Parsing the relationship between ambiguity and complexity: Some clues from university technology transfer.

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Introduction.

Complexity and ambiguity are supplanting uncertainty and indeterminacy as key concepts in current research examining the co-evolution of organizations, markets, and technologies. In recent years, diverse considerations of management strategy (Lane & Maxfield, 1997; Clippinger 1999), scientific collaboration (Galison, 1997), social (Padgett & Ansell, 1993) and technoscientific (Callon 1998; Law 1999) networks, 'new' economies (Stark 2001; Powell, White, & Koput 2001) and the dynamics of economic systems (Arthur, 1999; Arthur, Durlauf, & Lane 1997) have emphasized a conception of the economy as a complex adaptive system (CAS).

This emphasis has taken many forms, nevertheless some features (e.g. ambiguity, interdependence, heterogeneity, rapid unpredictable change, and multivocality) remain constant across interpretations. I argue that one of these, ambiguity, is fundamental to both the constitution of CAS systems and to strategic action within them. In this emerging formulation, then, ambiguity serves as both a catalyst for complexity and a resource for strategic action. Ironically, and in part because of its dual analytic role, ambiguity is itself a somewhat indistinct concept. This paper represents a first attempt to comprehend multiple images of ambiguity in the context of efforts to define and market early stage innovations in an elite university technology transfer office.

University technology transfer is a useful site to begin an examination of the relationship between technological, market, and mission ambiguities. University technologies are increasingly central to the development of regional economies (Saxenian 1994; Gibbons 1999), high tech industries (Zucker et. al. 1998; Powell 1996) and national innovation systems (Nelson 1994). American research universities, in particular, have a long history of responsiveness to and interactions with a variety of industries. Indeed, in the U.S., these key public research organizations have been viewed as catalysts for development (Feller 1990), integrative players in biomedical innovation networks (Owen-Smith et. al. 2001) and endogenous sources of technological and economic change (Rosenberg 2000). Clearly, there is much to be learned about the knowledge economy from a focus on university technology transfer.

In addition to these, now relatively obvious, outcomes of research commercialization in the academy, I contend that university technology transfer endeavors have a number of features that make them unique sites for examining ambiguity's dual role as resource and catalyst. I draw upon 10 months of ethnographic research in an elite academic technology transfer office to highlight those distinctive characteristics.

Three broad questions orient this effort:

1. How does university technology transfer contribute to complexity?
2. What types of ambiguities characterize these endeavors?
3. How can diverse ambiguities serve as catalysts for the creation of complex foresight horizons?

In order to address these questions I turn first to a brief discussion of the patenting and licensing process at the institution I dub Elite Private University (EPU). This description focuses attention on the specific characteristics of process, goals, technologies, and outcomes that make EPU technology transfer a thoroughly equivocal activity. I then move to a brief examination of the multiple analytic uses to which ambiguity is put in current social scientific research the draws on the CAS perspective. My goal here is not to present an exhaustive review of a research literature that is, itself, multi-faceted. Instead, I undertake a directed review with the intention of highlighting multiple views of the relationship between ambiguity and complexity. I then return the technology licensing office at EPU to examine two cases that help concretize the catalytic and strategic roles played of ambiguity.

Broadly, then, the focus of this paper is theoretical and its aims abstract. Instead of developing an image of university technology transfer that will hold across diverse arrangements to market academic innovations (Berkovitz et. al. 2001), I draw upon the details of a single exemplary case to ground more conceptual discussions. In essence, I am concerned with demonstrating the ways in which attempts to grapple with indistinct technologies and ambiguous markets can be understood to have broader ramifications for our understanding of the dynamics of complex technological and economic systems.

University technology transfer.

