Shaping Scientific Work: The Organization of Knowledge Communities

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Academic research is increasingly social (Powell, White, Koput, and Jason 2005; Rawlings and McFarland 2011). This change is evident in the move away from research produced by individual scientists to team-based production (Wuchty, Jones, and Uzzi 2007). The social nature of scientific work is also evident from the existence of peer, network, context, organizational, field, and subfield effects on scientific approaches, evaluations, and activity. This foundational paper synthesizes research that investigates how scientific work is socially situated – in research teams, departments, centers, peer networks, subfields, fields, and larger institutional environments (like academe and commercial science). While I focus largely on what we've learned substantively from such investigations, I also emphasize the theories and methods (particularly social network analyses) that seem to be well suited to such investigations. This lays the groundwork for a more speculative conclusion that focuses on theoretical developments and fruitful avenues for future research and investment.

The scope of this review paper is necessarily limited, and is driven partly by my research interests and areas of expertise. First, I focus on 'public' science, that is, science produced within the university context rather than in for-profit firms, though I discuss the increasing connectedness of public and private science in the sections on commerce and inclusiveness. Second, much of the literature on science focuses on the natural and physical sciences (Guetzkow, Lamont, and Mallard 2004). But given my expertise in the sociology of *social* science, I fill this void with references to my work and the work of others who have studied social scientific fields (Abbott 2000; Clemens, Powell, McIlwaine, and Okamoto 1995; Moody 2004). Third, I focus on scientific output in the form of publishing, and devote less attention to other important scientific products like citations and patents.

Although the question of topic selection is a classic one in the sociology of science (Merton 1982), I don't highlight that literature here. Briefly, social forces and relations influence scientists' decisions to study what they do. Scholars interested in such questions might revisit (Gieryn 1978) paper on problem choice. Intrinsic interest and desire for a cohesive research program is of course key, but external factors like level of competition in a research area, as well as economic, defense, and technology concerns can also affect problem choice. Owen-Smith, Scott, and McCormick (2012), among others, focus on the role of federal funding in shaping research topic selection: it encourages research in some areas and discourages research in others. Moral concerns – not only of scientists but within publics – are also relevant. A timely discussion about the ethical, legal, and regulatory issues involved with stem cell research are laid out in a 2012 issue of the *Journal of Policy Analysis and Management* (Vol. 31, No.3).

SPECIALIZATION IN SCIENCE

Specialization is a defining characteristic of modern science. As Blau wrote in *The Organization of Academic Work (1994:191)*, "the development of science is intimately bound up with increasing specialization." As scientific activity expanded up to and throughout the 20th century, it also became more specialized (de Solla Price 1963). Historical analyses of social change within science suggest that rapid growth of scientific fields (Kuhn 1962) prompted scientists, who are invariably keen on carving out manageable bodies of literature and on fostering their professional visibility (Ben-David and Collins 1966; de Solla Price 1963), to carve out new professional niches – often in the guise of sub-disciplines, or specialty areas (Mullins 1983). Simply put, working within a specialty area allows scientists to counteract overcrowding in their field, to stand out more easily, and to avoid being spread too thin (Hackett 2005). Like fields, subfields produce insights, provide structure to the academic labor market (where advertisements for positions are distinguished by both field and subfields), and prevent knowledge from becoming too abstract and overwhelming for scholars (Abbott 2001). These forces of growth and overcrowding were instrumental in creating the high degree of specialization that characterizes modern science (Wray 2005).

A large portion of my own research program has been devoted to understanding the implications of specialization for academics' careers, and especially gender differences in career outcomes. This entails a move away from macro-level analyses of fields and subfields (e.g., the number and clustering of research areas) toward individual-level analyses of scientists' research programs. It also entails a move away from the oft-studied *areas* of specialization (i.e, the subfields, sub-disciplines, or specialty areas that scholars associate with) toward what I call the *extent* of specialization. The extent of specialization (i.e., its form) and the area of specialization (i.e., its content) are distinct dimensions of specialization that are not necessarily related. Two academics could be similar in all regards – even with respect to their primary specialty area – but differ dramatically in the extent to which their successive papers and projects are related to their previous work: one could contribute repeatedly to the same subfield, whereas another could produce articles on a wide variety of topics. Two researchers could even conduct research in the same four areas (e.g., gender, family, law, and organizations in the field of sociology) and yet specialize to different extents: one researcher could devote 70% of her research to one area, and 10% to each of the remaining three areas, whereas the other researcher could devote 25% of his time to each area.

In general, I find that specializing is beneficial. Using probability samples of scholars from the understudied social sciences and humanities, I find that scholars who specialize to a large extent tend to have higher rates of productivity in the form of article publishing (Leahey 2006). This is likely because specializing allows one to master the literature, become familiar with important debates and gaps in the literature, and recognize new developments – all of which can boost productivity by making successive papers on that substantive topic easier to write and more likely to be accepted for publication. These productivity gains are translated into greater scholarly visibility and even higher earnings (Leahey 2007). This is likely because a focused research program allows one to quickly and easily develop a professional identity and niche. As Sonnert and Holton (1995:174) note, "…a clearly focused research program in a well-defined research area is commonly considered more advantageous to a career than undertaking disjointed projects." I also find that women's lower degree of specializing contributes to their lower levels of productivity and earnings, and thus helps explain gender gaps in scientific career outcomes. More recent work with Will Felps, Nees Jan Van Ess, and Ludo Waltman (2012) extends this research to the field of management science, develops a more sophisticated measure of specialization via latent semantic analysis, explores curvilinear effects of specialization, and documents an optimum level.

While specializing may be beneficial for individual scientists, it may be detrimental for the progress of science. Especially in the early 1990s, scholars expressed concern that increasing specialization would foster divisions among specialists such that few people will understand or care about work being conducted outside their specialty area (Blau 1994; Calhoun 1992; Collins 1994; Davis 1994; Stinchcombe 1994; Turner and Turner 1990). Fields, even inherently interstitial fields like sociology, were considered "insular" (Calhoun 1992) and an "archipelago of poorly connected islands of specialization" (Halliday and Janowitz 1992:25). Others have gone so far as to argue that there is no "pure" sociology anymore; rather, there are only sociologists of particular kinds -- political sociologists, sociologists of religion, and the like. In essence, sociology has "fragmented to an extraordinary degree" (Dogan and Pahre 1989b:66). The same could probably be said of other disciplines, like anthropology (where a strong divide exists between cultural and biological anthropologists) and physics (where experimental and theoretical physicists rarely interact) (Traweek 1992). In many disciplines, the shared norms and practices of specialty areas (Kuhn 1977), while helping members grasp otherwise complex subjects in a manageable way (Abbott 2001; Dogan and Pahre 1990), may also discourage innovative work on problems that fall between fields and subfields (Simon 1973; Star 1983).

