et al., 2011; Viegas et al., 2007; Kriplean et al., 2008; McDonald et al., 2011).

Other foundational research on motivation in peer production has explored why organizations,

firms and governments, rather than individual users, choose to participate in open source software (e.g., Lerner and Schankerman, 2010). In this vein, Schweik and English (2012) discuss firm-level motivations including the rate of innovation, the capacity to collaborate with other firms, and avoiding dependence on sole-source providers. Another major motivation for organizations is that participating in a peer production can permit the firm to develop in-house expertise in a tacit-knowledge rich innovation system and to increase the absorptive capacity of the firm (King and Lakhani, 2011).

New Directions

Recent empirical studies of motivation in peer production communities have drawn increasingly on observational data and field experiments. Much of this work has supported the finding that a mixture of motivations attract participants to contribute in peer production. That said, a growing number of studies also suggest that these motives interact with each other in unpredictable ways and, as a result, are vulnerable to "crowding out," such as when the introduction of extrinsic incentives undermines intrinsic motivation (Frey and Jegen, 2001). Robust evidence of varied participation patterns and motivations of contributors to peer production communities has given rise to other explanations of why peer producers do what they do. In particular, these newer accounts have focused on social status, peer effects, prosocial altruism, group identification, and related social psychological dimensions of group behavior.

Evidence from recent work on Wikipedia and related peer production projects has used observational data as well as field and laboratory experiments. The most important insight provided by some of this newer work is that contributors act for different reasons, and that theories based on a single uniform motivational model are likely to mischaracterize the motivational dynamics. For example, Restivo and van de Rijt (2012) randomly distributed "barnstars" (an informal award that any Wikipedian can give to another in recognition of contributions) to a sample of editors with high numbers of edits and found that the awards caused an increase of subsequent contributions. In a followup study, Restivo and van de Rijt (2014) use an additional experiment to show that the positive effects of the awards is only true among the most active Wikipedians. Similarly, Hill et al. (2012) use observational data to compare award recipients who displayed their barnstars as a public signal of accomplishment with those who did not and found that the "signalers" edited significantly more than the "non-signalers." Algan et al. (2013) combined observational data on the contribution history of 850 Wikipedians with the performance of the same individuals in a battery of laboratory social dilemmas. They show that that a preference for reciprocity (measured by contributions to public goods games), and trustworthy behavior (measured in a trust game) predict an increase in contributions up to the median editor, but that a preference for reciprocity no longer predicts contributions for editors above the median level. Instead, a preference for social signaling (identified partly from the Hill et al. dataset) predicts above-median contributions, but these high contributors

who are signalers do not exhibit particularly prosocial behavior in a laboratory setting. This study also shows that a lab-measured taste for altruism is not associated with increased contributions to Wikipedia. In field experiments conducted by affiliates of the Wikimedia Foundation, Halfaker et al. (2013b) demonstrated that a feedback tool could elicit increased contributions among new editors, so long as the cost (in terms of effort) of contribution remained low. Another study by Antin et al. (2012) combined longitudinal and survey data from a cohort of new Wikipedia contributors to show that differential patterns of contribution – as well as different reasons for contributing – emerge early in individual editors' contribution history.

Evidence from this newer body of research shows that motivations are diverse *within* contributors and that different contributors have different mixes of motivations. This depth and variety makes the problem of designing incentives for peer production systems more complex than foundational work suggested. Such complexity is further compounded by the fact that the impact of any given design intervention (e.g. the introduction of a system of reward or punishment) will necessarily focus on harnessing a particular motivational driver and will necessarily be non-separable from its effects on other motivational drivers. Experimental and observational data have exhaustively documented that the effects of the standard economic incentives like payment or punishment are not separable from their effects on social motivational vectors (Bowles and Hwang, 2008; Bowles and Polania-Reyes, 2012; Frey and Jegen, 2001; Frey, 1997). Similarly, social psychological motivations do not offer a panacea: recent evidence from exchange theory indicates that although the conferral of social status provides an effective mechanism for eliciting prosocial or altruistic behavior under many conditions (e.g., Willer, 2009), status-based incentives can generate diminishing returns beyond a certain point, and might even backfire when conferred upon individuals who do not value them (e.g., Hill et al., 2012).