In a recent review of the literature on academic technology transfer, Bozeman (2000) notes that it is easy to distinguish newcomers to the study of technology transfer from old hands because the old hands are confused. This confusion (a source of jokes among technology transfer professionals) results from the multiplicity of processes variously grouped under the heading 'technology transfer.' Bozeman (2000:3) defines technology transfer as " . . . the movement of know-how, technical knowledge, or technology from one organizational setting to another." Under this definition, university technology transfer encompasses any mechanism by which codified or tacit knowledge is moved from a campus to another setting. Such mechanisms run the gamut from very common, for instance the graduation of students who get jobs and 'transfer' knowledge gained at the university to their employees, to the more rare, for instance when a university acts as venture capitalist, funding a new firm based on faculty research.

The most common, and least controversial, means of academic technology transfer are those traditionally associated with university mission, education and research. Publication 'transfers' information from the university to the public domain where it can be freely used by other organizations. Likewise, well-educated students act as repositories for the tacit and explicit knowledge housed in a university. When students graduate and move into jobs, they carry new techniques and knowledge with them into the private sector.

The 1980 passage of the Bayh-Dole[1] act and the rise of expressly commercial metrics for evaluating the university and its technology transfer efforts (Slaughter & Rhoades 1996; Gumport 2000) changed the game of academic technology transfer. Since 1980, academic patenting has exploded with universities establishing intellectual property (IP) rights to research findings nearly 8 times more in 1998 than 18 years earlier (Owen-Smith 2000). This increasing focus on patenting is accompanied by more complex and controversial efforts to generate value from IP ownership. In recent years, university revenues from intellectual property licensing have increased dramatically topping $820 million in 1999 (AUTM 1999). Academic institutions have made forays into venture capital (Desruisseaux 2000), business incubation, equity ownership in faculty start-up companies, and even prototype development and other activities more typically associated with the D side of the R&D equation (Jensen & Thursby, forthcoming). As the

[1] A federal law which enabled non-profit institutes, universities and small businesses to take title to patents on findings from federally sponsored research.

once separate realms of the academy and the economy overlap, universities face a new constellation of challenges and opportunities.

Typically, complicated commercialization efforts are initiated and maintained in central university technology transfer offices. These offices are usually staffed by technically trained professionals (but generally not by working scientists and engineers) and are increasingly standard components of university tables of organization (Siegel et al 2000; Bercovitz et al 2001). Technology transfer offices are responsible for managing and marketing IP developed by faculty, students, and staff at U.S. universities. Work inside these offices spans research areas and crosses the academy industry divide by including firm representatives, faculty inventors, and university administrators in often far-reaching deals for academic IP (McCray & Croissant 2001). University technology transfer offices, then, are explicitly designed to function as "boundary objects" (Star & Griesmer, 1989) that bring together representatives from diverse and often conflicting arenas to accomplish a joint a goal, in this case the development of value from often nascent academic innovations.

Technology licensing professionals face numerous challenges. Not the least of which is the need to distill commercially viable 'technologies' from early stage scientific 'findings.' This process often begins in discussions between licensing professionals and faculty inventors, but final decisions about the characteristics and value of (and thus the markets for) new technologies are made collectively in meetings among licensing professionals.

Sources of ambiguity in university technologies.

University innovations are increasingly central to the development of new knowledge-based industries (Powell et al 1996; Gibbons 1999) and to the progress of more established commercial sectors (Jaffe 1989). But academic technologies share several features that make their uses and effects more equivocal than examinations of technology transfer commonly suggest. University innovations are typically at the cutting edge of science and engineering knowledge and they more often represent early stage "proofs of concept" than working prototype products (Thursby & Thursby 2001). The characteristics, uses, and values of academic innovations, then, are often indistinct.

Such inventions are generally created without extensive knowledge of existing IP that overlaps with or precedes them.[2] Thus, the market value of academic innovations is often dependent upon access to diverse 'background' rights.[3] Marketing academic technologies for industrial use can require complicated negotiations for access to patented innovations owned by industrial (or increasingly other academic) organizations.

Moreover, and unlike many industrial innovators, academic institutions are home to cutting edge research in many broad fields. The value of and used of patents and other forms of IP vary from sector to sector (Owen-Smith & Powell 2001). For instance, in physical science areas, such as semi-conductor chips, which are dominated by large firms whose complex technologies require multiple sets of patent rights for the creation of multi-technology products (Linden & Somaya 2001; Somaya & Teece 2001) individual patents are often licensed non-exclusively and serve as entry tickets to university-industry

[2] Academic research groups are typically less concerned with the contours of established IP than with the state of the art of published knowledge (Myers 1995).

