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How to Share "A Really Good Secret": Managing Sharing/Secrecy Tensions Around Scientific Knowledge Disclosure

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The diffusion of scientific knowledge is critical for innovation, entrepreneurship, and economic growth. Yet scientists face a fundamental dilemma when it comes to sharing such knowledge: sharing can simultaneously advance and challenge both academic and commercial interests. Although several studies explore the different reasons that scientists may or may not share, along with their overall propensity to do so, we have much less insight into how researchers who confront sharing/secrecy tensions attempt to manage them. In turn, our understanding of the ways in which scientists enable cumulative innovation through sharing, even as they attend to their private interests, remains limited. Based on qualitative analysis of 46 interviews and 58 oral histories with researchers in biotechnology and digital audio, I identify 4 tactics that researchers use to manage sharing/secrecy tensions—leveraging trust, strategic withholding, delaying, and patenting—and I analyze how the use of these tactics is tied to particular sharing practices, organizational environments (e.g., universities versus firms), and scientific fields. I then theorize how these tactics address different dimensions of sharing/secrecy tensions, working together as part of an integrated repertoire. Finally, I tie my findings to broader considerations around sharing, including managerial and policy initiatives aimed at promoting cumulative innovation.

Keywords: industrial science; academic science; disclosure and sharing; publishing and patenting; biotechnology; digital audio
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Introduction

Since its initial development in the 1970s, the recombinant DNA technique (rDNA) has been used in millions of scientific experiments conducted by tens of thousands of scientists who have employed it in the creation of hundreds of new products. The tremendous influence of a technique such as rDNA depends on a wide range of researchers learning how to perform it. Yet sharing such "know how" presents capable researchers with a dilemma: On one hand, there are a variety of benefits to sharing scientific knowledge, including boosting one's reputation or prestige (Merton 1973), attracting collaborators (Hicks 1995), and recruiting employees (Stern 2004). On the other hand, sharing erodes a scientist's competitive advantage and can enable others to "scoop" the scientist for academic credit (Campbell et al. 2002) or commercial success (Dasgupta and David 1994).

Although a growing literature has enumerated these different pressures, this literature has focused primarily on *whether* and *why* researchers share. It also has remained mired in disagreement, with different studies reaching opposing answers to these questions. By contrast, we have little insight into *how* researchers who confront sharing/secrecy tensions strive to manage them across different sharing practices, organizational contexts, and scientific fields. Understanding "how" is critical because it contextualizes competing results in the literature and increases our understanding of the ways in which scientists facilitate cumulative innovation through sharing even as they protect their private interests. In a society dependent on cumulative scientific knowledge to fuel innovation and economic growth (e.g., Cockburn and Henderson 1998, Furman and Stern 2011, Powell and Snellman 2004), this deeper understanding of the processes underlying sharing is essential.

My investigation focuses on four key techniques in biotechnology and digital audio, which together garnered two Nobel Prizes and transformed fields ranging from drug discovery to forensics to multimedia and Internet music. Based upon qualitative analyses of 46 interviews and 58 oral histories, I analyze how researchers facing sharing/secrecy pressures employ four primary mitigation tactics: leveraging trust, strategic withholding, delaying, and patenting. I also explore how these tactics are tied to particular sharing practices, university versus firm environments, and scientific fields.

My findings contribute to the literature on scientific knowledge sharing in multiple ways. First, I look beyond patenting to consider the full range of tactics that researchers employ to manage sharing/secrecy tensions. I also theorize how and why these tactics work by focusing on different dimensions of sharing and by working in tandem with one another. Finally, I consider how my findings inform managerial and policy initiatives aimed at scientific sharing and cumulative innovation.

Sharing/Secrecy Tensions in Communicating Scientific Knowledge

In a simplistic view, university-based scientists pursue curiosity-driven research and share their knowledge, whereas firm-based scientists pursue commercially oriented research and do not share. Alas, reality is more complex. Prior studies indicate that scientists in both university and firm environments both share and do not share for a variety of reasons.

Robert Merton (1942) conducted some of the earliest investigations of scientific sharing, arguing that scientists strive for prestige among their fellow scientists and that they build this prestige by openly sharing with one another. Merton, in fact, claimed that scientific sharing is both a norm and an institutional imperative—akin to what later scholars have labeled an "institutional logic" (Friedland and Alford 1991, Thornton et al. 2012). As Merton wrote, "Secrecy is the antithesis of this norm; full and open communication is its enactment" (Merton 1973, p. 274).

Although Merton associated sharing with academic research, more recent work finds that commercially oriented researchers, too, engage in considerable sharing. For example, Powell et al. (1996, p. 141) find that two commercial firms, Genentech and Chiron, are among the most visible organizations in molecular biology and genetics, as measured by papers published and citations to those papers. Cockburn and Henderson (1998) examine 20 large pharmaceutical firms and find that they collectively published 68,186 papers between 1980 and 1994. Across a variety of industries, Hicks (1995) finds that leading firms produce more journal publications than some universities and that their publications are comparable in quality, as measured by citations.

A variety of motivations may underlie such active sharing on the part of firms. Powell and Sandholtz (2012) appeal to a Mertonian explanation, noting that many biotech firm founders strove to reproduce academic rewards, including the premium placed on sharing through publications and presentations. Hicks (1995), by contrast, attributes sharing to a more instrumental desire to attract collaborators. Stern (2004) and Fini and Lacetera (2010) find that firms publish to attract and incentivize their employees. Bar-Gill and Parchomovsky (2003) argue that sharing scientific knowledge can encourage follow-on inventions by other groups, which in turn benefit the focal organization by building a market for its products. Parchomovsky (2000) also notes that firms can publish to establish prior art that prevents competitors from patenting. Finally, Murray and O'Mahony (2007) note that investors look favorably on publications, again signaling a commercial justification for researchers to share through publications (see also Pénin 2007). In many of these cases, prestige still serves as the underlying mechanism. For example, decomposing Murray and O'Mahony's (2007) argument, publications build prestige that encourages investment; in Hicks's (1995) work, publications build prestige that entices collaborators. The critical difference from Merton's conceptualization, however, is that prestige is merely a tool toward a financial end-goal rather than the end goal in itself.

This work highlights scientists' many motivations to share, other work emphasizes the risks, barriers, and disincentives associated with scientific sharing. For example, Dasgupta and David (1994) argue that scientists who strive for financial rewards will keep research secret to prevent other scientists from capitalizing on it (Dasgupta and David 1994, Murray and O'Mahony 2007, Sauermann and Stephan 2013, Stephan 2012). A number of studies reinforce the contention that commercial interests can inhibit scientific sharing. For example, Kleinman (2003), Krimsky (2003), and Popp Berman (2011) each offer detailed descriptions of how commercial incentives can serve as a disincentive for sharing since sharing could threaten the potential economic returns that a scientist could appropriate from his or her research. A series of surveys by Blumenthal and colleagues (1996, 1997) find that engagement in commercial activities is associated with publication delays, lack of engagement in publishing, and refusals to share research results. Campbell and colleagues (2000) also find that academic researchers who engage in patenting, a proxy for commercial interests, are themselves more likely to have data requests refused by others. In other words, commercial engagement has both first- and second-order dampening effects on sharing by limiting sharing directly and by limiting sharing with those who might themselves limit sharing. Finally, Cook-Deegan and McCormack (2001) suggest that patenting researchers sometimes fail to publish altogether. In each of these studies, financial interests undermine sharing since sharing could enable others to release competitive products and thus erode profits.

Critically, many of these studies on the relationship between commercial interests and sharing focus on university-based researchers. Thus, commercial interests—both as an incentive and barrier to sharing—may not be limited to firm-based scientists (e.g., Blumenthal et al. 1996, 1997; Campbell et al. 2000; Kleinman 2003; Krimsky 2003; Popp Berman 2011). Indeed, the tremendous growth in university patenting, licensing, and startup activity over the past three decades suggests that commercial interests permeate the vast majority of research universities, at least to some extent (AUTM 2014, Kenney 1988, Owen-Smith 2003). In turn, commercially fueled tensions between sharing and secrecy may confront researchers in both universities and firms.

Finally, other scholars focus on academic, rather than commercial, barriers to sharing. For example, Campbell and colleagues (2002) present survey evidence showing that the primary reasons for refusing to share are the effort required; the desire to protect a graduate student, postdoc, or junior faculty member's ability to publish; and the desire to protect one's own ability to publish.

In other words, publication strategies and busy schedules, not commercial interests, are the primary drivers behind refusals to share. Walsh and colleagues (Hong and Walsh 2009, Walsh and Hong 2003, Walsh et al. 2007) also study the reasons why researchers refuse to share, finding that academic competition, not commercial interests, is the primary driver. Shapin (2010), in fact, questions whether academic research was ever "pure," instead pointing to numerous sharing failures driven by intense academic competition.

This work highlights two main theoretical motivations for sharing and not sharing. First, some studies link sharing to what might be termed "academic rewards"—a desire to build the reputation, prestige, and status of a researcher or a researcher's organization, and an internalized understanding that sharing is an underlying norm of science. Viewed through this lens, the tension over sharing resides in the fact that sharing is necessary to obtain status yet also requires time and effort that detract from research activities and enables others to "scoop" one's research and capture these rewards for themselves.