Resolving the tensions between different motivations and incentives presents a design challenge for peer production systems and other collective intelligence platforms. The complex interdependence of motivations, incentive systems, and the social behaviors that distinct system designs elicit has led several prominent scholars to call for evidence-based social design (Kraut and Resnick, 2012) and cooperative human system design (Benkler, 2009, 2011). Research on FLOSS has demonstrated that, with the appropriate normative framing, it is possible to combine paid and unpaid contributions without crowding out intrinsic motivation (Alexy and Leitner, 2011). That said, we are not aware of any comparable studies of the successful integration of material and prosocial rewards in other areas of peer production. Indeed, websites like Weblogs Inc. have tried, and failed, to augment pure peer production systems by offering material rewards to top contributors. With habituation and practice, internalized prosocial behaviors may lead people to adopt a more, or less, cooperative stance in specific contexts based on their interpretation of the appropriate social practice and its coherence with their self-understanding of how to live well (von Krogh et al., 2012; Benkler and Nis-

senbaum, 2006). Practice and experience can shift individuals' proclivity to cooperate and make the work of designers or organizational leaders easier. Additionally, motivations can change and shift over time as certain forms of activity not visible in contribution logs, like reading Wikipedia, can both incentivize others to contribute and constitute an essential step toward participation (Antin and Cheshire, 2010).

Observational work that estimates the effects of motivational drivers across real communities offers an especially promising avenue for future work. Within this vein, planned and unplanned design changes to communities can provide "natural" experiments and may present particularly useful opportunities for researchers and community managers to evaluate changes to existing incentive systems. For example, Zhang and Zhu (2010) treat the Chinese government's decision to block Wikipedia as a natural experiment and estimate the effect of changes in "group size" on motivation to contribute among non-blocked users. Hill (2011) uses a change to the remixing site Scratch to estimate the causal effect of a newly introduced reputational incentive. Because most peer production systems are facilitated by software-defined web applications, changing the fundamental rules of engagement within peer production projects is simple and common. The diffusion of techniques like A/B testing and quasi-experimental data analysis thus provide an enormous untapped pool of opportunities to study motivation.

Peer production successfully elicits contributions from diverse individuals with diverse motivations – a quality that continues to distinguish it from similar forms of collective intelligence. Although an early body of literature helped establish and document a complex web of motivations, more recent studies have begun to disentangle the distinct motivational profiles among contributors across cultures and communities; the interactions between motivational drivers and motivational profiles; as well as the design choices that can elicit and shape contribution.

QUALITY

A third focus of research into peer production focuses on the quality of peer production's outputs. The capacity of peer production communities like FLOSS and Wikipedia to create complex, technical products whose quality and scale rivals, and frequently outcompetes, the products of professional workforces in resource-rich firms has driven both popular and academic interest. Indeed, the presence of novel organizational structures and unusual approaches to incentivizing contributors may have been uninteresting to many scholars of peer production if the products had been consistently of low quality. However, by the late 1990s, FLOSS projects including GNU/Linux and Apache were widely considered to be of higher quality than proprietary alternatives (i.e., proprietary UNIX operating systems and proprietary web servers like Microsoft's IIS, respectively). Over time, other peer produced goods have also equaled or overtaken their direct proprietary competitors. Recent

work has begun to probe more deeply into different dimensions along which quality can be conceptualized and measured. This new scholarship has given rise to a more nuanced understanding of the different mechanisms through which high quality resources arise, and founder, in peer production.

Foundational Work

FLOSS has been described as built upon a process that will inherently lead to high quality outputs (Weber, 2004). A prominent FLOSS practitioner and advocate, Raymond (1999) used the example of the Linux kernel to coin what he called Linus' Law – "with enough eyeballs, all bugs are shallow" – suggesting that FLOSS projects, by incorporating contributions from a large number of participants, would have fewer bugs than software developed through closed models. The mission statement of Open Source Initiative, the non-profit advocacy organization founded by Raymond in 1998, argues that, "the promise of open source is better quality, higher reliability, more flexibility, lower cost, and an end to predatory vendor lock-in"[3] and is the cited inspiration for many early academic studies of FLOSS (e.g., von Krogh and von Hippel, 2006). Practitioner-advocates, FLOSS entrepreneurs, and scholars have each assumed that the peer produced nature of FLOSS carried inherent quality benefits.