[3] One little understood characteristic of U.S. patent law is that patent rights convey the ability to preclude others from using a technology, *not* a positive right to use an invention. Thus patents can be issued on technologies that cannot be 'practiced,' used commercially without gaining rights to existing intellectual property that may be in the hands of competitors.

networks. In these sectors, intellectual property assures freedom of action and strategic advantage is more a function of speed, secrecy, and time to market. In contrast, bringing biomedical innovations to market often requires massive investments of time, capital, and expertise as firms navigate the FDA approval process. Under these conditions, patents themselves confer strategic advantage and exclusive licensing arrangements are necessary to induce firms to undertake costly development efforts and risky clinical trials.

Furthermore, academic inventions are more likely to be multi-disciplinary than industrial patents (Henderson et al 1998). Technologies developed in photonics institutes and biomedical engineering programs, for instance, can span sectors. In cases such as these, firms that do not usually take notice of one another may find themselves competing for access to the same piece of university IP. When this occurs, different standards for valuing and using patents can cause conflicts as university licensing professionals attempt to negotiate and manage 'dockets' that encompass overlapping non-exclusive and exclusive licenses, various forms of limited exclusivity,[4] and milestone dependent deals.

Finally, many faculty and university administrators feel some ambivalence about university based IP and technology marketing efforts (Owen-Smith & Powell 2001b). Academic efforts at patenting and licensing flout the norms of information disclosure and reward systems that traditionally define academic science (Dasgupta & David 1987, 1994). Where publications and priority are the coin of the realm in academic science (Merton, 1968, 1988) patenting, with its focus on property rights and de-emphasis of scientific peer review (Etzkowitz and Webster 1995) is more typically associated with industrial research endeavors. The increasing prevalence of academic patenting, then,

[4] Licensing arrangements can be completely exclusive or simply represent non-exclusive 'tolls' for use of a piece of IP. In between these two extremes, technological field of use, geographic, time limited and 'but for' exclusivities commonly characterize deals involving technologies that span multiple markets or sectors.

heralds a shift in the norms and practices that characterize academic science and engineering. The implications of this shift are apparent in the mission statements of academic technology transfer offices which generally emphasize the simultaneous pursuit of social good and returns on investment.

Constructing technologies and markets at EPU.

The general trends highlighted above are apparent in the technology licensing office (TLO) at Elite Private University (EPU).[5] I draw on interviews with more than 35 licensing professionals, inventors, and administrators at EPU and ten months of observational field work in the TLO to describe an exemplary university licensing process and highlight the sources and roles of ambiguity in university technology transfer.

EPU is one of the nation's most successful universities in terms of both academic and commercial accomplishment. Its large (more than 20 people), well-established (founded in the late 1970s) and successful (tens of millions in yearly licensing revenue) technology licensing office is influential among other universities[6] and is among the most effective at transferring university innovations to industry. Functionally, the TLO is organized into two subject area teams. The 'Bioteam' deals exclusively with biomedical innovations largely drawn from EPU's research oriented medical school. In contrast, the 'Physci' (pronounced 'fi-sci') team focuses more on engineering, software, and device innovations that result from research in physical science and engineering laboratories. There is some overlap between the two groups as three members of the office staff, the

[5] In the interests of maintaining confidentiality I have altered some characteristics of organizations, individuals, and technologies and assigned pseudonyms to relevant individual and institutional actors.
[6] Three TLO professionals serve in administrative capacities in the nations' major technology transfer professional association.

director and two senior licensing associates, work on both types of technology. In the parlance of the TLO, these office generalists "go both ways."

While individual licensing associates have complete control over the dockets assigned to them "from cradle to grave" much of the work of defining the characteristics and markets for new innovations goes on in weekly team meetings where active dockets and new disclosures are discussed over coffee and bagels. While I have conducted formal interviews with the majority of TLO licensing personnel, much of the data that supports this analysis comes from observations of discussions in bioteam and physci team meetings.