Other studies appeal to a second theoretical motivation, linking sharing to what might be termed "commercial interests," or the web of activities that directly or indirectly influence the financial gain that a researcher or her organization might realize. Viewed through this lens, the tension over sharing stems from the fact that sharing simultaneously boosts commercial interests by facilitating recruiting and collaborations, serving as an IP barrier, attracting investors, and so on, and threatens commercial interests by revealing knowledge that competitors can use for their own financial gain. Table 1 summarizes these different perspectives on sharing. As noted, both academic and commercial motivations may operate simultaneously, regardless of a given researcher's employment in a university versus a firm. The net effect, therefore, is that researchers in both university *and* firm environments can confront sharing tensions around both academic *and* commercial interests. In turn, the literature on whether and why scientists share remains conflicted since different studies appeal to different motivations, and typically explore only one organization type and one form of sharing, such as publishing.

A striking feature of this literature, and one that may be associated with the conflicting results, is that it considers sharing itself to be a dichotomous decision; because the central question is "whether" a researcher shares, the "answer" takes the form of "yes" or "no." In some contexts, of course, such a perspective might be appropriate—namely, when the focus of sharing is well defined, discrete/indivisible, and insensitive to the manner in which it is shared. Consider, for example, the televisions, computers, drugs, and other common items at the center of many diffusion studies (Geroski 2000, Rogers 2010). Practically speaking, one receives such an item or not, and whether it is procured through Amazon or at a local retailer has little effect on its form, function, or use. As scholars have long acknowledged, however, "knowledge" is a different kind of good (Arrow 1962), which is multifaceted (e.g., Polanyi 1967), shaped by context and practice (e.g., Brown and Duguid 2001, Cook and Brown 1999), and potentially shared in a variety of different ways (e.g., Agrawal and Henderson 2002, Cohen et al. 2002). Asking whether or not a scientist shares knowledge, therefore, can be problematic since it leaves little room for exploration of "what" is shared, when, with

Table 1 Summary of Academic and Commercial Incentives to Share and Not Share

	Academic*	Commercial*
Share	—Sharing is the means by which others learn about one's work, thus building one's prestige/status/reputation (Merton 1942, 1973)	—Sharing enables a commercial research effort to: • Attract collaborators (Hicks 1995) • Recruit and retain employes (Stern 2004, Fini and Lacetera 2010) • Build a market (Bar-Gill and Parchomovsky 2003) • Establish a prior art barrier for patenting (Parchomovsky 2000) • Attract investors (Murray and O'Mahony 2007)
Don't share	—Sharing requires time and effort, which detracts from research activities that could build prestige/status/reputation (Campbell et al. 2002, Hong and Walsh 2009, Walsh et al. 2007) —Sharing could enable others to "scoop" (Campbell et al. 2002, Hong and Walsh 2009, Walsh et al. 2007)	—Sharing could enable others to exploit knowledge for their own financial benefit, and potentially at the economic cost of the sharer (Dasgupta and David 1994, Murray and O'Mahony 2007, Sauermann and Stephan 2013)

*"Academic" and "commercial" here refer not to the organization type (e.g., university or firm) but rather to the underlying motivations.

whom, and in what ways—compressing sharing itself into a unidimensional construct and leading, potentially, to the very confusion that seems to characterize the sharing literature.

In turn, a more fruitful approach to understanding scientific sharing might move beyond asking "whether" scientists share to instead explore "how" scientists manage sharing dilemmas. Unfortunately, the literature offers little insight into "how," focusing almost exclusively on patents as the solution (Heller and Eisenberg 1998, Scotchmer 1991, Shapiro 2001) and still disagreeing on whether patents enable sharing (Azoulay et al. 2009, Stephan et al. 2007, Walsh et al. 2003) or dampen it (Heller and Eisenberg 1998, Murray and Stern 2007). In this study, therefore, I take a deep dive into how scientists with knowledge of key techniques manage the tension between sharing and secrecy, and how sharing practices, organizational affiliations, and scientific fields may influence their approaches.

Data and Methods

Research Design

The exploratory nature of this research question required an in-depth qualitative approach. Therefore, I conducted an inductive, multiple-case study (Eisenhardt 1989) around how researchers shared knowledge around specific scientific techniques, what sharing/secrecy tensions arose, and how they managed these tensions. I focused on knowledge pertaining to how to perform the techniques, not just sharing about their general existence (Garud 1997). Such "know how" is especially valuable because it enables other researchers to replicate and build upon a scientist's work (e.g., Zucker et al. 1998), and thus to capture both present and future value connected with it. In turn, sharing tensions around "know how" may be heightened because of this value.

Consistent with the inductive case-study approach, I focused on four cases of special interest rather than building a large sample (Eisenhardt 1989, Yin 2008). All of my cases are science-based innovations that have had a transformative effect on their respective fields, facilitating enormous academic and commercial follow-on work. I followed Eisenhardt (1989) in selecting individual cases that filled different categories and types. Specifically, some previous studies, as discussed, suggest that sharing tensions may differ for techniques stemming from universities versus commercial firms. Thus, I considered techniques with origins in each type of organization. Moreover, the consideration of techniques from different technical/scientific fields aids in the identification of processes that may be obscured with too narrow a focus (Eisenhardt and Graebner 2007). For reasons both pragmatic and conceptual, I selected techniques from biotechnology and digital audio. On a pragmatic level, I hold a degree in computer music and have done lab work in biology. These experiences facilitated detailed interviews. From a conceptual perspective, these fields vary along a number of dimensions detailed in Table 2. These differences enhanced my ability to identify sharing tensions and mitigation tactics that are not specific to an idiosyncratic field (Eisenhardt and Graebner 2007).

With these guidelines in mind, I conducted preliminary interviews with three experts each in biotechnology and in digital audio to identify specific techniques that might be similar within technical areas (e.g., within biotechnology or digital audio) and divergent in organizational origin (e.g., universities versus firms). On the basis of these experts' recommendations, I selected four focal techniques that populated a two-by-two matrix of field and organizational origin (see Table 2).

In biotechnology, I focused on recombinant DNA (rDNA) and polymerase chain reaction (PCR). Stanley Cohen at Stanford University and Herb Boyer at the University of California at San Francisco invented rDNA. The technique permits the insertion of a foreign segment of DNA into a host organism and is widely considered to be one of the foundational enabling technologies for the entire biotechnology industry. Its invention led to the Nobel Prize in Chemistry in 1980. Kary Mullis invented PCR while he worked at the biotechnology firm Cetus. The technique permits rapid amplification of a small amount of DNA to produce the mass quantities necessary for diagnoses and experimentation. It has become a basic tool among biochemists, and it led to the Nobel Prize in Chemistry in 1993 (Hughes 2001a, Nelson 2016, Rabinow 1996).

In digital audio, I focused on two inventions that enable music synthesis and compression. Julius Smith of Stanford University invented waveguide physical modeling synthesis (PM), which uses mathematical models of acoustic phenomena to synthesize highly realistic sounds. The technique generates the sound in computer sound cards, video game consoles, and high-quality electronic musical instruments. Karlheinz Brandenburg and James Johnston of AT&T invented the perceptual audio coding (PAC) technique that underlies MP3s and other audio file standards. The technique exploits psychoacoustic phenomena to compress sound files, permitting rapid transmission and high-density storage (Nelson 2015).

My level of analysis was the individual. I drew on interviews and oral histories with 104 individuals related to the technologies at hand. Eisenhardt and Graebner (2007, p. 28) suggest that interview data should employ "numerous and highly knowledgeable informants who view the focal phenomena from diverse perspectives" to mitigate bias. Therefore, I drew upon interviews and oral histories with the inventors, other individuals in their labs, researchers who shared know-how at various points in time, and personnel in related positions such as technology licensing who had deep knowledge of a technique and of the influence of different sharing/secrecy considerations.

Table 2 Techniques Investigated and Field Differences

	Field	
	Biotechnology	Digital audio
Dimensions of contrast		
Underlying disciplines	Biology, chemistry, biochemistry	Psychoacoustics, computer science, electrical engineering
Relative size of field	Large	Small
Primary research publication outlets	Peer-reviewed journals	Conference proceedings, peer-reviewed journals
Role of patents	Very significant	Less significant
Organization origin of specific cases		
University	Recombinant DNA (rDNA)	Physical modeling (PM)
Firm	Polymerase chain reaction (PCR)	Perceptual audio coding (PAC)

Table 3 details the composition of my interviewees and my use of oral histories from external sources. The online appendix (available as supplemental material at http://dx.doi.org/10.1287/orsc.2015.1040) elaborates on this table by listing each interviewee and oral history participant associated with each case. Specifically, I began by drawing upon oral histories conducted by historians associated with four organizations: the Bancroft Oral History Project at the University of California at Berkeley, the Smithsonian Institution, the Institute of Electrical and Electronics Engineers (IEEE), and the National Association of Music Merchants (NAMM). Although the format of these histories varied, each oral history offers a narrative of events from the perspective of a key figure, as prompted by an interviewer.

The use of these oral histories served four purposes. First, it allowed me to draw upon a wider range of informants than I could reasonably interview myself. Second, since I did not construct or influence the oral history questions, it permitted me to sidestep the concern that I may have influenced informants' responses. Third, it allowed me to address concerns about retrospective bias since the oral histories date back to 1982, shortly after invention of the techniques. Finally, published oral histories permit the public identification of particular individuals and their affiliations. Together, the oral history transcripts fill more than 4,000 pages, though only a portion of each history directly addresses the sharing/secrecy tensions at the heart of my investigation.