Raymond's argument for the superiority of FLOSS' development methodology gained currency as FLOSS emerged from relative obscurity in the late 1990s and began to be adopted by individuals and firms. The GNU/Linux operating system became peer production's most widely discussed success, and remains widely used today in a variety of types of systems. Recognizing the value produced through peer production, many established companies, including Google, HP, and Oracle, followed IBM's early lead and adopted FLOSS in major parts of their technology business. For example, Google's strategic decision to develop Android as FLOSS allowed its product to catch up to and overtake Apple's iOS as the dominant smart phone operating system. FLOSS-focused start-ups, like Red Hat, have ranked among the fastest growing technology companies over the last decade (Savitz, 2012). FLOSS has also been particularly important in the creation of Internet infrastructure. This includes both web servers and server-side scripting languages where, in both cases, a series of FLOSS systems have held a majority of market share for as long as statistics have been kept (Netcraft, 2013; Q-Success, 2013). Although Microsoft's Internet Explorer once held over 95% of the market after it squeezed Netscape Navigator out (illegally, according to antitrust adjudications in both the US and EU), FLOSS browsers Chrome and Firefox now hold nearly half of the market (Vaughan-Nichols, 2013). Recent industry surveys suggest that almost 40% of firms engaged in software development develop and contribute to FLOSS (Lerner and Schankerman, 2010). Others have suggested that FLOSS is more innovative (Bonaccorsi and Rossi, 2003; von Krogh, 2003; Lorenzi and Rossi, 2008).

[3] http://opensource.org/about (Accessed July 6, 2013)

Like FLOSS, Wikipedia's success has been connected to its quality which, in turn, has also been associated with its basis in collaboration from peer production. In a widely cited study, writers at the journal *Nature* presented evidence that a series of Wikipedia articles were of comparable quality to articles on the same subjects in the Encyclopedia Britannica after experts recruited by the journal found approximately the same number of errors in each (Giles, 2005). Although there is no statistically significant correlation between the number of edits to a Wikipedia article and the number of errors in each article within the *Nature* sample,[4] other studies of Wikipedia have shown that articles with more intense collaboration tend to be rated as being of higher quality by other Wikipedia contributors (Wilkinson and Huberman, 2007; Kittur et al., 2009). Similarly, articles on US politics tend to become less biased as the number and intensity of contributors grows (Greenstein and Zhu, 2012). Other studies of Wikipedia have associated Wikipedia's open editing model to the fact that vandalism is detected and removed within minutes or seconds (Viegas et al., 2004).

The success of FLOSS and Wikipedia has inspired the adoption of peer production in a wide array of industries. Maurer (2010) describes instances where distributed, non-state, non-market action was able to deliver public goods, ranging from nanotechnology safety standards to a synthetic DNA anti-terrorism code. Online business models that depend on peer production (and related commons-based approaches) have out-competed those that depend on more traditional, price-cleared or firm-centric models of production. For example, Flickr, Photobucket, and Google Images, all of which incorporate peer production as a core driver of their platform, have produced vast repositories of stock photography and overshadowed Corbis, the largest stock photography firm using a purely proprietary business model. YouTube, Google video, and Vimeo all rely heavily on peer production for their video content and each is more popular than the studio-produced models of Hulu, Vevo, or even Netflix (though Netflix, the most widely used among these, is roughly as popular as Vimeo). The peer produced TripAdvisor is more popular than Lonely Planet, Fodor's, or Frommers for travel guides. In restaurant reviews, Yelp is more widely used than proprietary alternatives. Both for-profit and non-profit organizations that have incorporated peer production models have thrived in the networked environment, often overcoming competition from more traditional, market- and firm-based models.