Research suggests otherwise. Rather than pigeonholing sociologists, specialization may expand horizons and move research forward in integrative and original ways (Dogan and Pahre 1989a). Specialization -- at least at an aggregate level -- can be compatible with integration. Although training, resource allocation (e.g., faculty lines), and institutional forces help hold various disciplines and sub-disciplines together for reasons unrelated to the promotion of integrative research (Sewell 1989), intense work in a single subfield may, paradoxically, serve as a springboard from which subfield-spanning work develops. Specialization may encourage scholars to choose area(s) of expertise, recognize their respective limitations, and subsequently join them. This is what Moody (2004) finds in his study of over three decades of sociological research: while there are many distinct topic clusters, collaborative ties link these together to form a dense network. Abbott (2001) delineates the various benefits that emerge from linking areas of research, which include not only creativity (p. 230) but also better, more complete knowledge (p. 32), major changes in the field (p. 32), a rerouting of the mainstream (p. 143), and the only kind of universal social scientific knowledge: that which provides "tentative bridges between local knowledges" (p. 5). The macro-level benefits of increased specialization may be most apparent when specialization promotes collaboration and boundary-spanning (e.g., inter-disciplinary) research, the topics I turn to next.

SCIENTIFIC COLLABORATION

Another revolutionary change in science over the past few decades has been the rise of collaboration – what has been termed the cornerstone of academic social activity (Hagstrom 1965). Sole-authored works used to dominate science, and are still somewhat common in the social sciences. But increasingly, scientists work with others as part of research teams. This trend toward larger team sizes began as early as the beginning of the 20th century (de Solla Price 1963). In the field of sociology, collaboration rates increased from 11% in 1935 to over 50% in 2005 (Hunter and Leahey 2008). Wuchty et al. (2007) show that the trend for social sciences mirrors science and engineering, where the percentage of papers authored by teams rose from 50% in 1955 to over 75% by 2000. Team size is also growing: averaging 1.9 authors per paper in 1955 and 3.5 authors per paper in 2000. These trends hold for patents as well as papers. Wuchty and colleagues (2007:1037) also find a "broad tendency for teams to produce more highly cited work than individual authors." Collaborative teams produce more papers, more high-impact papers, and garner more citations (Lee and Bozeman 2005; Xiaolin Shi 2009). Clearly, collaboration is beneficial for individual scientists (Presser 1980) and perhaps for scientific progress more generally (Hara, Solomon, Kim, and Sonnenwald 2003).

A reliance on published works to identify collaborative ties has two important implications.[1] First, estimates of scientific collaboration are necessarily conservative. The typical indicator of collaboration is article co-authorship. This form of output is more tangible than other forms of collaboration (for example, sharing data, exchanging ideas, helping colleagues learn new techniques) and captures the two key elements of collaboration: working together for a common goal and sharing knowledge (Hara, Solomon, Kim, and Sonnenwald 2003). But it is conservative and fails to capture more informal collaborations and to recognize the contributions of students and other assistants, who are not always given coauthor status. Second, using co-authorship to measure collaboration means that investigations of team *formation* are few and far between. How and why do individuals come together, and work jointly? Such important questions on emergence are just starting to be answered at the level of teams (Leahey and Reikowsky 2008), fields (Frickel 2004), and region (Powell, Packalen, and Whittington 2012).[2]

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[1] Most research on collaboration relies on published records and thus coauthorship ties. Exceptions include Bozeman and Corley (2004) and Boardman and Corley (2008) who use a broader operationalization for collaboration that focuses on time allocation.

[2] Surprisingly little sociological research has been conducted on team composition, and how and why teams come together; this is likely the focus of the more psychologically-oriented Science of Team Science literature. Sociologists have also shied away from analyses of technology's role in collaboration. Computing power and advances that permit free video-conferencing, document sharing, screen-sharing, and simultaneous co-editing capability have likely promoted and helped maintain scientific collaboration; perhaps the economics of science literature pays more attention to such important factors.

Some evidence suggests that increasing specialization in science has directly or indirectly promoted collaboration. Classic (Cole and Zuckerman 1975) as well as more recent (Moody 2004) studies have documented a positive relationship between the growth of specialty areas and collaboration rates. As universities have grown and become research-intensive, the resultant internal differentiation often impedes communication among units (Biancani, McFarland, Dahlander, and Owens 2012; Friedkin 1978). Increasing specialization and differentiation raise concerns that departments are silos that don't – and effectively can't – interact with, and stay abreast of developments in, other fields (Brint 2005; Brint, Turk-Bicakci, Proctor, and Murphy 2008). Specializing most likely increases the 'reinforcing' style of collaborative research that is undertaken with scholars in one's field or subfield (Leahey and Reikowsky 2008), but it may also encourage boundary-spanning and collaborative efforts.

This connection may be attributable to two factors. First, specialty areas are large and highly productive. Thus, it may still be difficult for an individual researcher to digest all the literature in one specialty area, thereby encouraging collaboration with others in that area (Hudson 1996). Second, science that spans boundaries (subfields, fields) is highly regarded (National Academies of Science, National Academy of Engineering, and Medicine 2005) and valued by researchers for its novelty and usefulness (Leahey and Moody 2012). Although Collins (1986:1355) argues that "the easiest way to establish links among specialized viewpoints is to incorporate them into oneself," most researchers choose to find a collaborator who possesses the expertise that they lack (Boh, Ren, Kiesler, and Bussjaeger 2007; Wray 2005). Because "an individual scientist can seldom provide all the expertise and resources necessary to address complex research problems" (Hara, Solomon, Kim, and Sonnenwald 2003:952), collaborating may be the most efficient way for individuals with a fractional paper in them to produce a complete paper (de Solla Price 1963). This is especially true if the research spans specialty areas or disciplines, and the authors' areas of expertise are complementary (e.g., one author is an expert in A, the other is an expert in B, and they join together to write a paper about AB). This is the type of collaborator that Bozeman and Corley (2004) refer to as "tacticians." Leahey and Reikowsky (Leahey and Reikowsky 2008) find evidence for this style of collaboration, but at least in the social sciences, it is still rare.