The oral histories tended to emphasize particular individuals and organizations. For example, Genentech appears frequently in the rDNA oral histories because it was one of the first firms to attempt commercialization of rDNA. Similarly, the oral histories focus on well-known individuals in the biotechnology and audio communities. After I went through the oral histories, therefore, I identified types of individuals that appeared underrepresented, such as graduate students and lab technicians. I also had a special interest in interviewing the inventors in cases not covered by the oral histories. As my initial interviews proceeded, my list of potential interviewees grew through a snowball process. I continued until I perceived that I was no longer gaining new information or insights, conducting 46 interviews in total.

In addition to interviews and oral histories, I drew upon extensive archival data surrounding each invention. These materials included correspondence, minutes of meetings, articles, and records pertaining to licensees and potential licensees. I obtained these data from the Stanford University Archives, the Stanford Office of Technology Licensing, and NAMM. In total, I collected approximately 600 pages of archival materials. These archival materials

Table 3 Interview Composition and Sources, and Archival Materials

	rDNA	PCR	PM	PAC
Interviews conducted by author*	10	16	18	12
Oral history sources and numbers	Bancroft (28)	Bancroft (3) Smithsonian (14)	National Association of Music Merchants (NAMM) (6)	Institute of Electrical and Electronics Engineers (IEEE) (8)
Archival materials	Stanford University archives	(none)	Stanford Office of Technology Licensing; Stanford University archives	NAMM

*As detailed in the online appendix, some interviewees discussed multiple techniques and I count them in each relevant column. I interviewed a total of 46 separate individuals.

aided in assembling case histories around each technique, in identifying potential interviewees, and in pointing toward specific considerations that may have affected sharing considerations. Although I do not have archival data around the PCR technique, I did consult third-party resources around this case (e.g., Rabinow 1996) to enhance my understanding of the historic context and considerations.

Data Analysis

Using qualitative analysis techniques outlined by Strauss and Corbin (1998), I coded all interviews and oral histories, and I engaged in iterations between my data and my emerging framework. My unit of analysis was the interaction between a knowledgeable researcher and a researcher or researchers with whom this person might share. My specific interest lay in identifying reasons for sharing or not, potential sharing tensions, and ways in which researchers managed such tensions across different sharing practices. Thus, I began by flagging each part of an interview or oral history that pertained to sharing/secrecy tensions. I then coded these instances for the specific sharing practice used, such as hands-on training or texts that provided step-by-step instructions. The following passage from an oral history with Herb Heyneker, a knowledgeable Genentech researcher, provides an example of sharing:

> I received an invitation from Charles Weissmann to visit his lab in Zurich with the goal to help to teach them some of the recombinant DNA technologies. Of course I was very flattered, and I accepted the invitation, and for almost two weeks I was in his lab. We started a project, and I have forgotten even what it was, but mainly it was to teach them techniques—the way we did reactions, the way we analyzed the results.... The work went well. I think the transfer of technology was successful. (Heyneker 2004)

I initially coded this passage with the description, "working together in the same lab." I then aggregated similar sharing practices under the broad umbrella of "hands-on training" since the key distinguishing aspect of this approach concerned the side-by-side (e.g., physically colocated) reproduction of the technique. Ultimately, I identified five primary sharing practices: *hands-on training*, or a "teacher" and "learner" physically working alongside one another; *interactive conversations* that permitted detailed questions-and-answers; *formal presentations*, as at a conference; *publications*, including articles, books, and patents; and *tools and products*, which included "kits" and automated equipment in the biotechnology cases and "codecs" or prepackaged computer code in the audio cases. There was variation within these practices. For example, different scientific publications revealed different aspects of knowledge, and different researchers might interpret even the same publication differently. Nonetheless, each of the five labels captures a practice that contains greater coherence within the category than across it (Strauss and Corbin 1998). I also found that these five sharing practices aligned with those identified in prior survey research (Agrawal and Henderson 2002, Cohen et al. 2002), bolstering my confidence in their identification.

Descriptions of sharing/secrecy tensions and how researchers managed them lie at the heart of my analysis. Heyneker, the Genentech researcher, offered an example when describing a formal presentation:

> We presented the data without showing the DNA sequence, because we kept that for ourselves; it was too proprietary. We gave this picture of what the molecule looked like, that there was this serine protease and kringle part to it. So we could tell a nice story. Also, we let the audience know that the protein sequence and the DNA sequence were perfectly in sync with each other. (Heyneker 2004)

Heyneker goes on to describe Genentech's commercial interests in the knowledge that he could have shared and how the presence of a competitor from Abbott Labs in the audience shaped his decision. I initially coded such passages for the specific example described, such as "showing some data but not other data" in Heyneker's example. Once I had coded each example, I then reviewed these specific codes and assigned them to more general codes—such as "withholding some data" in Heyneker's example. This process led me to identify four primary tactics that researchers employed to manage sharing/secrecy tensions: *leveraging trust*, or relying upon a social relationship to protect private interests; *strategic withholding*, or withholding some information; *delaying*, or waiting until a later time to share; and *patenting*, or employing a legal means of intellectual property protection.

Next, I examined how these tactics aligned with different sharing practices, organizational contexts, and the two scientific fields—assessing, for example, if *strategic withholding* seemed more prevalent in the biotechnology or digital audio episodes. Of course, neither my sample nor my analysis process permit a reliable quantification of differences. My interest, instead, lay in leveraging these apparent patterns to inform my understanding of how each tactic works and of the boundary conditions surrounding it.

Finally, I examined which tactics were mentioned together in the same episode. Where tactics were mentioned together, I worked to discern how they seemed to influence one another by assessing, for example, whether particular tactics served as substitutes or complements for one another. I also noted the sequence in such cases; e.g., if one tactic clearly proceeded/followed another.

Results

Scientists with knowledge of how to perform each of the techniques faced tensions between sharing and secrecy. Table 4 offers several excerpts from the interviews and oral histories that illustrate these tensions and that underscore

Table 4 Examples of Sharing/Secrecy Tensions Associated with Each Technique

Technique	Organizational affiliation of interviewee*	Illustrative quotes
rDNA	University	1. "[Stan Cohen, the coinventor] didn't want to talk about it until it was in print or published…[But] this was an important meeting, and this was the sort of place where you wanted to talk about things like that; you wanted to get the feedback. …I wanted to talk about it." —Herb Boyer, coinventor (Boyer 2001)
	University	2. "If an academic scientist were to share information regarding the optimal pH, the source of material, the temperature, the medium in which that test was done, then a half dozen others can do the same thing, and hearing about it might even publish it first. It is a real risk" —Arthur Kornberg, former head of Stanford's Department of Biochemistry (Kornberg 1998).
PCR	Firm	3. "We were under pressure…we needed to have the patent position covered and a publication out on it, so that we would be covered in that respect for putting out a product. …We were under the gun to get a product out the door." —Stephen Scharf, research associate at Cetus (Smithsonian 1993)
	Firm	4. "[The negotiations with a potential partner] influenced the publication decisions…they might wish to prevent or delay the publication of the method. Secondly, because many scientists were beginning to apply it widely, there would be pressure, ultimately, to publish the applications of it or to commercialize them so the method might become public. And then, finally, I was concerned that Kary [Mullis, the inventor] himself might discuss the method with people outside the company who might publish it before him." —Tom White, senior director of research at Cetus (Smithsonian 1993)
PM	University	5. "Meeting participants expressed concerns about drift through the academic community. …It was decided that it was inevitable that [PM] will be widely disseminated. [But], we will not give [other] academics the sounds." —Minutes from a 1994 meeting of university-based PM researchers (Stanford University archives)
	University	6. "We weren't supposed to be giving away the know-how to do that stuff, but whatever. It's a university, right?" —University-based research associate (personal interview #26 2004)
	University	7. "People would basically go into secrecy mode. You're supposed to be able to talk about findings in the lab. But, what if you talk about them in a seminar and someone from outside attends? You could argue that that's public disclosure and lose the patent." —Professor of music (personal interview #23 2004).
PAC	Firm	8. "My firm moved from not caring at all…and saying, 'publish it all,' to being more closed, to then opening up again under the fear that 'We're going to look like we're behind [competitors in technology development]. We've got to publish this stuff.'" —Engineer at a major consumer technology firm (personal interview #42 2007)
	Firm	9. "I never patented those [aspects of PAC]. …I just published it, putting it in the public domain. Later I saw my chief patent attorney, Al Hirsch, and said, 'Al, did I make a mistake? Everybody is manufacturing this.'" —Manfred Schroeder, engineer at Bell Labs (Schroeder 1994)
	Firm	10. "People are real worried about someone leaking information, about our competitors finding out what we're doing or how we're doing it." —Audio engineer at a major consumer technology firm (personal interview #45 2007)

*Organizational affiliation tied to the time period referenced in the quote. Many interviewees moved back and forth between university and firm appointments.

various reasons for sharing and secrecy. As the table makes clear, scientists in both universities and firms faced tensions tied to both academic and commercial motivations. For example, the concern expressed by Tom White in the second PCR quote (#4) is with who would publish the technique first, even though Cetus was a commercial enterprise. Conversely, the salient risk in the third PM quote (#7) concerns losing patent protection—a commercial risk—even though the interviewee is a university professor reflecting on sharing in an academic lab. Indeed, I found that a respondent's affiliation with a university versus a firm offered little guidance as to whether he or she would reflect on tensions tied to academic or commercial interests—or both.