While choices about patenting and licensing deals are the responsibility of individual associates, team meetings are designed to provide a 'resource' for those decisions.[7] Generally chaired by the TLO's director, team meetings are comprised of licensing associates' serial descriptions of interesting or problematic deals in progress. Because team meetings serve as a resource for the resolution of complex issues, the discussions that I witness are likely to represent more intractable deals and technologies than are the norm.

Observations in these meetings provide a useful window into sources and uses of ambiguity in university technology marketing. The discussions in such meetings leave one with a pervasive sense that the objects (technologies) being marketed are indistinct and often of equivocal value, that markets are uncertain and changeable, and that formal deals are only the first step in ongoing negotiations about rights to and uses for new

[7] The rhetoric of individual responsibility for technologies is a strong feature of TLO discussions. The only formal oversight mechanism in the office is the requirement that the director personally sign every contract. Team meetings, then, provide a resource for relatively autonomous decision makers and enable individuals to draw on the collective memory and experience of other team members to ground or justify their own choices.

inventions. Meeting discussions, then, suggest that the relatively clean and intentional image TLO staff members present in interviews masks the details of a complex and highly ambiguous process.

Consider the key inputs to decisions about patenting and licensing as described by Larry, a senior licensing associate and one of the TLO's three 'generalists.'

Interview Excerpt: Deciding whether to pursue a patent.

> For example, you might look at the inventor. If you have an inventor that has a good track record, then even though you are not quite sure you put more weight on somebody who has been successful before. So you look at a lot of different aspects and parameters and weigh them accordingly. Out of that analysis comes a decision to go forward or not go forward. Or you can decide to just let it cook a little bit. You put it back in the lab and let them do a little more work, and then you wait. But again you have to have that entrepreneurial understanding to take a risk on some things.
>
> **JOS: What else do you consider?**
>
> Well, other than the inventors, we look at what the market is. There are some objective things that we can look at; what the market is, where the industry is heading. For example, you might think that because of digital cameras an invention that deals with film is probably not a good thing to invest in. For a few years it might be good. If you have an invention that is related to digital photography or high-density storage, then you know the market is headed that way. So, right now we have some objective knowledge about the market.
>
> We look at the market, we look at the barriers -- this is more subjective -- we look at the barriers to implementation. I can give you an example of a great technology that has a tremendous barrier to implementation. That is the instrument that lets you move individual atoms. You can do it in a lab. They have done it. They have been doing it for years, but to get that into a product that will go in your house, that is

> probably 20 years down the road. So you may try to ride something like that a little bit. You don't throw everything that you've got at it. You hedge your bets a little bit. You look at the market size. You look at the people. You look at the obstacles and then you get back to industry.

The first thing to notice about this narrative is the diverse skill set that licensing associates bring to bear in evaluating a technology. A wide range of information, running the gamut from a 'loose' technical understanding of the innovation to a sense of overall market conditions, barriers to development and long term potential for commercial success are central to this description of the decision process. In the broadest sense, Larry's discussion highlights three key factors for TLO decision-making. On this view, strategic choices about patents are based on perceived characteristics of inventors, technologies, and markets. I argue that at least two of these factors, the characteristics of inventions and of markets for them, are sometimes subject to extreme ambiguity. Basing patenting decisions on these criteria, then, may be as much a function of constructing the bases of decisions as of discovering them.

Even in Larry's relatively clean description of the inputs to his decisions, it is difficult to separate out characteristics of the technology from knowledge about the markets where it may have value. Since much of the information TLO staff members draw on in making these decisions comes from the process of 'shopping' technologies to industry, defining an invention is inextricably linked with determining a market. Inputs to decision making in the TLO, then, can be conceived of as the results of strategic efforts by licensing professionals searching for information that will help them decide what they have to sell and who it might be valuable to. In essence, university technology transfer can be seen as a process by which markets and inventions are co-constructed as strategic actors struggle to manage multiple ambiguities.