While it is common to view collaboration in opposition to a scientific norm of individualism (Hackett 2005; Merton 1973), at least one prevalent style of collaboration is consistent with the norm of individualism. Collaborative research that reinforces (Leahey and Reikowsky 2008) and consolidates (Foster, Rzhetsky, and Evans 2012) known areas of expertise is, arguably, an extension of sole-authored research. The close collaboration that takes place between mentors and their students also tends to be reinforcing, as students often take up a subset of their mentor's research program (Bozeman and Corley 2004; Crane 1969; Mullins 1983). Reinforcing and consolidating styles of collaboration likely improve efficiency and productivity: when labor is divided, "returns to the time spent on tasks are usually greater to workers who concentrate on a narrower range of skills" (Becker and Murphy 1992:1137). Certainly, some types of labor are easier to divide than others. Hunter and Leahey (2008) and Moody (2004) find that articles that rely on quantitative methods are more likely to be coauthored; it is arguably easier to delegate tasks in a quantitative project than a qualitative one (except perhaps comparative case studies). Projects requiring large amounts of primary data collection are also conducive to the division of labor that collaboration entails (Hunter and Leahey 2008).

This style of collaboration – in which coauthors' knowledge domains overlap considerably – is common in sociology, characterizing 70% of coauthored sociology articles (Leahey and Reikowsky 2008), and in biomedical chemistry, where 'repeat consolidations' far outnumber the exploration of new chemicals and relationships (Foster, Rzhetsky, and Evans 2012). Of all co-authored articles in Leahey and Moody's (2012) sample of sociology articles, 80% fall into a single specialty area. Clearly, a large proportion of research today is focused on depth: scholars join together with others who share their area(s) of expertise and produce work that contributes to a single research area. It also suggests that 'sticking with one's own' is a viable and common strategy in this age of what some call hyper-specialization and fractionalization (Collins 1986; Davis 2001). Indeed, Leahey (2006; 2007) documents the returns from specializing (whether alone or with like-minded others) in terms of productivity, scholarly visibility, and academic earnings.

The focused, specialized, and consolidated research that characterizes much of science today is relatively low risk, but may be sacrificing potentially large gains. When coauthors share areas of expertise, the typical costs of collaboration (e.g., coordination, control, different motives (Shrum, Genuth, and Chompalov 2007)) are mitigated: epistemological divides (Knorr Cetina 1999) are rare, shared understandings are easier to achieve (Lamont 2009), and efficient and exploitative search strategies are possible (March 1991). All of these reduce uncertainty and foster confidence in predictable and positive outcomes. But this "reliable succession" (Bourdieu 1975) also has drawbacks. Namely, it does not foster broad exploration, the pooling of diverse ideas, and the development of new, creative ideas. It rarely pushes the boundaries of science in new and fruitful ways. It may not be conducive to scientific breakthroughs and transformative science.

Theories of recombinant innovation (Hargadon 2002; Weitzman 1998) and network diversity (Burt 2004a) suggest that pulling together ideas from extant, distinct domains is a – if not *the* – route to new, creative, ideas. In the realm of science, this is best accomplished via collaboration, given that scientists tend to specialize, and scientists' stocks of knowledge are dependent upon prior experiences, contacts, and context (Gieryn 1978; Long and McGinnis 1981). Leahey and Reikowsky's (2008) research finds that these styles of collaboration – what they call 'complementary specialists' and 'generalists broaching a new topic' – are rare in the field of sociology, representing 11% and 18% of the sampled articles, respectively. But these collaborative styles illuminate the bright side of increasing specialization in science: It encourages a branching out, whether through finding a fellow specialist with different but complementary interests, or by moving forward to a new topic area – via accretion, substitution, or migration (Gieryn 1978). Though uncommon, these boundary-spanning collaborations may be more fruitful: publications that spans subfields and fields have greater impact, as measured by citation counts (Leahey, Beckman, and Stanko 2012; Leahey and Moody 2012); domain-spanning is also conducive the development of patentable ideas

(Fleming, Mingo, and Chen 2007). The theorized (and in many cases realized) benefits of domain-spanning underlie recent efforts to encourage collaborations across domains, especially disciplines (National Academies of Science, National Academy of Engineering, and Medicine 2005).

INTER-DISCIPLINARITY

Indeed, domain-spanning research is being promoted at various levels. As Hackett and Rhoten (2009:409) summarize, the integration (or synthesis) of ideas, methods, and data from distinct disciplines has been a transformative force in science, one that has attracted policy interventions, program innovations, and financial resources. This is evident from the recent enthusiasm for mixed methods (Leahey 2007a), interdisciplinarity (National Academies of Science, National Academy of Engineering, and Medicine 2005), synthesis (Parker and Hackett 2012), as well as cross-cutting funding initiatives (NSF's IGERT and CREATIV)[3] and the proliferation of fellowship programs hospitable to interdisciplinarity (Lamont 2009) and explicitly supportive of it (e.g., The Radcliffe Institute for Advanced Study at Harvard). Increasingly, available external and internal funding is restricted to multi-disciplinary teams. Interdisciplinarity has become "synonymous with all things progressive about research and education" (Rhoten and Parker 2004).

These commitments are influencing the kind of research that is being conducted. An inter-disciplinary mode of research, which "integrates perspectives, information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines" (National Academies of Science, National Academy of Engineering, and Medicine 2005:188) – is on the rise. Gibbons et al. (1994) refers to this as Mode 2 science. Inter-disciplinary scholarship is increasingly prevalent in the social sciences (Brint 2005; Jacobs and Frickel 2009) and the natural sciences (Rhoten and Pfirman 2007). In unpublished study, Bozeman finds that 25-30% of science and engineering faculty members at major US research universities are affiliated with at least one interdisciplinary venture (Vastag 2008). In the field of ecology, synthesis centers are supporting researchers who want to cross traditional divides of method, theory, subfield, and ecological niche (Hampton and Parker 2011).