In light of these tensions, the central question that I address is *how* do scientists manage them? I found that scientists relied primarily on four tactics. In the sections that follow, I elaborate on each of these four tactics. I also consider the interaction between these tactics and different sharing practices, and whether university versus firm—and audio versus biotechnology—researchers differed in their discussion of them. In the final section of the findings, I theorize how these tactics address different aspects of the sharing/secrecy dilemma, and I explore how they are used in combination with one another as part of an overall strategy to share while protecting private interests.

Leveraging Trust

A primary means of managing sharing/secrecy tensions was to leverage the trust that a potential sharer had in a potential recipient. For example, Jeff, a firm-based audio researcher, explained his sharing of knowledge about PAC by noting, "There's a trust that builds. I suppose someone could just take it [e.g., the knowledge]. But in the end, you just trust that they won't" (personal interview #43 2007).

Conversely, interviewees raised concerns about being "scooped" commercially or in terms of scientific priority if they shared with someone whom they did not trust, as the exchange below indicates:

> Interviewer: Thinking back to the early years of PM, imagine that someone whom you didn't know wanted to sit with you and learn the technique and she approached you. How would you respond?
>
> Steve: Well, first I'd want to know why she approached me! [Laughter] The thing is, I guess it's an issue both of knowing and of trust. We knew that PM was valuable. We knew that academics and guys in industry wanted to get their hands on it. And we were happy to see that happen. But we're also looking out for our own interests. You want to share with people that you know and that you trust. Otherwise, they go off and write a paper or they try to patent something or whatever and you've lost control. (Personal interview #22 2004)

Steve thus suggests the following calculus: (1) People with whom he shares value their personal relationship with him; (2) a violation of trust would harm this relationship; and (3) potential violators place more value in the relationship than they do in the personal gain that would come from exploiting knowledge at Steve's expense. Thus, scientists might be expected to share more when they have a deep personal relationship with someone.

Of course, previous work also has emphasized trust as critical to scientific sharing (Bouty 2000, Janowicz-Panjaitan and Noorderhaven 2009, Kachra and White 2008, Levin and Cross 2004, Liebeskind and Oliver 1998). My findings move beyond identifying trust as a general facilitator, however, by linking it specifically to hands-on training and informal conversations. Precisely because trust was tied to personal relationships, it works best with sharing processes that also are personal. By contrast, trust was less effective at managing tensions tied to formal presentations and to publications, since those sharing practices typically reached people who lacked a personal relationship. As one university-based PM researcher explained, "I tend to get mauled at conferences. If I know someone, or if we share a close connection with a third person, I'll of course talk to them. But, it's hard to connect and share with random people with no context" (personal interview #23 2008). Another university-based researcher noted, "I know the people who I know. I sort of know the people who I talk with at meetings. And I have no idea who reads my papers" (personal interview #1 2008). Similarly, a firm-based PAC researcher described the tension around early attempts to diffuse the technology through publications:

> I thought of this like a secret, but a really, really good secret. So, I wanted to share it with people. But, there's a difference between sharing it with your friend at the lunch table and standing up on your chair and announcing it to the whole cafeteria. I felt like fully disclosing it in every detail in a publication was more akin to standing on a chair, and I was hesitant to do that right away. (Personal interview #42 2007)

As these quotes indicate, interviewees clearly delineated between different sharing practices when describing trust as a way to mitigate sharing tensions. Thus, leveraging trust played an important role around hands-on training and interactive conversations, but it played little role in managing tensions associated with sharing practices that reached beyond personal networks.

All scientists in my study built and leveraged personal networks, and these networks crisscrossed university and firm boundaries. As one firm-based digital audio researcher, David, explained:

> You have to remember that we're all trained in universities [referring to people who practice in the digital audio field]. Some of us then go on to firms, and some stay in academia ... but we all have that common heritage. So, when I came up with [an adaptation of the PAC technique], it was natural to talk with my former classmates and mentors and others. (Personal interview #41 2006)

In considering whether university and firm researchers differ in their leveraging of trust to manage tensions, the salient question thus becomes whether one organization type or another facilitates more or different network building. Although one might expect universities to be more open, a common reason for sharing by firm-based scientists was to build their personal networks beyond the firm. Moreover, firm managers encouraged this practice. As Ron Cape, who cofounded the biotech firm Cetus, explained:

> One of the things we used to mention in recruiting [is] that we had ... [people] who left their academic positions to take full-time jobs with a biotech company, and then two or three or five years later, went back to an equally prestigious job in some academic institution. They, in other words, were able to keep their reputation growing and keep contributing and growing as people in the biotech companies .... I think all of the companies were aware of the fact that one of the appeals of being in a biotech company ... is your freedom to disseminate your ideas and to exchange ideas at scientific meetings with other scientists in other places. (Cape 2006)

Cape, in other words, highlights how Cetus encouraged scientists to attend to their reputations and to build exchange networks with scientists in other organizations. Given these dynamics within firms, I found little evidence of university-firm differences in the leveraging of trust to facilitate sharing.

A second factor that could shape the use of trust is the scientific field and, particularly, the field's size. As network theorists point out, smaller industries may be more likely to spawn "small world networks," in which participants are linked to one another by a small number of steps (Uzzi and Spiro 2005). Unlike their biotechnology counterparts, audio industry interviewees offered many references to the small size of their field. Accordingly, audio interviewees also indicated that a given individual's personal relationships might traverse a greater portion of the audio field. As music-synthesis industry observer Craig Anderton explained:

> This is not an industry that's big . . . so you're only left with people who actually care about the music and about making cool tools. You walk along a NAMM show floor [the major trade show] and competitors hang out with each other. These guys have products from other companies in their booths. They'll all hang out afterwards. (Anderton 2005)

Similarly, an early PAC researcher remarked, "We all knew each other and we all shared everything . . . [In] the electronic music world, everyone kind of knows each other" (personal interview #37 2005). These quotes thus suggest that leveraging trust may play a more prominent role in smaller industries.

Strategic Withholding

A second tactic that scientists used to manage sharing/secrecy tensions was to share some, but not all, of their related knowledge—a tactic that I label "strategic withholding." For example, one university-based researcher, Paul, recalled how a wide range of factors could impact one's ability to perform the PM technique and how he did not share all of them:

> Paul: Early on, I wrote up a guide as to exactly how this worked. But, you're always making decisions with such a guide . . . . Do I say which processor was in my PC? Which version of UNIX? My sound card configuration? My monitor speakers? . . . All of these things—and a lot more—would in theory affect the [ability to do it]. And I could have tried to write up all of them. And then I wouldn't actually be pushing research and using the technique, I'd just be describing it . . . [So], you tend to find a balance.
>
> Interviewer: Say more. How did you determine that balance?
>
> Paul: Well, it's not easy. It's obviously not in my interest to share too much. I mean, I want to be a good citizen, but I also want to be a good researcher.
>
> (Personal interview #23 2007)

Paul's comments reflect a tension between sharing with the scientific community and keeping knowledge secret to benefit his own research. His approach, in turn, was to withhold some knowledge.

As another example, Herb Heyneker, a Genentech researcher at the time, discussed how he shared some things during a conference presentation and not other things:

> We presented the data without showing the DNA sequence, because we kept that for ourselves; it was too proprietary. We gave this picture of what the molecule looked like . . . so we could tell a nice story. Also, we let the audience know that the protein sequence and the DNA sequence were perfectly in sync with each other. (Heyneker 2004)

Heyneker, too, thus indicates how sharing some—but not all—knowledge enabled researchers to manage tensions: they could meet sharing imperatives by sharing something, while protecting their private interests by not revealing enough to enable others to replicate the research.

Strategic withholding appeals to knowledge as multidimensional and situated in practice (Polanyi 1967, Cook and Brown 1999). That is, knowledge of how to perform techniques is not a binary proposition in which one shares or possesses the knowledge or not. Instead, performing PM, for example, requires knowledge of a variety of dimensions of both acoustics and electrical engineering. Getting it to "work," as Paul's quote above indicates, requires mastery of all of these dimensions and of the interactions between them. Strategic withholding takes advantage of this complexity by simultaneously engaging in sharing (by sharing some things) *and* secrecy (by not sharing other things). In other words, it attempts to manage the sharing/secrecy tension by doing a bit of both.

Strategic withholding was a particularly effective tactic because it was not obvious if or why a researcher was doing it. First, potential "learners" did not always know if they had been told enough to perform a technique; even if their own attempt failed, they did not know if that failure was caused by incomplete sharing or a failure on their own part. Second, even if a "learner" found that she had not been told enough, it was not always obvious why: It could be that a sharer simply assumed that certain details were not important or worth writing down, as the first part of Paul's quote about the PM guide seems to indicate. Or, it could be that the sharer simply did not know how to articulate some aspect of the technique. As another PM researcher, Elizabeth, remarked, "We were still figuring these things out for ourselves. It's not like, 'Eureka! This is it!'" (personal interview #26 2004). Or, it could be that partial sharing was actually strategic withholding—an intentional tactic to protect private interests. For example, Elizabeth's remark continues, "But, we had a pretty good idea of what you could call the tacit stuff and we'd tell that to some [people] and not to others" (personal interview #26 2004). Because these different reasons were difficult for learners to parse, strategic withholding was an effective means to protect knowledge while not overtly refusing to share. Thus, strategic withholding offered both the academic and commercial benefits of sharing, by building prestige and enhancing commercial considerations, and the academic and commercial benefits of *not* sharing, by maintaining enough secrecy that the ultimate ability to perform a technique could be limited.