Consider a discussion excerpted from field notes taken during a bioteam meeting. Here Larry, Jenny (the TLO's only Ph.D. trained licensing associate), Sara (Larry's assistant) and Susan (the TLO's director) are discussing attempts to market a technology derived from research in a famous biochemist's laboratory. The technology is relatively straightforward, it is a method for blocking the expression of a gene necessary for bacterial reproduction, but it has multiple uses that cross several markets.

The particular strain of bacteria this invention targets has been linked to the build up of arterial plaques, which in turn are thought to be a primary cause of heart attacks. Similar bacteria have also been implicated in tooth decay and the stinky laundry. The technology is potentially of value to three types of firms, biotech or pharmaceutical firms interested in cardiopulmonary drugs, firms that market dental hygiene products, and companies involved in the production of anti-bacterial laundry detergents. In keeping with explicit university policy, TLO associates attempt to market this technology as broadly as possible, thus, they prefer to engage as many different potential developers as possible.[8]

This variation is important because different licensing strategies are suited to each market. Long-term exclusivity will be necessary to induce biotechnology or

[8] The proclivity for such broad marketing strategies is another interesting feature of university technology transfer. At EPU, concerns that the public and the press will perceive attempts to limit the development possibilities of an invention by negotiating blanket exclusivities result in often torturous attempts to make inventions available to as many markets as possible. Combined with a licensing strategy which is expressly designed to maximize long term relationships with industrial partners, sometimes at the expense of immediate revenue returns to licensing, the tendency to market broadly has the effect of creating multiple and often conflicting relationships that must be managed over the life span of a patent by the associate who licensed it. Instead of viewing TLO licensing deals primarily as the 'hand-off' of an academic technology to an industrial developer, deals must be understood as opening moves in the development and maintenance of a web off corporate affiliations centered in the TLO.

pharmaceutical firms to invest in the arduous development and regulatory processes necessary to the creation of a new cardiovascular drug. In contrast, relatively inexpensive non-exclusive licenses for use in toothpaste and laundry detergent will help ensure the technology's broad adoption in these relatively cheap and low investment products. Nevertheless, the conditions of all these deals must be negotiated in such a way that non-exclusive uses of the innovation do not impinge upon the exclusive uses that will be built into a license for drug development. In this instance, ambiguity must, at least as far as is possible, be removed from descriptions of the uses to which different classes of licensee can put the EPU technology. Negotiating these detailed 'field of use' licenses requires two things: (1) the definition of clear and parallel uses of the technology, and (2) agreement among all licensing parties that the defined fields of use offer appropriate protections for drug development and freedom of action for firms involved in selling home products.

Despite being relatively straightforward, the 'bacteria technology' is ambiguous in the sense that it has multiple uses that cross established markets. The portions of the technology that are actually owned by EPU are also indistinct. A patent application has been filed, but no response has been received from the patent office. Here, the difficulties of negotiating multiple, distinct and non-ambiguous fields of use is complicated by the fact that EPU's rights of ownership are, as yet, completely undefined. The discussion presented below revolves around plans to broadly market an innovation across multiple and potentially conflicting industry sectors before any legal rights of ownership have stabilized. Despite clear indications of the markets and uses for this innovation, it remains a highly ambiguous technology on multiple dimensions.

Field note excerpt: Ambiguous technology 1,

Larry: There is this case I talked about before. The case with X (a senior faculty member), KKK production in bacteria. He can block the gene for kinase and can interrupt the metabolism of a bacterium, which kills it. That's something that's interesting to lots of folks. You all heard about the plaques in arteries and how they are caused by bacteria, well, X thinks that the plaques on teeth are the same way. He believes he can put this substance in toothpaste and kill the bacteria that causes plaque on teeth. So, it's really exciting. Anyway, we told [a mid sized biotech firm] about it and they said 'oh yeah, go ahead and file' so we did. But now they don't want the thing. There's another company X is related to, Z-biotech. They want an exclusive license, but we have to shop it around now that we have an application in.