These commitments are also influencing the kinds of scientists who are being trained for PhD-level work. In their study of members of five NSF-funded environmental programs, Rhoten and Parker (2004) found that graduate students demonstrated higher rates of interdisciplinarity than professors (62% compared to 49%, respectively). But graduate students were also more likely to recognize the potential risks of pursuing an interdisciplinary path, such as a longer time spent getting established in one's career and known in one's field. Young scientists in training feel the "tension between the scientific promise of the interdisciplinary path and the academic prospect of the tenure track" (p. 2046). Although

[3] IGERT is the "Integrative Graduate Education and Research Traineeship" Program; CREATIV is the "Creative Research Awards for Transformative Interdisciplinary Ventures," a pilot mechanism intended to support bold interdisciplinary projects in all NSF-supported areas of research.

interdisciplinary centers and training program are springing up and offering graduate students opportunities to experience "cutting edge research and cross-fertilization," employers still prefer to hire scientists who have stayed in established disciplines (Nelson 2011). This and other drawbacks of interdisciplinarity are elaborated in Jacobs and Frickel's (2009) *Annual Review of Sociology* piece.

The potential drawbacks of inter-disciplinary training manifest themselves even before students prepare for the academic job market. In their fascinating charrette experiment that compared groups of IGERT-trained and traditional (disciplinary) graduate students, Hackett and Rhoten (2009) found that IGERT training, at least in the early years, improved the quality and process of collaborative research. However, among groups comprised of older (3rd and 4th year) graduate students, the two IGERT-trained groups' work was evaluated as less original and less successfully interdisciplinary. Based on observations of group dynamics, Hackett and Rhoten found that IGERT students focused on form over content: they got bogged down in *enacting* rather than *being* an interdisciplinary, collaborative team – they were aware of the rules but could not fulfill the associated roles. This, they suggest, might be attributable to a reversion to conventional, disciplinary roots in later years, as advanced graduate students encounter "the more treacherous waters and institutional realities of a nascent professional career (culminating in the prospect of a discipline-dominated job market)" (p.424). Based on these findings, Hackett and Rhoten (p.427) encourage training programs to start with a strong disciplinary foundation before moving into interdisciplinary immersion.

The drawbacks of engaging in inter-disciplinary research extend to later career stages. A number of studies document penalties associated with crossing disciplinary lines. On the producer side, it is challenging for scholars to accommodate the research mores and concepts of multiple specialty areas (Lamont, Mallard, and Guetzkow 2006), to master and adequately represent literature from distinct subfields, and to produce output that is standard in form and content. On the audience side, experts in different subfields may disagree on the merits of a paper (Lamont 2009), and this conflict may be particularly evident when an integrative paper is in the review stage. Birnbaum (1981) found that research that does not fit neatly within the substantive bounds of "normal science" is typically received by journal editors and reviewers with irritation, confusion, and misunderstanding. This makes the road to journal publication challenging (Ritzer 1998). Former sociology journal editors reinforced this point. Stephen Cole (1993:337) believed that if an author writes an article on "a relatively narrow subject…the chances of the article being accepted are significantly greater than if the author is more ambitious." Rita Simon (1994:34) noted that "works of imagination, innovation, and iconoclasm may fail to receive positive appraisals from reviewers who are good at catching errors and omissions but might miss a gem, or at least the unusual, the provocative, the outside the mainstream submission." Indeed, in my concurrent work with Christine Beckman, we find that while interdisciplinarity positively affects scholars' visibility, it takes a toll on their productivity.

Most investigations of domain-spanning simply assess *whether* boundary-spanning has occurred (Clemens, Powell, McIlwaine, and Okamoto 1995; Fleming, Mingo, and Chen 2007), but consideration of the novelty of the pairing is critical for elucidating processes of innovation. To our knowledge, only Braun and Schubert (2003) and Leahey and Moody (2012) have empirically assessed the uniqueness, or rarity, of combinations. Porter, Cohen, Roessner, and Perreault (2007) has developed a measure of domain integration that incorporates the relationships between domains: are they paired frequently in the literature, or rarely? This is ideal because it is *new* connections (not common ones) that help define originality (Guetzkow, Lamont, and Mallard 2004). The most fertile creative products are "drawn from domains that are far apart" (Poincare 1952 [1908]) and the best conceptual metaphors are those that create ties across great distances (Knorr Cetina 1980). Put simply, integrative work can be more or less innovative, depending on the relationship between the integrated entities (Carnabuci and Bruggerman 2009: 608). For most analyses, it is possible to examine not only whether two domains are spanned, but also how rarely they are spanned, which provides an indication of the novelty of the pairing.

Using these more nuanced measures, a number of recent (unpublished) papers document benefits to domain-spanning. My research with James Moody (2012) samples Sociology articles that do and do not span sub-field boundaries to assess the potential penalties and benefits of what we call 'subfield integration.' Perhaps because domain-spanning is positively valenced in academe, our results reveal negligible penalties (integrative articles are no less likely to be published in lower tier journals) and tangible benefits (higher citation rates) associated with subfield integration. My research with Christine Beckman literally takes this up a level, to explore field-spanning, that is, interdisciplinarity. Using a sample of scientists affiliated with IUCRCs, and Porter's (2007) measure of interdisciplinarity, we find that papers that draw on a larger and broader set of disciplines are more useful to the scientific community, as evidenced by citation rates. Uzzi and colleagues' (2012) recent work corroborates this finding with data from a broader swath of scientists whose work is indexed in the Web of Science (1980-2000). They find that papers with an optimal mix of conventional knowledge and novel knowledge have the highest average citation impact across all fields of science. The optimal mix is 90% conventional well understood knowledge and 10% novelty, where novelty can be completely new ideas or the bringing together of conventional ideas for the first time.

As Murray (2010) makes clear, when distinct institutional logics and epistemologies meet, it can create uneasy tension. Shrum, Genuth, and Chompalov (2007) and Cummings and Kiesler (2005; 2007) document the coordination costs associated with multi-university research teams. They also document conditions under which such costs can be reduced, for example, if collaborators have previously worked together (Cummings and Kiesler 2008). Regarding the potential costs to inter-disciplinary and other kinds of domain-spanning research, it is helpful to think about producer-side effects and audience-side effects, following organizational ecology (Hannan 2010). The challenge of interdisciplinarity for producers (i.e., scientists) is to master multiple domains of knowledge and related techniques. While this is ameliorated by pulling together experts from the different domains and dividing up labor, epistemological differences and different stocks of tacit knowledge still present challenges. Interdisciplinarity is also challenging for audiences – individuals who sit on funding and fellowship panels

(Lamont 2009), journal editors, and peer scientists who review manuscripts and read the literature relevant to their own work. Audiences find it more difficult to understand, place, and evaluate work that spans intellectual domains (Lamont, Mallard, and Guetzkow 2006; Mansilla 2006). In essence, research that doesn't fall cleanly within a single domain may be difficult to produce and also difficult to assess.