Interviewees typically described strategic withholding alongside the sharing practices of formal presentations and publications. This association is logical since hands-on training, in contrast to these practices, involved trusted personal relationships that reduced sharing/secrecy tensions and thus reduced the need for strategic withholding. Moreover, hands-on training and tools/products, by definition, worked toward enabling another person to fully, not "partially," perform a technique.

As with leveraging trust, I did not find that strategic withholding was more common in universities or firms. I did find, however, that it seemed more common in biotechnology than in digital audio. Biotechnology researchers talked about "touching" and "feeling" biological materials, and they described how these materials were susceptible to a wide array of environmental conditions that influenced whether or not the technique worked. For example, biochemist Dennis Kleid recalled a trip to MIT in the 1970s. While there, he realized why it was difficult to learn to perform DNA synthesis simply by relying on the information that had been revealed in publications:

> Kleid: In the three or four days I was at MIT on this trip and interview, I saw how they were making DNA. Even though there were a lot of publications on the chemistry, you don't see the equipment, how they were doing it, how they were watching out for the water—making sure everything was absolutely dry. They had all these different instruments and equipment to keep every single molecule of water away.
>
> Interviewer: Information you couldn't get by reading the articles?
>
> Kleid: No, not the equipment part; I was using all the wrong things. (Kleid 2002)

Kleid's experience shows how failure to reveal even seemingly trivial details, such as the specific equipment used, could prevent others from reproducing a technique. To be sure, important tacit dimensions were present in audio, too, as when interviewees described "having an ear" for something, and this very tacitness opened up space for strategic withholding to operate. For example, one PM expert described how with sound synthesis, "The key was in voicing [programming the actual sounds]. You could do [the] engineering implementation based on the article. But you couldn't make it sound good" (personal interview #18 2005). Yet whereas such details influenced whether the technique worked "well" or sounded "good" in the audio cases, in the biotechnology cases these details affected whether the techniques worked at all. Thus, technical features of the audio field, including the comparatively controlled and well-understood environment, seemed to limit the dimensions of knowledge that potential sharers could strategically withhold.

Delaying

A third tactic that researchers used to mitigate sharing/secrecy tensions was to delay sharing. For example, Stan Cohen, coinventor of rDNA, recalled, "Herb [Boyer, the other coinventor] and I agreed that our results shouldn't be talked about publicly until all of the controls were done and we had pulled the data together in a manuscript" (Cohen 2009). Although Cohen and Boyer both shared privately with specific individuals, they consciously delayed sharing through public talks.

Similarly, David Goeddel, the Genentech researcher, described how Genentech delayed publication of an rDNA application that would have enabled other researchers to use the technique:

> [Bob Swanson, the CEO] said, "Okay, I'm not going to tell you you can't publish. But does anyone else have tPA cloned?" And we said, "No, no one else." "Then why do you need to publish it now?" "Well, we want to publish it first." "Okay, let's wait a few months and then see." And in a few months—it might have been three months or so—we heard a rumor that someone else might have it. We went back and met with Bob and he said, "Okay, publish it. You still get to be first, but you don't give away the information too early." (Goeddel 2003)

This approach enabled Goeddel to claim academic priority by "being first," while protecting his firm's commercial interests by not giving competitors early insight into Genentech's application of rDNA.

Delaying works by taking advantage of the timeliness of knowledge. Reflecting on timeliness and PCR, Randy Saiki, a Cetus Research Associate, recalled in 1992, about eight years after PCR's invention:

> There was a graduate student who was talking about using PCR and various methods to analyze mutations ... at the very end, he said, "Well, they all work, but the big limitation is PCR takes three hours to do." And it was like, "Yeah, but if you didn't do PCR, it would take you two months." [Laughter] The point I'm making is it's become such a standard methodology. ... [I]t's calmed down a lot, because now everyone knows how to do it. Everyone understands it. (Smithsonian 1993)

In the early years of a technique, however, knowledge of how to do it is valuable precisely because *not* everyone understands it (Zucker et al. 1998). In turn, as more people gain knowledge over time, the value of excluding others through secrecy decreases. Thus, delaying works to mitigate sharing/secrecy tensions by taking advantage of timeliness—still sharing, yet timing this sharing for when the knowledge itself offers less of a comparative advantage. In the commercial context, delaying thus enables one to beat competitors to the market and to extract rents for a longer period of time before competitors catch up. In an academic context, where researchers strive to "be first," delaying enables a knowledgeable researcher to maintain a head start on follow-on applications.

As the quotes above indicate, delaying was used alongside presentations and scientific publications. It also was used with tools/products. For example, Stan Cohen, the rDNA coinventor, described his anguish over whether or not to share a particular DNA plasmid, pSC101, with a colleague, Dave Hogness. As Cohen recalled:

> Dave was a friend and had been quite generous to me personally in letting me work in his lab when I first came to Stanford. I appreciated that and had expressed my gratitude to him many times, and so I was initially inclined to give pSC101 to him. But when I discussed this with Herb [Boyer, Cohen's coinventor], his remark was, "Are you crazy? Do you really want to do that at this point?" ... The discussions that were going on between Dave Hogness and me came to the attention of Paul Berg, who was then Chair of the Department of Biochemistry. Paul was very angry about my decision to delay providing pSC101 to Dave. (Cohen 2009)

Cohen's dilemma was not over *whether* to share the plasmid, but rather *when* he should share it. Delaying was primarily associated with formal presentations, publications, and tools/products because these sharing practices, in contrast to hands-on training and informal one-on-one conversations, could spread knowledge to a wide range of researchers. As Rachel, a PAC researcher, noted, "The problem with publishing [details on how to perform PAC] is that once it's out, it's out. There's no taking it back. So you want to think carefully before rushing to do it. You certainly wouldn't do so before you published your own work [based on the technique]" (personal interview #36 2005). Rachel thus indicates that she would publish follow-on work before publishing knowledge about how to perform the core technique.

In both the audio and biotechnology cases, delaying was an important tactic. In audio, however, it also explicitly linked different sharing practices: An audio conference presentation is accompanied by simultaneous publication of the same material in conference proceedings, which are widely read and count toward promotion and tenure decisions. Thus, I found that audio researchers, especially, delayed conference presentations since presentations and publications could be inseparable.

Organizational policies and resources also shaped the use of delaying, though not in ways that clearly distinguished universities and firms. First, although some universities' policies prohibit lengthy publication delays, university researchers nonetheless engaged in delaying, as the above quotes indicate (see also Thursby and Thursby 2003). Moreover, interviewees indicated that firms limited delaying since they valued their scientists' ability to publish. As Genentech's cofounder, Bob Swanson, explained in an oral history:

> Swanson: What happened [at Genentech] is: scientists, you write and publish just about as quickly as you can, and we'll make sure the patent attorneys work around the clock on the weekends to get the patent application filed before the publication actually gets out there. In reality, that was the right message to send from both sides: scientists, you're in control of this, and we're going to have business or patent people work to your schedule. What happened in reality was that there were compromises: "I've got to get this patent application in. Can you send your manuscript in to Nature two weeks later." But we're talking weeks, days, not a longer delay.
>
> Interviewer: You're saying that scientific communication was not substantially delayed because of the patenting process?
>
> Swanson: Not at all. It went essentially on schedule—probably faster than it would have happened in the academic world. (Swanson 2000)

Of course, as Swanson's remarks signal, patenting in particular can encourage delaying since patentability depends on knowledge not being public already. I did not find, however, that delaying to aid patentability was tied to a particular organization type. In fact, firms arguably delayed *less* than universities for patenting reasons because they had more extensive resources to quickly execute upon patents. For example, Eli Lilly and Genentech researcher William Young recalled:

> What would happen was that the lawyers were the ones that ended up working through the night to get something written up. Rather than saying to the scientists, "No, you have to wait till the next meeting to do that [talk about a scientific finding]."

For all of these reasons, I did not find that delaying was particularly associated with universities or firms. I hasten to add, however, that this finding may be tied to special characteristics of the four techniques I investigated, as I discuss later.

Patenting

Finally, as the prior literature notes (e.g., Scotchmer 1991) researchers could rely on patenting to mitigate sharing/secrecy tensions. A patent gives the patent holder the right to exclude others from making, using, or selling the patented knowledge, thus protecting commercial interests. With commercial interests protected, patents in turn enable a researcher to share, effectively furthering his or her commercial *and* academic interests. As Arthur Riggs, a molecular biologist and rDNA pioneer at City of Hope National Medical Center, explained in an oral history:

> I would not have accepted the contract [with a leading biotechnology firm], I would have not done the work, if we didn't have the right to publish. So the way it was able to go forward was that we had to submit the patents, and then we could publish. I became aware that the alternative was secrecy. So trade secrets was the alternative. So either you patent and publish, and you try to tell the world about it as much as you can, or the alternative is you keep it a

> trade secret and you don't tell anybody about it. I came to understand, and I still think it's definitely true, that patents are wonderful because they promote the flow of information for research. (Riggs 2006)

Similarly, Chiron CEO Edward Penhoet claimed:

> One of the reasons why good scientists were willing to go to biotech companies . . . was because they could have their cake and eat it too. To put it in plain terms, they wanted to be rich and famous. So they could have it both ways, but you could only have it both ways if you believed that patents were going to be useful. Because otherwise, you couldn't give away all your secrets, which you do when you publish. (Hughes 2001b)

In short, patenting can enable a researcher to realize the academic and commercial upside of sharing, while reducing or eliminating the commercial downside of sharing.