Jenny: Is it a gene patent?

Sara: No, it's a method for blocking gene expression. We have this super-broad claim

Jessie: OK, do we have an actual agent?

Larry: No

Jenny: So what do we have, just a thought that this might work?

Larry: Z-biotech is going to screen the compounds. They have a list of about 200,000 compounds to work with. We already have a non-ex with them, but they really want an exclusive on this. There are other companies on it too though, Pharmaceutical-A, Pharmaceutical-B, Chemical-A and several others want it. Professor X really wants to go with Z-Biotech because he thinks they can move fastest on it. I told him that we have to open it to bids or joint exclusives. The main problem is that other companies are interested but Z-biotech is ready.

Susan: So is that the issue? Time?

Sara: We only just started marketing this a month ago. They are really moving quickly.

Jenny: Have you gotten an office action yet?

Larry: You are such a skeptic.

This interaction centers on a set of ambiguities created by attempts to market this new technology. First, multiple firms want access to the innovation for diverse purposes. If the TLO staff decides to license the invention to multiple developers, they will need to negotiate clear descriptions of the non-overlapping fields in which it can be used. Aggressively marketing this invention in such a manner collapses once separate groups of developers into a single 'market,' in the sense put forth by Harrison White (1981). Here an ambiguous technology recombines markets by forcing once divergent groups of producers to take each other's actions into account as they work to develop disparate products. These firms will generally not compete for customers, instead, their responses to each other will be based in shared reliance on a single university technology. In a very practical sense, marketing this ambiguous technology creates complexity by increasing coupling across once separate sectors. In more expressly network imagery, TLO attempts to negotiate related though parallel fields of use and EPU's general focus on relationship creation through licensing result in a situation where the TLO contracts industry networks, contributing to the creation of a 'small world' (Watts & Strogatz, 1998).

This recombination of markets can occur despite, and perhaps because of, the indistinctness of EPU ownership rights. In the notes presented above,

Jenny acts as a skeptic, repeatedly asking questions about what the university actually owns. Because the US patent office has not yet responded to EPU's application (there has not been an 'office action') licensing associates have no information about the extent of their intellectual property protection. It is highly likely that the 'super broad claim'[9] touted by Sara will be struck down or modified during the course of patent prosecution.[10]

TLO negotiations of specific field of use licenses require the definition of specific boundaries to the use of a technology that as yet lacks legal definition. Because patent prosecution is a relatively long process, it is entirely possible that licensing negotiations will be completed before the extent of EPU's IP rights is determined. Interactions with the patent office introduce another layer of uncertainty to licensing negotiations and contribute to the relational quality of those deals by making it likely that their details will need to be repeatedly renegotiated in response to ongoing patent prosecution.

These descriptions of the difficulties inherent in marketing even a relatively clear university invention highlight some of the sources of ambiguity in EPU technology transfer efforts. Where Larry describes a relatively straightforward decision process that focuses on three clear inputs, discussions of technology marketing strategy in bioteam meetings suggest that technology transfer is far from unequivocal. Instead, these discussions imply a process less like a race between well defined starting and ending points, than like a rugby scrum where diverse sets of players come together to collectively push an often ill defined 'object' toward multiple and sometimes competing goals (Rosenbloom & Spencer 1996). Technological and legal ambiguities provide resources for licensing associates engaged in attempts to broadly market academic innovations. But the very ambiguities that can serve as a resource for strategic action

[9] In the language of patent rights, a 'claim' is a formal component of a patent. Claims are one sentence descriptions that formally establish the meets and bounds of IP ownership. If patents can be analogized to deeds, claims are the equivalent of descriptions of property lines.

[10] While it is not a topic for this discussion, interactions with the patent office are interesting in themselves as patent examiners are charged with reducing the ambiguity and breadth of claims while patent holders attempt to maintain exactly those ambiguities in order to achieve the broadest possible protection.

have the effect of increasing the heterogeneity and relational coupling of the markets in which innovations have value. In this sense, EPU efforts to market innovations draw on 'product' ambiguity as a resource and in so doing catalyze environmental complexity.