RESEARCH CENTERS

University research centers are a relatively new organizational form, one that scarcely existed before 1980. According to Geiger (1990), the number of research centers almost doubled between 1980 and 1985, and as of 2009, elite research universities housed an average of 95 centers each. Biancani and colleagues (2012) suggest that centers have risen to fill the need for universities to scale up in and age of increasing specialization; they bring together researchers with expertise in distinct disciplines to address complex problems that are often situated in the gaps between disciplines.

One function of university-based research centers is to institutionalize such cross-disciplinary collaboration and thereby encourage rewards associated with domain spanning while mitigating possible costs. In *The Organization of Academic Work*, Blau (1994:214) suggests that "universities create the institutional conditions that foster creative research and help advance knowledge" because they house "a large number of scientists and scholars in diverse disciplines," and this is "fertile soil for social contacts and exchanges of ideas that stimulate fresh ideas." Although there are few clear-cut definitions of exactly what constitutes a research center, they are typically extra-departmental, are intended to foster collaboration among researchers (Boardman and Corley 2008), and hold little line management or promotion authority over faculty affiliated with the center (Bozeman and Boardman 2003). Many research centers also occupy a separate physical space from departments. For these reasons, the effectiveness of research centers may be limited.

But research suggests that centers do indeed serve this collaborative function. In their study of 1600 science and engineering faculty, Boardman and Corley (2008) find that center affiliation promotes research collaboration across departmental lines. Using a unique in-depth, longitudinal case study, Biancani and colleagues (2012) investigate whether interdisciplinary research centers at an elite research university influence academic activities. The author(s) find that these centers do not infringe upon regular scholarly activities (writing grants, publishing, serving on PhD committees, and the like) of academic departments but effectively channel the activities within the centers and thereby reshape work patterns at the individual and dyadic level. They do this primarily by promoting the formation of new ties (e.g., two people serve on the same PhD committee, write a grant proposal together, or publish a paper together) across departments. This is true for centers more closely aligned with the high-consensus natural sciences.

Increasingly, science – especially cross-disciplinary science – is conducted by what are called "distributed teams" – those whose members hail from different and often distant locations.

Boh et al. (2007) suggest that the increase in distributed teams in science is partly attributable to a desire to attain necessary and complementary expertise. Some federally-funded research centers are required to include faculty from multiple universities, but even faculty unaffiliated with centers conduct research with faculty at other universities (Boardman and Corley 2008:911). In a recent paper in *Science*, Wuchty et al. (2008) document the rise of multi-university research teams: while they hardly existed in 1975, by 2000 they constitute almost a third of all science and engineering papers. This trend is largely driven by elite institutions, whose faculty members collaborate with faculty at other elite institutions (Jones, Wuchty, and Uzzi 2008). These cross-university papers with at least one elite institution represented also receive more than their expected share of citations, contributing to a concentration in the production of high-impact knowledge.

INDUSTRY TIES

Many research centers cross disciplines and organizations; some even cross sectors (Bozeman and Boardman 2003). For example, since 2003, NSF has helped fund "Industry/University Collaborative Research Centers" (I/UCRC) that conduct research of interest to both the industry and the university. These centers encourage companies to harness R&D investments and foster relevant skill accumulation among graduate students. Such centers allow universities to conduct industrially relevant research and improve their global competitiveness.

Even outside the domain of research centers, university scientists become involved with private, commercial science in multiple ways: patenting, licensing, firm founding, consulting, and sitting on scientific advisory boards. Not only the variety but also the intensity of university-industry relations expanded since the passage of the Bayh-Dole act in 1980,[4] which allowed universities to retain intellectual property rights over ideas developed with the support of federal funding (Owen-Smith 2005b). The commercialization of academic research, and what is often called "academic entrepreneurship," has been nothing short of 'revolutionary' (Etzkowitz, Webster, and Healey 1998). One leader of this trend, Stanford, leapt from zero inventors (faculty named as assignees on patents) in 1970 to 475 inventors by the year 2000 (Colyvas and Powell 2007:233). Another indicator of increasing academic entrepreneurship is the scaffolding and institutional support that universities provide to faculty, typically in the form of Technology Licensing Offices. TLOs now exist at almost every major research university, and their efforts resulted in over 20,000 patents and $1billion in revenue in the year 2000 alone (Owen-Smith 2005a). Academic scientists were also instrumental in helping found bio-tech start-up companies, small science-based companies in the life sciences, especially genetics (Luo, Koput, and Powell 2009; Zucker and Darby 1996; Zucker, Darby, and Armstrong 2002), which have become central players in the world of biotechnology (Powell, Koput, and Smith-Doerr 1996).

[4] Institutional analyses suggest that university-industry relations well established well before the passage of Bayh-Dole; see Popp Berman (2008; 2012) and Croissant and Smith-Doerr (2008).

What prompts university scientists to engage with industry in these ways? Stuart and Ding (2006) find that the commercial orientation of one's colleagues and coauthors prompts transitions, as does working at an institution with a medical school. Zucker and Darby (1996) find that it is typically star scientists – with strong academic reputations and high citation rates, who are drawn into commercial work. In their study of almost 4000 life scientists, Azoulay and colleagues (2007) show patenting events are typically preceded by a flurry of publications, suggesting not a substitution effect but rather a complementary relationship between these two forms of scientific output. They also find that opportunities for patenting are necessary for patenting to occur. The boundary between academe and industry has become quite porous (Colyvas and Powell 2007), and this affects expectations and modes of evaluation for academic scientists (Boardman and Corley 2008; Kleinman and Vallas 2001; Owen-Smith and Powell 2001; Smith-Doerr 2005; Youtie and Corley 2011).