Patenting, of course, is a form of disclosure or sharing in itself since patent applications must reveal considerable technical detail. Patent applications and issued patents also require that the information contained therein not be public already and, in turn, they make this information public. For these reasons, patenting was tied especially to publicly oriented sharing practices—formal presentations, publications, and tools/products. For example, as Dennis Kleid of Genentech argued:

> What usually happens at Genentech is the scientist wants to publish his paper, or he wants to go to a meeting and talk about his project. So before he does that, he's got to go to the patent attorneys and see if there's anything patentable there. If there is, then they've got to write up a patent [application] for it before he sends in his paper. So there is a trade-off between those two things. (Kleid 2002)

In other words, Kleid claims that patenting enables open sharing through presentations and publications. Similarly, Mitchell, a former executive at a major PCR instrumentation company, argued, "What you have to do . . . is really work early on the intellectual property issues. You don't want to give things away in a pub with no protection" (personal interview #11 2005). Thus, he, too, ties sharing through a publication to patenting.

Because universities also have commercial interests, scientists in both universities and firms reflected upon patenting as a means of managing sharing/secrecy tensions. For example, in describing sharing knowledge with other university researchers, Peter, a university-based research associate, argued, "It was all about open sharing of ideas, and it was an academic environment. Besides, there were a lot of patents [that Stanford had filed]" (personal interview #25 2004). In other words, Peter suggests that the existence of patents facilitated sharing in an academic environment. To be sure, this finding is related both to the historic period I investigate, when university patents grew dramatically (Mowery et al. 2001, Henderson et al. 1998), and to my selection of commercially important and patented university technologies. Nonetheless, the finding that patenting can facilitate sharing in and by a university underscores the mixed academic and commercial incentives that confront many research organizations.

Finally, I found that patenting played a more pronounced role in the biotechnology cases than in the digital audio cases. For example, Genentech's general counsel, Tom Kiley, argued:

> Patents count a lot more in the pharmaceutical industry than they do in, say, information technology where products are rapidly obsolesced and the patents seldom if ever catch up. (Kiley 2002)

Similarly, an engineer for a streaming-audio firm remarked, "We have patents, but mostly we have speed and innovation. Things move quickly and people always invent around you, so we've just found that a better bet is to keep moving than to sit back and rely on a patent" (personal interview #41 2006). These statements complement survey data showing that patents are critical in the life sciences but less prominent in industries like audio (Cohen et al. 2000). They also suggest that different features of knowledge make different tactics more or less effective or important. Tom Kiley, quoted above, continues:

> In the pharmaceutical industry . . . products have long lifetimes and so patents can be important in preserving exclusivity. The patents are needed because of the deep investment this heavily regulated industry requires of its participants. Nobody's going to spend hundreds of millions of dollars to get a drug approved if the generics can then replicate the drug and put it on the market in the next month. (Kiley 2002)

Thus, Kiley argues that the importance of patenting in the life sciences is tied to the fact that drugs are difficult and expensive to develop but easy to mimic, and that they have long shelf lives. In turn, patenting is an especially important tactic for managing sharing/secrecy considerations around other innovations that share these characteristics—and a less important one around innovations that do not.

A Repertoire of Responses

Fundamentally, sharing involves a trade-off between gains and losses. In the world of academic incentives, the gain is fame and the loss is getting scooped for credit. In the world of commercial incentives, the gain bolsters economic performance and the loss hurts it (see Table 1). In turn, the four tactics detailed above represent different approaches to attempt to realize the benefits of sharing while minimizing the losses. Leveraging trust works to minimize the likelihood of a loss by betting that social norms prevail and that the cost of damaging a relationship exceeds the benefit of exploiting knowledge at the sharer's expense. Strategic withholding also attempts to minimize the likelihood of a loss, yet in a different way—by reducing a recipient's ability to fully exploit knowledge. By contrast, delaying works not by reducing the likelihood of loss by rather by reducing the value of loss; because the competitive value of knowledge decreases over time, delaying limits sharing to a time when this value is reduced. Patenting, by contrast, works to reduce the commercial or financial loss by leveraging the legal system's ability to impose damages and to force competing groups to cease activity.

These different tactics also address different aspects of the sharing/secrecy dilemma: Leveraging trust manipulates "who" is shared with, thus protecting private interests through a social mechanism. Strategic withholding manipulates "what" is shared and delaying manipulates "when" sharing occurs, thus protecting private interests by leveraging the content and timing of information. Patenting focuses on legal protection, leveraging a regulatory system to protect interests. In this way, different tactics are not pure substitutes but rather leverage different mechanisms.

These tactics also work alongside different knowledge sharing practices, which vary in their information content, interactivity, and reach. Hands-on training, for example, is information rich and highly interactive but with limited reach. Informal conversations also are highly interactive but with less information content and limited reach. Formal presentations have significant reach but less information content and less interactivity. Publications have significant reach but with less information content and no interactivity. Finally, tools/products have significant reach and contain a great deal of embedded information but with no interactivity. In turn, different tactics align more or less with these different features: Leveraging trust is inherently interpersonal and thus is found alongside the sharing practices that have short reach and high interactivity—namely, hands-on training and informal conversations. Strategic withholding works by manipulating the amount of information shared and thus works alongside sharing practices that are less information rich—namely, interactive conversations, formal presentations, and publications. Delaying works by manipulating the timing of information and thus works alongside sharing practices with broad reach—public presentations, publications and tools/products. Finally, like delaying, patenting attends explicitly to those sharing practices that have broad reach since patentability requires nonpublic disclosure. Table 5 summarizes these findings, highlighting the different tactics, how and why they work, and the primary associated sharing practices.

Precisely because different sharing practices convey different things and different tactics address different aspects of the sharing/secrecy dilemma, any given scientist will share through multiple practices and will leverage multiple tactics. Genentech researcher Diane Pennica, for example, described how she used rDNA techniques to clone t-PA, a protein involved in breaking down blood clots:

> After the cloning [of t-PA], I submitted an abstract to a meeting to give the talk on the cloning.... It was going to be the announcement. I had to write an abstract that was very vague: We're trying to do this, this is how we're trying to do it. I couldn't say anything, and our lawyers said, "No, you can't say it because it would be like a public announcement." ...The patent had been filed, but not released, so it's not public knowledge that we had done this. So, I had to make a very vague abstract. The meeting accepted it but they put me as the last speaker on the last day.... [The organizers] said, "Because we don't know what you're going to talk about, and you didn't give any information." I said, "Well, I can't give any information—I guess you'll see when I get up there and talk whether it's of interest." (Pennica 2004)

Pennica goes on to describe how her talk was of *great* interest to the attendees, because she shared details of how she cloned t-PA. Her description of the episode also highlights how she strung together different sharing practices and tactics: Pennica engaged in strategic withholding around her abstract and in delaying to facilitate the patent before sharing more fully through a formal presentation.

As Pennica's quote indicates, the use of multiple tactics also enabled tactics to moderate or influence one another. Recall, for example, the PM researcher, Elizabeth, quoted earlier:

> I suppose there's an advantage early on that no one really knows how much we know. And we were still figuring these things out for ourselves.... But, we had a pretty good idea of what you could call the tacit stuff and we'd tell that to some [people] and not to others.
> (Personal interview #26 2004)

This quote suggests that strategic withholding might be applied differently to those who shared trusted personal relationships versus those who did not. In other words, the nuance of a tactic such as strategic withholding could be shaped by the use of another tactic, such as leveraging trust.

In other cases, different tactics might be used sequentially, as often happened with "delaying," which is an inherently time-sensitive tactic. For example, Roberto Crea, a DNA chemist and Genentech cofounder, described how he combined patenting and delaying to protect private interests:

> The policy [at Genentech] was that we should publish as if we were in academia, with only the provision that if what we were going to publish represented intellectual property, we wanted to make sure that we first filed for a patent. Then we disclosed the information to the public.
> (Crea 2004)

Thus, Crea first protected Genentech's interests with delaying and then protected them by patenting.