Recombination, robust action, and complex horizons.

Three key analytic constructs inform my thinking about the dual role of ambiguity university technology licensing. Padgett and Ansell's (1993) treatment of ambiguity as a strategic resource in the rise of the Medici in Renaissance Florence highlights strategic uses of multivocality while emphasizing that the ambiguities which enable robust action are the outcome of particularly configured social networks. David Stark's (1997, 1999, 2001) examinations of recombinant capital and organizational heterarchies in post-socialist economies also highlights strategic uses of equivocality in corporate and individual hedging strategies. Where Padgett and Ansell (1993: 264) argue explicitly that strategically useful varieties of ambiguity are the outcome of social configurations, Stark (2001:39) argues that complexity is an outcome of multiple, equivocal, principles of justification. By implying that ambiguity can catalyze complexity, Stark leaves open the possibility of feedback loops by which intentional uses of equivocality can result in changes to the landscape on which decisions made.

In an examination of strategy and complexity in the evolution of telecommunications, Lane and Maxfield (1997) further link strategic uses of ambiguity with alterations in the environment. These theorists argue that complex foresight horizons and ambiguity are flipsides of the same coin:

> . . . suppose the very structure of a firm's world – that is, the set of agents that inhabit it and the set of artifacts around which action is organized – undergoes cascades of rapid change. Then . . . the world in which you must act does not sit passively out there waiting to be yield up its secrets.

> Instead, your world is under active construction, you are part of the construction crew, and there isn't any blueprint (Lane & Maxfield 1997: 170)

At the heart of Lane and Maxfield's conception of complexity, then, is a notion of cascades of unpredictable change. In my view, indeterminate waves of change are enabled by tight coupling among heterogeneous actors.[11] It is not enough to have structural diversity, disparate systems of meaning and regimes of worth must also be connected.[12] Whether the sources of change are technological, political, or structural, heterogeneity and dense connectivity are central to both the creation of complexity and the strategic use of ambiguity.

I contend that paying attention to the details of technology marketing efforts in a single university can provide further clues to the relationship between complexity and ambiguity. EPU is home to multiple systems of meaning and principles of justification. Ongoing conflicts about the legitimacy of importing commercial norms and standards of value to academic institutions (Brown 2000) suggest internal conflicts about sources of value in university endeavors. Moreover, the distinct characteristics of some EPU technologies, the TLO's expressly long term and relationally focused licensing strategies, the diversity of scientific outputs, and the university's structural role as a bridge between otherwise unconnected market sectors suggests that licensing team meetings may be

[11] See Perrow (1984) and Vaughan (1999) for discussion of the ways in which tight coupling and rapid change in complex organizational systems can contribute to unpredictable though thoroughly 'normal' mistakes, accidents, and disasters.

[12] Note that the network structure which Padgett and Ansell (1993) believe explains Cosimo's ability to act robustly had two important features. First, the Medici family occupied a structurally powerful position as a bridge between otherwise separate and competing social groups. Importantly, however, the network itself was composed of multiple types of ties relating to family, business, and politics. Cosimo's Delphic actions, then, may have been enabled both by the tendency of rival parties not to speak with each other and by the overlap of multiple types of relationships. Under these conditions, "single actions can be interpreted coherently from multiple perspectives simultaneously" (Padgett & Ansell 1993: 1263).

ground zero for strategic attempts to turn ambiguity into advantage and for the acceleration of complexity in EPU's environment.

My discussion of the complexities inherent in licensing a university based biochemical invention suggests that attempts to capitalize on technological ambiguities can result in the creation of more complex environments for action. But what is missing from that example is the sense that licensing deals are affairs involving commitments with relatively long time horizons. Moreover, in these affairs, ambiguous technologies can lead TLO to be polygamous in the sense that they commit to relationships with multiple partners as they strive to license technologies for as many uses as possible.[13]

In this context, then, the heterogeneous connections and tight coupling that enable cascades of change in technology markets can be seen as an outcome of attempts to capitalize on ambiguous innovations. Here strategic action helps to create a complex environment, but that environment is, by its very nature, responsive to such actions. Licensing deals, then, take on a life of their own and often head in unpredictable directions as marketing strategies alter environments and those alterations in turn reconfigure the contours of deals.