Has commercialization benefitted or harmed faculty? How has it influenced the traditional mission of universities? The scholarship is bifurcated, largely because it is based on heterogeneous case studies rather than average effects (Bozeman and Boardman in press). One camp posits that interactions with industry are beneficial to economic development and technology transfer (Etzkowitz, Webster, and Healey 1998) and that both individual and university level reputations can be enhanced by commercial endeavors (Azoulay, Ding, and Stuart 2007; Colyvas and Powell 2007; Owen-Smith 2003). For example, Owen-Smith (2003:1085) identifies a set of scientific elite universities that maintained their strong scientific reputations even as their patenting activity grew, suggesting that "academic reputations can be parlayed into patenting success without damage." While these scholars acknowledge initial challenges associated with increasing commercialization, such as conflicts of interest, they do not view than as generally detrimental. Another camp suggests that such interactions (and "academic capitalism" more generally) can be harmful, especially to the traditional education mission of universities (Slaughter and Rhoades 2004). The theory-driven nature of academic science might also be threatened, as "industry sponsorship limits the social, organizational, and geographic distance that sponsored ideas travel over time" (Evans 2010). In their comprehensive analysis of numerous research centers, Bozeman and Boardman (in press) find that faculty who engage with industry (largely through research centers) are no less likely to retreat from teaching obligations – even at the least profitable undergraduate level. They conclude that the two camp model is likely too stark: while cases exist to support each perspective, the overall effect is somewhere in between.

GENDER

Academic entrepreneurship, especially in the life sciences, has served as a strategic research site for studies of gender inequality in science, perhaps because 'new terrain' is typically male terrain (Reskin and Roos 1991). Laurel Smith-Doerr (2004a; b) has studied women scientists' success in the life sciences, comparing traditional and hierarchical academic setting with the more flexible and network-oriented industry setting for biotechnology. In contrast to the stereotypically exclusive old-boy networks, she finds that the flexibility of the network form of organization is better for women scientists' careers than the more rigid academic setting, especially regarding promotion. Women are almost eight times more likely to hold a supervisory position in a biotech firm than in more hierarchical academic settings. Smith-Doerr attributes this to the increased transparency, choice regarding collegial relationships, and collective rewards that characterize the network form of organization (Smith-Doerr 2004a:46). Women scientists are less likely to sit on companies' scientific advisory boards and less likely to patent, though their patents are subsequently cited as much, if not more, than men's (Ding, Murray, and Stuart 2006; Whittington and Smith-Doerr 2008). There is organizational variation in these effects: women in the flat, flexible, network-based biotech firms are more likely to become patent-holding inventors than women in traditional academic departments (Whittington and Smith-Doerr 2008).

Even within academic settings, organizational context matters: women tend to be located in less research-oriented settings and in female-dominated fields and subfields (Haberfeld and Shenhav 1990; Reskin 1978; Tolbert 1986). These different locations partly explain women's lower productivity, which has been studied much more extensively than women's patenting. Cole and Zuckerman (1984) referred to gender differences in research productivity as the "productivity puzzle" because efforts to account for the differences were at that time unsuccessful. Since then, scholars such as Keith et al. (2002), Fox (1983; 1985), Ward and Grant (1995) have identified individual and institutional level factors that help explain variation in productivity, and Xie and Shauman (1998) were able to explain almost all variation. Scholars are also beginning to examine institutional and field variation in work-family conflict and policies intended to ameliorate such conflict, and how this affects career advancement and commitment for male and female scientists (Bowman and Feeney 2012; Fox, Fonseca, and Bao 2011). Bowman and Feeney (2012) find that generous family leave policies facilitate scientists' productivity and leadership, particularly for women. Mary Frank Fox (2005; 2011) examines not only marital and parental status, but characteristics of those relationships – such as whether a marriage is a first or subsequent marriage, and the spouse's occupation. She finds that marriage to a fellow scientist eases the work-family balancing act and allows women scientists to be more productive.

However, these structural characteristics could be reflecting unmeasured characteristics like encouragement, expectations, motivation, satisfaction with work, or a commitment to either the breadth or depth of research. Indeed, my research on the extent of specialization reveals its role as a mechanism by which gender differences in science are perpetuated. Regardless of specialty area, I find that partly because women do not specialize to the extent that men do, their productivity suffers (Leahey 2006). This, in turn, limits scholarly visibility (as assessed by citations) and eventually earnings (Leahey 2007b).

THEORIZING the Organization of Science

When distinct realms (e.g., two sub-disciplines, two disciplines, public and private science, ethical/political concerns and scientific ones) meet, what happens? In my own work on subfield integration and interdisciplinarity, I have struggled to bring together two seemingly opposed theoretical perspectives. The first is the literature on categories within organizational ecology, which stipulates that entities (e.g., papers, persons, patents, organizations) that span categories are penalized. Penalties emanate from both producer side and audience side mechanisms: it is more difficult for a producer (e.g., scientist or research team) to master distinct bodies of literature and effectively speak to multiple subfields or fields; and it is also more difficult for the audience to effectively place and evaluate category-spanning work, such as inter-disciplinary work (Hannan 2010). In contrast, the literatures on diversity, networks , and recombinant innovation all suggest that spanning distinct realms can be fruitful: exploring distant realms (March 1991), bridging distinct departments or cliques (Burt 2004b), and pulling ideas from one realm into another via analogical transfer (Fleming 2001; Hargadon 2002; Weitzman 1998) brings about fresh, novel, good ideas. These literatures aren't always applied to science, but they could and should be, as many topics discussed heretofore pertain to boundaries: between ethical/political/scientific influences on topic selection; across fields and subfields; between collaborators' departments, institutions, and geographic locations; and between academe and industry. Which perspective is correct?

It depends. Both theories are advancing by delineating scope conditions, comparing levels of analysis, and assessing the role of moderating conditions. Our finding of no penalty associated with integrative sociology articles led Jim Moody and me to suggest that our discipline (and academe in general) may be more supportive of cross-cutting initiatives than markets for goods and services that are typically studied by organizational ecologists, i.e., the category contrast between sociological subfields may not be stark. So the institutional environment might matter. Christine Beckman and I found penalties to accrue to individual scientists who engaged in IDR, but not to interdisciplinary papers. So level of analysis might matter. Fleming et al. (2007) find that bridging diverse domains fosters the development of new ideas, but not their diffusion; for diffusion, the trust that emanates from cohesive networks is more critical. So the stage in the process of idea development might matter.