Similarly, an independent consultant in digital audio, Greg, described combining strategic withholding, delaying, and patenting:

> It [an application] was premiered at the Computer Music Conference.... It was either '82 or '83. ...I also presented

Table 5 Tactics to Address Sharing Secrecy Tensions

Tactic	Illustrative quotes	How it works	Why it works	Primary associated sharing practices*	Field emphasis**
Leveraging trust	PCR: "I knew Tom and I could trust him" —University-based lab technician (personal interview #4 2007) PM: "I think he [the sharer] knew that I wouldn't do anything [to harm his interests]." —Music Ph.D. student (personal interview #31 2008) PAC: "I share a lot of things [about how to optimize PAC] with good friends. They do, too. There's a familiarity, a trust, that underlies it." —Audio engineer at a major consumer technology firm (personal interview #45 2007)	Relies on a social relationship	Researchers are embedded in social relationships, the value of which exceed the benefit of violating trust	Hands-on training, interactive conversations	Audio
Strategic withholding	PCR: "[Norm Arnheim] wrote up an abstract [of the presentation]…I've forgotten the wording, but it didn't describe how you do it, and he just said, Mullis and Faloona, in preparation, 'we have amplified the beta-globin locus of,' you know, 'and therefore we were able to detect it.' And then I said, 'Okay, you can say that,' and I don't consider that…it's not telling them how to do it." —Kary Mullis, coinventor (Smithsonian 1993) rDNA: "You couldn't find it [one of the steps in rDNA] in books, and it was…very valuable in terms of making these delicate proteins fully functional in large quantities and in an economic way. …[But] it was not published because…it's an accretion of little pieces of information that taken individually may not be particularly significant, but in the aggregate are very, very valuable." —Tom Kiley, Genentech counsel (Kiley 2002)	Prevents full replication	Knowledge is multidimensional and situated in practice	Interactive conversations, presentations and publications	Biotech
Delaying	rDNA: "Herb and I agreed that our results shouldn't be talked about publicly until all of the controls were done and we had pulled the data together in a manuscript." —Stan Cohen, coinventor (Cohen 2009) PCR: "At some point we [decided we] would no longer delay the first application paper." —Tom White, senior director of research at Cetus (Smithsonian 1993)	Defers sharing until later	As time passes, knowledge provides less of a competitive advantage	Presentations, publications, and tools/products	Equal (but especially common with audio presentations)
Patenting	rDNA: "The intent (of the patent) was to eliminate any motivation for secrecy." —Stan Cohen, coinventor (Cohen 2009) PM: "It was a normal academic environment in terms of developing patentable inventions and stuff. Stumble on something, and file a patent…and it would be shared with the university in the usual way [i.e., published]" —University-based research associate (personal interview #26 2004)	Signals legal protection	Restricts the ability of others to financially profit from the knowledge	Presentations, publications, and tools/products	Biotech

*Tactics were primarily associated with these practices, but not limited solely to them. **Each tactic was used by researchers in each field. Here, "emphasis" indicates if the tactic was especially prevalent or emphasized alongside a particular field.

> the paper that was co-authored by Julius [Smith, the inventor] and that was before we had published it.... A lot of the details were in that paper, whereas in the public paper—I mean the [earlier] one at the Biennale—we were kind of secretive because we were still trying to figure out what the deal was with the patents and such. (Personal interview #33 2009).

In other words, Greg was "kind of secretive" (e.g., strategic withholding) for a period of time (e.g., delaying) until he figured out his patent application. Again, tactics and sharing practices unfold over time, and the presence of one tactic moderates the use of another one.

Here, it is useful to appreciate that each tactic also presents a trade-off. For example, Roche and Cetus researcher Tom White described the danger of delaying:

> On many of these things we were working on, it was such a competitive field that oftentimes in the scientific literature and the patent literature, the dates of submission of some of these articles of the journals would be within days or weeks, or at most a month or two. If you didn't publish your own scientists' work, in fact, within a couple of weeks, you'd be reading about your competitors' comparable work, and then you would not only not derive any of the benefits of publishing your own work, but you'd be on the receiving end of the harm. (Smithsonian 1993)

Thus, delaying protected knowledge but also increased one's risk of getting scooped. Similarly, if researchers shared only with those people with whom they have close personal connections, they would realize increased protection but at the simultaneous cost of failing to realize the academic and commercial benefits stemming from broader acknowledgement; if they strategically withheld too much, they might not realize the benefits that accrue from sharing; and so on.

Moreover, the risks associated with each tactic could be difficult to calculate. Recall, for example, the earlier description by Genentech's Dave Goeddel of delaying publication of an rDNA application until they "heard a rumor that someone else might have it." The obvious danger of such an approach is that one might not "hear the rumor" or might miscalculate another group's activities and capabilities. For example, Roberto Crea, a DNA chemist at Genentech, described in an oral history how a competitor engaged in strategic withholding, but miscalculated as to just which missing pieces would inhibit another group (in this case, Genentech) from profiting from the information:

> Crea: The whole race [for isolating interferon, a key protein] was won when a scientist from Genentech attended a meeting, and he copied down the first four amino acids of fibroblast interferon which were flashed on a screen by one of the scientists who was working in interferon in Japan. With that information, we were immediately jumping ahead of the competition, because we were immediately synthesizing the DNA and giving the molecular biologists the unique tools to go out and fish out the gene.
>
> Interviewer: Was that a slip on the part of the presenting scientist?
>
> Crea: In retrospect, the presenting scientist will probably never forgive himself. But at that time nobody really had perceived the powerful technology machinery that we had put together at Genentech. It wasn't until later that it became apparent that a small piece of information—but crucial piece of information—can start a snowball effect if you have the technology to turn that bit of information into a unique strategy that nobody else can adopt. So that will give you an unfair advantage. (Crea 2004)

In other words, each tactic presents trade-offs since no one has complete insight into exactly what information will be valuable to who and when. Thus, although the tactics help to manage sharing/secrecy tensions, questions of how and when to use them can present dilemmas of their own.

Discussion

The sharing and spread of scientific knowledge is critical for innovation, entrepreneurship and economic growth (Cockburn and Henderson 1998, Furman et al. 2010, Powell and Snellman 2004). Yet despite a great deal of evidence on the sharing/secrecy tensions that scientists face, our understanding of *how* they mitigate these tensions has been limited. In turn, our understanding of the dynamics of scientific progress itself has remained incomplete.

In this paper, I have unveiled a set of tactics that scientists employ in their quest to share knowledge, thus reaping the associated academic and/or commercial benefits, even as they protect their private academic and/or commercial interests. I also have theorized how these tactics operate on different aspects of the sharing/secrecy dilemma—social, informational, and legal—and how they interact with features of organizational contexts, scientific fields and sharing practices. As I elaborate below, these findings hold implications both for the conflicting results in the literature on whether scientists share and for more general considerations about policies that can enable cumulative innovation.

Managing Sharing/Secrecy Tensions

The tensions underlying scientific sharing and secrecy have garnered significant attention from scholars, but with conflicting results. Thus, some studies conclude that commercial interests restrict sharing (Blumenthal et al. 1997, Campbell et al. 2002, Heller and Eisenberg 1998, Krimsky 2003, Thursby and Thursby 2002), other studies find that commercial interests can encourage sharing (Cockburn and Henderson 1998, Hicks 1995, Pénin 2007), and other studies find no effect (Agrawal and Henderson 2002, Azoulay et al. 2009, Stephan et al. 2007, Walsh et al. 2007). Still other studies find that academic, not commercial, interests can underlie reduced sharing (Walsh and Hong 2003, Walsh et al. 2007, Hong and Walsh 2009). My study responds to Sauermann and Stephan's (2013) call to investigate "public science" and "private science" simultaneously in multiple organizational environments, and it provides evidence on all sides of the sharing/secrecy debate: academic and commercial interests within both universities and firms can give rise to both sharing and secrecy.

Whereas the literature has focused on whether scientists share, my study instead acknowledges that multiple pressures exist and explores how scientists manage these tensions. Fundamentally, my work intertwines the tactics scientists employ to manage sharing/secrecy tensions with the practices they employ to share in the first place. Several studies have detailed different scientific knowledge sharing practices (Agrawal and Henderson 2002, Bekkers and Freitas 2008, Cohen et al. 2002, Nelson 2012, Wright et al. 2008). My study complements this work by analyzing not only how knowledge is shared through different practices but also how the tactics that researchers use to mitigate sharing tensions interact with these practices. For example, researchers may rely more on trusted personal connections when engaged in hands-on sharing or one-on-one conversations, but more on delaying or strategic withholding when sharing via a publication. This finding—that how knowledge is protected depends on how knowledge is shared—is important to furthering the conversation about whether and when scientists share because prior studies have tended to focus on lone sharing practices, such as publishing. Consider, however, a scientist who offers hands-on training to a trusted colleague at time y, but delays a publication until time $y+2$. If we ask at time $y+1$ whether this scientist "shared" and our measure is a publication, our answer will be "no." If we assess sharing as revealing through hands-on training, however, then our answer will be "yes." If we ask at time $y+2$, our answer also will be "yes." In other words, conflicting results in the literature as to "whether" scientists share are inseparable from the literature's relative lack of attention to "how" scientists share.

My findings also address conflicting prior results by investigating "what" is shared, conceptualizing knowledge as multidimensional, embedded in practice, and at least somewhat tacit (Brown and Duguid 2001, Cook and Brown 1999). Existing work on scientific sharing has investigated situations in which the focus of sharing is relatively defined and discrete, as with the production and distribution of a publication or the sharing of genes, plasmids, tissues, or organisms (e.g., Blumenthal et al. 1997, Campbell et al. 2000, Walsh et al. 2007). By contrast, the mitigation tactics that I identify leverage the fact that sharing may *not* be dichotomous; that some dimensions, but not others, may be shared; that the performance of a technique itself can have ambiguity as to "when," "why," and even "whether" it works; and that a scientific community may not know what a potential sharer knows and when. Thus, the tactics I identify reflect, to different degrees, a situation in which scientific knowledge may be, in the words of Cambrosio and Keating (1988, p. 244), characterized by a mixture of "local knowledge, tacit knowledge and 'magic,'" and in which tacitness itself may be a reflection of the incentive system at play rather than an inherent characteristic of knowledge (Cowan et al. 2000). In turn, scientists can leverage these features of knowledge to simultaneously share and protect their private interests.