New Directions

Recent research has stepped back from the simple association of peer production with high quality and has problematized earlier celebratory accounts. This has entailed moving beyond the rhetoric of Raymond (1999) to cease taking the high quality of peer produced resources for granted. Toward that end, this newer wave of scholarship has looked at large datasets of attempts of peer production

[4] Analysis of data by the authors of this article using public data from nature study published line. http://www.nature.com/nature/journal/v438/n7070/extref/438900a-s1.doc (Accessed July 6, 2013)

and documented that the vast majority of would-be peer production projects fail to attract communities – an obvious prerequisite to high quality through collaboration. Additional scholarship has suggested that quality cannot be taken for granted even in situations where large communities of collaborators are mobilized. Finally, recent work has evaluated peer production in terms of a series of different types and dimensions of quality. In following these three paths, scholars have begun to consider variation within peer production projects to understand when and why peer production leads to different kinds of high quality outputs.

Contrary to the claims of foundational accounts, studies have suggested that the vast majority of attempts at peer production fail to attract the large crowd whose aggregate contributions might invoke Linus' law. Lacking any substantive collaboration, these projects do not constitute examples of peer production. Healy and Schussman (2003) first showed that the median number of contributors to a FLOSS project hosted on SourceForge is one. Schweik and English (2012) demonstrated that even among FLOSS projects that have produced successful and sustainable information commons, the median number of contributors is a single individual. A series of studies of remixing suggest that more than 90% of projects uploaded to remixing sites are never remixed at all (Luther et al., 2010; Yew, 2009; Hill and Monroy-Hernandez, 2013b). Reich et al. (2012) have shown that most attempts to create wikis within classroom environments fail to attract contributions. Hill (2013) has shown that even Wikipedia was preceded by seven other attempts to create online, freely-available, collaborative encyclopedias – all of which failed to created communities on anything approaching the scale of Wikipedia.

The relative infrequency of peer production within domains like FLOSS does not necessarily pose a theoretical problem for peer production since the success of the phenomenon is not defined in terms of the proportion of viable projects. That said, the fact that peer production seems so difficult to achieve, and that the vast majority of attempts at peer production never attract a community, is worrisome for those who value the high quality public goods made available freely on the Internet through peer production. Although this has constituted an inconvenient fact in peer production practice, it also reflects an important opportunity for future research. By focusing only on the projects that successfully mobilize contributors, researchers interested in *when* peer production occurs or the reasons *why* it succeeds at producing high quality outputs have systematically selected on their dependent variables. An important direction for peer production research will be to study these failures.

Several critics of peer production have questioned whether large scale collaborations can ever lead to high quality outputs. Although relying primarily on rhetoric and anecdote, Keen (2007) argued that the openness of peer production to participation leads to products that are amateurish and of inferior quality. Similarly, Lanier (2010) suggested that Wikipedia's reliance on mass collaboration results in articles that are sterile and lack a single voice. These dismissive treatments are

problematic because peer production obviously does lead to high quality outputs in some situations. A more fruitful approach considers variation in peer production success to understand when and where it works better and worse. For example, Duguid (2006) raised a series of theoretical challenges for peer production and suggests that it may work less well outside of software development. Benkler (2006) speculated that peer production may be better at producing functional works like operating system software and encyclopedias than creative works like code or art. In support of this idea, research by Hill and Monroy-Hernandez (2013a) from the youth-based remixing community *Scratch* suggested that collaborative works tend to be rated lower than *de novo* projects and that the gap in quality between remixes and non-remixes narrows for code-heavy projects, but expands enormously for media-intense works.

Just as peer produced goods vary in their nature and form, there is also enormous variation between and within projects in terms of the dimensions along which quality might be evaluated. In the case of Wikipedia, scholars have assessed the encyclopedia in terms of factual accuracy, scope of coverage, political bias, expert evaluation, and peer evaluation – often drawing different conclusions about the quality of Wikipedia or particular articles. Many studies have suggested that Wikipedia has uneven topic coverage. One group of studies has found uneven cross-cultural and cross-language coverage between Wikipedias and shown that the unevenness corresponds to other forms of socioeconomic and cultural inequality (Arazy and Nov, 2010; Royal and Kapila, 2009; Pfeil et al., 2006; Bao et al., 2012; Hecht and Gergle, 2009). Inequality in gender participation (see Glott et al., 2010; Hill and Shaw, 2013) has also been connected to underproduction of Wikipedia articles on topics related to women (Antin et al., 2011; Reagle and Rhue, 2011). Many explanations for this variation exist, but Halavais and Lackaff (2008) offer a succinct summary: "Wikipedia's topical coverage is driven by the interests of its users, and as a result, the reliability and completeness of Wikipedia is likely to be different depending on the subject area of the article."