Such a focus on moderating conditions is critical; *under what conditions* do some outcomes emerge, rather than others? This is the question we need to be asking (Murray 2010:379). Identifying and elaborating such contingencies permits a fine-tuning of the general findings from network diversity, recombinant innovation, and organizational ecology theories (Podolny, Toby, and Hannan 1996; Ruef and Patterson 2009; Zuckerman, Kim, Ukanwa, and Rittmann 2003). It also helps identify optimal balance points amidst trade-offs and tensions. For example, with collaborators Felps, van Eck, and Waltman, I have found that the extent of specialization promotes productivity, but only up to a certain extent.

In her recent work on the academic-industry divide, Fionna Murray (2010) confronts a similar disjuncture, and does a brilliant job resolving it. She is interested in hybrid zones that lie between two worlds, or institutional logics -- for example, the logic of academe and the logic of industry. She classifies scholarship on hybrid zones into three camps. The <u>hostile worlds</u> perspective is concerned largely with dominance: that one logic is invading and eradicating the other. The <u>blended worlds</u> perspective suggests that previous distinctions are often erased through contact and intermingling. The <u>coexisting worlds</u> approach shows how creative new outcomes can emerge from the exchange of different material and resources, and thus helps explain the stability of, say, disciplines in the face of interdisciplinarity. Murray contends, however, that none of these approaches characterizes the boundary between the logic of science and the logic of commerce, which has been fraught with tension. She deems it critical to investigate both the emergence of hybrids (and the mechanisms that give rise to them) as well as the meaning that hybrids have for the two 'worlds.' Her analysis of a landmark case at the industry-university divide – DuPont's exclusive license to Harvard's patented Oncomouse (a mouse genetically engineered for use in cancer studies) – shows hybrids can be produced via differentiation and not just blending. It also shows that meaning matters: "scientists changed the traditional meaning of patents and incorporated them into hybrid exchanges at the boundary as a means of maintaining (and even strengthening) the distinction between academic and commercial logics. Consequently, while patents changed the boundary between academia and commerce, scientists' boundary work changed patents…and produced hybrids that maintained the two worlds in productive tension" (p.346).

What are the implications of Murray's study for research on the organization of scientific work? First and foremost, we need to better theorize (and when possible, investigate) the role of mechanisms in producing effects. Powell, Packalen, and Whittington (2012) attend to this more than the rest of us in their study of emergence, as does Frickel (2004) in his study of the evolution of genetic toxicology. In my studies of gender differences in productivity and academic earnings (Leahey 2006; 2007), the extent to which scholars specialize was theorized (and found) to be an important mechanism that helps explain why and how women produce and earn less than men. And in concurrent work, Jim Moody and I have purposefully devised two measures of subfield integration, whose juxtaposition and comparison allowed us to uncover the mechanism of 'perceived novelty' to be operating. Sociologists of science interested in mechanisms might find Neil Gross' (2009) pragmatist theory of social mechanisms helpful. Given the timing of their research and their distinct areas of expertise, it is unlikely that Murray was familiar with Gross' theory, but she corroborates much of Gross' advice – for example, culture and subjective meaning are critical to her explanation and help us understand how academic and commercial logics can coexist, even if not peacefully. Murray also undertakes a multi-methodological approach, which Gross (2009:378) views as conducive to the uncovering of mechanisms.[5]

My coauthor Cindy Cain and I have also moved in this direction with our current SciSIP–funded project. We draw upon essays written by authors of Citation Classics (papers that have surpassed a discipline-specific threshold for number of citations) years after the publication of their paper. As reflective and personal accounts of the production, dissemination, and reception of a scientific paper, these essays reveal the rarely observable 'contingent discourse'

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[5] A large portion of Joseph Hermanowicz's (1998; 2003; 2006; 2009) research program has also been devoted to understanding the mechanisms behind scientists' success, and the meaning they attribute to it. Hermanowicz explores the role of ambition, reference groups of peer scientists, ideas about success and failure, and reward systems – most of which vary across institutional types and career stage.

(Gilbert and Mulkay 1984) and subjective meaning surrounding scientific success. As Merton (1948 [1968]:4) notes, publicly available data on scientific products represent few of the "intuitive leaps, false starts, mistakes, loose ends, and happy accidents that actually clutter up the inquiry." Our main goal is to identify the factors that *scientists themselves* invoke as they recount and interpret their success. Many of these factors can only – or best – be identified by the 'cultural producer' himself. Of course, scientists recount the help of collaborators both because they were (likely) helpful and because such acknowledgment is expected/normative. This 'dual nature' of accounts (Griswold 1987) makes their content all the more illuminating: it gives us a better sense of not just scientific success but the culture and context surrounding it. We also invoke co-PI Ragin's (2008) Qualitative Comparative Analysis to demonstrate the various ways in which known factors are elucidated by scientists and to assess which factors work in conjunction, producing something like "recipes" for scientific success. In this way, we heed Gross' (2009) and Murray's (2010) advice for both multi-methodological investigations and a focus on mechanisms and moderators.

MEASURING The Organization of Science: Network Analysis

While many of the studies we discuss above allude to the idea of social networks and their influence (e.g., (Zucker, Darby, and Torero 2002), an increasing number are utilizing formal network analytic techniques. These techniques allow researchers to explicitly measure the connections among scientists and science organizations. Relations, or ties, represent "flows" from one actor to another (Breiger 2004; Wasserman and Faust 1994). For instance, patent citations may represent both a flow of knowledge from one actor to another as well as a flow of deference running in the opposite direction (Podolny and Stuart 1995).

Strong ties and closed, cohesive network structures are typically supportive in nature and facilitate trust. This, in turn, facilitates the diffusion of ideas (Fleming, Mingo, and Chen 2007). In their study of faculty members at a prestigious R1 university, Rawlings and McFarland (2011) found that peer influence is enhanced when ties are strong, when ties are differentiated by status, and when ties share a department or college. This "suggests that organizational initiatives focusing on increasing awareness and promoting collaboration may be effective tools in increasing organizational productivity" (p.1014). The dark side of such close ties is that they can be exclusive. In a study of male and female scientists within STEM fields, Etzkowitz, Kemelgor, and Uzzi (2000) found that female scientists have more intra-departmental ties (and fewer inter-departmental ties) compared to men. Moreover, males form collegial support relations with other males, but fail to reciprocate with female scientists. Instead of formal discrimination, females are excluded from informal support networks and professional events, spend more time maintaining face-to-face relations in harsh social conditions, and are closed off from knowledge of their field in general and failed research projects in particular.