As this discussion highlights, the different tactics that I identify also play to different aspects of the sharing/secrecy dilemma. Thus, sharing is not a yes/no decision; rather, it is a process influenced by considerations of with whom, when, and what, and by the status of intellectual property protection. Stated differently, sharing is thus a matter of attending to social (with whom), informational (when and what), and legal (IP) considerations simultaneously. Murray and O'Mahony (2007, p. 1016) observe that little work integrates legal considerations with other social and economic influences. They write, "To date, organizational theory has paid little attention to the role of law, while economic studies tend to neglect the impact of [social] norms." My work responds to this charge by analyzing how a legal institution (patents) can interact with social relations (trusted relationships) and with calculations around the value of "partial" knowledge (strategic withholding) at a particular point in time (delaying).

The fact that different tactics appeal to different aspects of the sharing/secrecy dilemma also suggests that the tactics themselves are not simple substitutes so much as different tools in a repertoire. Thus, in order to understand how patenting affects sharing, as one example, my work suggests that scholars need to consider patenting alongside other tactics and in the context of a particular scientific field. Indeed, there is vigorous debate regarding whether patents are "good" or "bad" for innovation, with some scholars pointing to their positive role in incentivizing research (e.g., Arora et al. 2001) and to the fact that they induce sharing over secrecy (e.g., Azoulay et al. 2009, Doll 1998), and other scholars pointing to patent "thickets" (Shapiro 2001) and to patent-related transaction costs that impede cooperation and limit data availability (e.g., Heller and Eisenberg 1998), thus dampening innovation. My study, of course, was not designed to resolve this broader debate. Yet it does contribute to it.

On the one hand, I provide evidence that patenting "works as advertised": it induces knowledgeable researchers to share what they might otherwise keep to themselves, even in universities. On the other hand, my ultimate emphasis on patenting as one tool in a repertoire signals that researchers can use other tactics, too, both to share knowledge and to protect it. Thus, my study suggests that if our interest is in sharing and secrecy as a whole, then existing work that focuses on the relationship between patenting and publishing (e.g., Azoulay et al. 2009, Stephan et al. 2007) might fruitfully be extended to examine how other tactics shape other sharing practices. It also suggests that economists who study the incentives underlying sharing/secrecy considerations (e.g., Azoulay et al. 2009, Stern 2004, Stephan et al. 2007) might fruitfully engage with scholars who draw upon a sociological perspective on knowledge (e.g., Brown and Duguid 2001, Cook and Brown 1999, Kaplan 2011).

Of course, sharing/secrecy considerations extend far beyond the context of scientific knowledge, permeating most every aspect of organizational life (Costas and Grey 2014). In turn, my focus on how individuals leverage social, informational, and legal protections as they share different things in different ways is applicable to a wide range of scenarios. For example,Fauchart and von Hippel (2008) describe how high-end French chefs face a dilemma around sharing new recipes, since sharing boosts their status yet also enables imitators. My work suggests that the way in which chefs may share while protecting their interests will depend on the sharing practice in question. Thus, chefs may interact directly with trusted colleagues, as Fauchart and von Hippel (2008) demonstrate. Yet they also may delay and/or leave out certain details (strategic withholding) as they share through conversations, written recipes, and other practices. As another example, composers often desire to promote new songs while preventing other composers from copying. Although the literature focuses on legal protection (copyright) in such cases (Marshall and Frith 2013), my results suggest that composers might also share with trusted colleagues or delay sharing via some practices, distinguishing, for example, between live performances and recordings. In other words, in most any context, "whether" sharing occurs may be inseparable from "how" it occurs.

Promoting Sharing and Follow-On Work

The sharing of scientific knowledge is critical not as an end in itself but rather because it enables, in the words of Murray and O'Mahony (2007, p. 1006), "reuse, recombination, and accumulation" that can underlie future scientific advances. A growing body of work provides empirical evidence that open sharing enables follow-on work. For example, Williams (2013) examined subsequent innovation stemming from two sources of data on the sequencing of the human genome: the public Human Genome Project and the private firm Celera, which protected its data with patents. Williams (2013, p. 1) finds that Celera's intellectual property "led to reductions in subsequent scientific research and product development on the order of 20 to 30 percent." In other words, intellectual property enforcement appears to dampen subsequent innovation.

Williams' study focuses on patenting as the means by which knowledge is protected. My study complements this work by suggesting that leveraging trust, delaying, and strategic withholding—alternative means of protecting knowledge—may also shape follow-on scientific research. At first glance, strategic withholding and delaying would seem to harm such work by limiting the ability of others to reuse, recombine, and accumulate thoroughly and in a timely fashion. Overreliance on personal relationships for sharing also might limit the reach of research. In other words, each of the four tactics that emerge from my study have the potential to dampen cumulative innovation.

In turn, managers and policy makers, who have given considerable thought to patenting, might also develop initiatives around strategic withholding, delaying, and trusted personal networks. For example, managers could strive to develop policies and environments that encourage frequent interactions among researchers, which might build personal relationships and trust. Organizational rules, such as many universities already specify, might prevent delaying. Funding agencies might require both biological materials and detailed how-to descriptions to be deposited and shared, limiting strategic withholding.

At the same time, however, my results suggest that there may be an inherent trade-off in such approaches: The unifying feature of the tactics that I identify is that they enable a researcher to balance the tension between sharing and secrecy. To the extent that policies remove degrees of freedom around these tactics, they may ironically drive down the incidence of sharing by limiting the ways in which scientists can share while still protecting their interests. Put slightly differently, policy changes aimed at limiting these tactics may increase the timeliness and quality of sharing (by limiting delaying and strategic withholding, specifically), but may decrease the overall incidence of sharing if scientists determine that the benefits no longer outweigh the risks or costs—opting instead for secrecy. Ironically, therefore, we may see more sharing when scientists can, in fact, appeal to these tactics, even though these tactics serve to limit various dimensions of sharing.

Moreover, it may not be desirable to eliminate sharing/secrecy tensions. Studying a very different context, mushroom collectors, Fine and Holyfield (1996, p. 24) find that the tension between attachment, which reflects and builds trust, and competition, which can fuel secrecy, "builds social order." In this view, the dynamic between sharing and secrecy serves to establish a cohesive community through an ongoing cycle of trust building and secret revealing. Thus, attempts to short-circuit the specific tactics that scientists employ in this cycle might ironically serve to limit the growth of scientific communities.

Clearly, the organizational and public policy prescriptions for whether and how to encourage sharing are ripe for further investigation. Fortunately, we already have a model for such studies, based upon the requirement that patent applications disclose knowledge, a form of forced sharing: Recent work examines when this sharing requirement leads organizations to forego patents to maintain secrecy and when patenting nonetheless proceeds, thus amplifying sharing through this disclosure requirement (Hall et al. 2014). My results suggest that such work should be extended to other tactics beyond patenting and that the outcome around these other tactics will hinge on the scientific field, the sharing practice, and the state of knowledge at play.

Finally, as my work highlights, these issues confront not only firms but also universities and other organizations that embody multiple and competing goals and incentives. Thus, debates aimed at spurring sharing in light of private interests might usefully bring together organizations from different sectors rather than relying on stylized views of universities as "open" and firms as "closed." In the process, they may reveal how organizational policies may, in fact, need to transcend organizations themselves—especially in fields marked by frequent personnel exchange and mobility.

Additional Research Opportunities

The exploratory nature of this study and the in-depth qualitative approach suggest a number of additional research opportunities. To begin, the techniques that I trace are unique in several respects. Future work is needed to determine how practices and influences may differ for incremental technologies or for technologies in other fields (Bekkers and Freitas 2008). More generally, I focus on techniques that have diffused widely and that are highly influential. A fruitful future exercise, therefore, might compare tactics surrounding a wider range of techniques, including those techniques that were not successful, to clarify both similarities and differences (e.g., Davis and Greve 1997).

Second, as other scholars note, sharing is but one aspect of scientific practice. Murray and O'Mahony (2007), for example, detail how public and private science differ in terms of disclosure, access, and rewards. Sauermann and Stephan (2013) propose a model of public and private science that includes four elements: the nature of work, characteristics of the workplace, characteristics of workers, and the disclosure of research results. These studies, therefore, highlight how sharing is part of a larger system of norms, goals, motivations, and practices. Although my work elaborates on one part of this model, a question remains as to how this elaboration interacts with other aspects of science.

Finally, my desire to capture a lengthy time series, which entailed focusing on techniques from the 1970s and 1980s, also means that influences may have changed in ways that I do not capture. The rDNA technique, in particular, emerged before the Bayh-Dole Act of 1980, which encouraged commercialization of university research. In turn, some scholars suggest that private-science concerns have continued to grow in university environments (Murray 2010, Popp Berman 2011). These developments may further accentuate sharing/secrecy pressures and may heighten the importance of certain tactics in managing these tensions.

Similarly, recent years have witnessed the emergence of new sharing technologies, including Internet web pages, email, videoconferencing services such as Skype, and open access journals. These developments have undoubtedly altered sharing practices and, with them, the tensions between sharing and secrecy. Together, these opportunities highlight our nascent understanding of the tensions encountered in scientific knowledge sharing and of the ways in which individuals manage these tensions. Despite considerable progress in the literature, studies of scientific practice continue to hold much promise.

Supplemental Material

Supplemental material to this paper is available at http://dx.doi.org/10.1287/orsc.2015.1040.

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