A related series of studies have sought to unpack the dynamics of collaboration and to understand which features of peer productions support the creation of higher quality content. This topic has been studied especially closely in the case of Wikipedia, where particular organizational attributes, routines, norms, and technical features impact the quality of individual contributions as well as the final, collaborative product. For example, experienced contributors possess a deeper sense of ownership and commitment, leading them to make more durable contributions that, in Wikipedia's case, drove the growth of the encyclopedia (Halfaker et al., 2009; Priedhorsky et al., 2007). Other work has shown that persistent subcommunities of contributors can develop stable dynamics of coordination, leading to more productive collaboration with higher quality products (Kittur and Kraut, 2008). At the same time, experienced editors can wield their expertise against new contributors, removing their contributions and undermining their motivation to edit in the future (Halfaker et al., 2011, 2013a). Other work has suggested that this process can shrink the pool from

which future experienced contributors and leaders can be drawn (Loubser, 2010). Harsh treatment of newcomers can also undermine quality in other, less obvious ways. For example, while experienced editors may perceive low quality contributions from inexperienced editors as a nuisance, "newbie" edits also attract the attention of experienced community members to improve popular pages they might otherwise have ignored (Gorbatai, 2012).

An important remaining question is whether, and to what extent, the dynamics, routines, infrastructure, and mechanisms that support peer production in intensively studied projects like the English language version of Wikipedia generalize to other communities engaged in other kinds of collaborative activity. Here, peer production researchers may do well to draw on approaches applied to other areas of collective intelligence, such as crowdsourcing, where more precise analyses of the relationship between tasks, system design, and the quality of collaborative outputs have already been performed (e.g., Yu and Nickerson, 2011). Ultimately, this is an area where further comparative study across platforms, communities, contexts, and tasks will be imperative (e.g., Roth et al., 2008; Kittur and Kraut, 2010).

CONCLUSION

For scholars of collective intelligence in the social sciences and legal scholarship, three of the most important and confounding challenges have been in regards to organization, motivation, and quality in the context of peer production. As we have suggested, these themes do not reflect an attempt to be exhaustive, proscriptive, or predictive of future research. In addition to our incomplete reviews of the literature addressing each of these themes, there are many bodies of research that build on, and are related to, peer production that we have not addressed. Nevertheless, our approach illustrates how studies of peer production and collective intelligence have already engaged with sustained debates that range across the social sciences and suggests how they might productively continue to do so. Interested readers seeking a deeper understanding of collective intelligence in the social sciences and legal scholarship should recognize that this chapter provides an entry point into these topics, but remains far from a comprehensive summary.

The limitations of prior peer production scholarship underscores the opportunities for continued social scientific study of peer production and collective intelligence from a variety of theoretical and methodological perspectives. We have highlighted several of what we feel are the most promising areas for future work. As we have suggested, studies that engage in comparative analysis, consider failed as well as successful efforts, and identify causal mechanisms can contribute a great deal. Likewise, work that challenges, extends or elaborates the major theoretical puzzles encompassed by any of the three areas will speak to a wide variety of peer produced phenomena.

Finally, there is an important possibility to use evidence from peer production as a foundation

to challenge and extend the literature on collective intelligence and, perhaps, to contribute to more general theories of human behavior and cooperation. Peer production systems combine novel and creative social practices and forms of organization with the creation of truly unprecedented sources of behavioral data. Never, before peer production, have scholars possessed full transcripts of every interaction, communication, and contribution to a collective endeavor or to a particular public good. With the widespread availability of massive datasets of peer production communities – many of them publicly released under free or open licenses that permit research and reuse – it has become possible to harness the tactics and tools of computational science for the comparative study of social action. Substantively, this means that there are many opportunities to conduct research that cuts across traditional divisions between micro-, meso-, and macro-level social analysis. There are also opportunities to revisit classical concerns of social scientific theory through a lens of evidence that is granular and exhaustive.

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