Weak ties (characterized by occasional or indirect contact that isn't emotionally intensive) typically function as bridges between groups and provide access to novel information (Burt 2005; Granovetter 1973). Thus, scientists and scientific organizations who occupy structural holes are thought to accrue information advantages that assist in developing original ideas

(Fleming, Mingo, and Chen 2007). But information is not the same as know-how: the transference of skills and expertise (Kogut and Zander 1992). As Ahuja (2000) documents in his study of chemical patent holders, weak ties that constitute structural holes may be ideal for transferring information, but their lack of trust hinders the transfer of know-how, ultimately restricting the rate of patenting.

Inter-organizational networks are thus critical for understanding social influences on science. Innovations, in the form of patents, occur within a technological niche, an "idea space" that includes a focal patent, all the patents it cites, and all future patents that cite it (Podolny and Stuart 1995; Podolny, Stuart, and Hannan 1996). In a network study of patent citations within the semiconductor industry between 1976 and 1991, Podolny and Stuart (1995) found that high-status organizations are sought out by others and their innovations less likely to become dead ends. In a follow-up study, Podolny, Stuart, and Hannan (1996) found that higher levels of organizational status increase sales growth. However, in both studies, the effects of organizational status were reduced by technological crowding.

Inter-organizational ties seem particularly crucial to success in biotechnology, given its close ties to public universities and the market demand for new medicine (Porter, Whittington, and Powell 2005). In their now classic paper, Powell, Koput, and Smith-Doerr (1996) argue that biotech innovation occurs within networks of inter-organizational collaborations. By utilizing data on different types of collaborations, they find that even when specific projects cease, organizations typically form new partnerships of a different type, facilitating the movement of biotechnology firms from the periphery of the social network towards the center. Central firms are in better position to acquire new knowledge, exploit it, and go public. Collaborations set the "growth clock in motion" and begin a cyclical path where collaborations increase centrality, additional collaborations, and subsequently growth.

Regional effects are apparent, too. To investigate the effects of regional clusters on innovation, Owen-Smith and Powell (2004) compared contractual relations between different types of firms, such as biotechnology firms, public research organizations, and venture capitalist firms during the period 1988-1999. By comparing a network of relations between 114 firms within the Boston area to an expanded network outside of Boston (n=626), they are able to separate effects of collaborating in local networks from inter-regional collaborations. Because public research organizations bridged different types of organizations associated with biotechnology in Boston, research knowledge diffused throughout biotechnology firms, a finding echoed in Porter, Whittington, and Powell (2005). Thus increasing ties to local firms had a positive effect on patenting frequency, a result attributed to geographic propinquity and the institutional character of biotechnology.

CONCLUSION

Clearly, there have been large changes in the structure and process of science in last few decades. Researchers have become highly specialized and are collaborating to a greater extent. Inter-disciplinary, synthetic work is increasingly prized – by funding agencies that support cross-cutting research streams and by universities that are restructuring toward research centers that facilitate cross-disciplinary contact. Ties to industry have expanded dramatically, as faculty members publish and patent with industry researchers, serve on advisory boards, and found companies of their own.

The sociological literature focuses on describing these pervasive changes, and assessing their implications – on the kind of research that is conducted (Moody 2004), on university structure (Biancani et al), on faculty inter-relationships (Rawlings, McFarland, Dahlander, and Wang 2010), on firm and regional networks (Whittington, Owen-Smith, and Powell 2009), and on scientists' careers (Leahey 2006; 2007b; Leahey, Beckman, and Stanko 2012). Less sociological space has been devoted to understanding the cause(s) of these changes. Certainly, the trends I describe affect each other: specialization may be driving collaboration and, perhaps ironically, inter-disciplinarity. But what drives specialization? Sociologists theorize about such root causes, and in this way science serves us well by providing a map (Fleming 2001). But we rarely have the means to address them empirically.

Technology is likely a root cause of many of these changes, one that also allows us to address new and important question empirically. Technology, perhaps in addition to the sheer growth of higher education, has driven many of the changes I discuss in this paper. Without computer technology (the Internet, Skype, document-sharing programs, co-editing software) collaboration (particularly collaboration across institutions and geographic boundaries) would have remained minimal in spite of increased specialization (Hunter and Leahey 2008). Technology is also permitting researchers to access new kinds of data, and to leverage greater amounts of data, to help answer important science policy questions. Productivity does require self-report any longer, culling data from CVs and the Web of Science is standard. The usefulness of innovations can be assessed from the patent citation database. Article citations are captured regularly and by various sources (Web of Science, Google Scholar); as access to full text articles eases, we can construct more inclusive measures of usefulness – for example, by counting the number of times an article is downloaded electronically.

As federal and state budgets tighten, and as policy makers expect returns on scientific investments, the criterion of 'broader impact' becomes just as (if not more) important as 'intellectual merit.' This moves university research away from traditional academic values (knowledge for its own sake), toward a model that is more closely aligned with industry (where commercial usefulness and applicability of knowledge is valued). Universities are asymmetrically converging toward industry values and standards (Kleinman and Vallas 2001). University research centers have increased in number and size in the last few decades, and faculty members no longer shun the thought of having rights over their intellectual property (Owen-Smith and Powell 2001).

While assessments of impact are rare, federal agencies like NSF have clearly helped drive this new mode of science. Through initiatives like CREATIV, INCPIRE, IUCRCs, IGERT, and the like, they are encouraging collaboration within academe and between academe and industry, fostering inter-disciplinary research, and training graduate students in ways that facilitate entrance into industry careers. NSF is helping academic researchers stay relevant, valued, and needed beyond the classroom.

Federal funding agencies, while keeping a pace with (if not foreseeing) new realities, are wisely remaining true to their roots. Science – the core of NSF's missions – is critical to research and innovation. Without science, research would likely proceed in a less efficient and relatively ad-hoc, way, incrementally trying out new possibilities without the guidance that scientific theories and explanations provides as a map (Fleming 2001). In this way, not only researchers, research centers, and universities, and even federal agencies like NSF are hybrid organizations spanning two traditionally distinct realms: traditional academic science and commercial research. By promoting transformative research within the academy, NSF is providing guidance to academia, and slowly but firmly helping academe adjust to this new reality. Like universities and researchers themselves, NSF may be experiencing some tension over these distinct but complementary goals, but it appears to be the kind of productive tension that Murray (2010) describes.

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