Consider an extended excerpt from field notes taken during a Physci team meeting in the TLO. Where the earlier excerpt highlighted some characteristics of early

[13] Powell, White and Koput (2001) argue that it is exactly the ability to 'practice polygamy with good taste' that enables cascades of change and abrupt phase transitions in diverse biotechnology networks. Likewise, Owen-Smith and colleagues (Owen-Smith, Riccaboni, Pammolli & Powell, 2001) argue that universities and other public research institutions play a unique and essential role in U.S. biomedical innovation networks by collapsing distances among corporate competitors and enabling the information transfer and spillover benefits characteristic of small world networks (Watts & Strogatz 1998).

stage marketing strategy, the interaction that follows[14] emphasizes interconnections between the details of licensing deals and the larger environment.

Indeed, this conversation suggests that attempts to license single technologies for multiple uses in the context of technological and market change can result in complex situations. Strategically altering the conditions of one deal to accommodate transformations in the environment can have cascading effects. The technology being discussed is a particular type of lens that was originally developed for use in holographic projection. Since the TLO's first attempts to license the invention, market and technological conditions have shifted and the innovation has received interest from firms in fields as varied as high-density storage, laser holography, optical networking, and wireless technologies.

Field note excerpt: Ambiguous technology 2

Larry: Should I talk about XYZ technology? We're licensing that to P-co [a local faculty startup company] and the technologies are causing their building to brown out. So, they're moving to a new campus. In the meantime, they want to get together with us to 'clarify' some points in the license. Which of course means they want to broaden it.

Susan: [laughing] Sure, just like our 'clarify' means narrow.

Larry: Andrew says our clarify means narrow *and* charge more. We've been talking for a year about a license and over the course of that year the technology has gotten more and more valuable. So we're holding firm in our attempt to keep their field of use limited. P-co has the field of use when using F-connectors, but no one really knows what that means in terms of products or markets. So, there's some maneuvering going on here. They're trying to define optical processors with details of what an optical processor does, which is lots of things. We looked at that and

[14] Involving Larry, Susan, Megan (another 'office generalist'), and Carrie (a Physci team licensing associate).

thought, whoa, too much exclusivity. So we called them up and said no, no, no.

Now they are going for exclusivity based on a specific 4E architecture. They took that right out of Professor G's old textbook and they said 'Look, this is your university's textbook, you have to buy the definition in here.' We think we might just take that, but there are two prior non-exclusive licenses. So I said we had to go back to those companies and make the changes. But P-co said no. They just want it relative to the existing rights. So, that's the background.

Now, the catch is that under the definition of exclusivity we've been using, we've been leaving government rights but allowing no further licenses on the processors. So, we've got to handle any further developments in the technology without having them be able to say that we've broadened the new licenses to cut into their original fields of use.

Susan: Does that include the license with Foreign Multinational Corporation [FMC]?

Larry: No, the P-co field of use excludes displays.

Susan: Good, but are we ever going to get into trouble on the definition of a display?

Larry: Maybe, for FMC we define displays but do not include the methods used, because we figured the display definition was broader. I could put the same definition in the P-co license.

Susan: [looking around the conference table] Well, what do you think?

Megan: My only problem with the new definition is that if you change it with P-co and then you go to renew FMC, you're going to have to renegotiate that one as well. So I'd say we should go simpler.

Larry: Yeah, good idea. This is a really interesting case. The technology is really valuable in a bunch of broad markets, but it's so complex that the lesson is if you have to define anything cut it down as much as possible.

Susan: But the digital camera case was a lot like this one, right?

Larry: Yeah, it was very similar

Susan: I think we went exclusive but for the existing licensees there rather than trying to define fields of use. [To Megan] Would that work for the Asia Electronic case?

Megan: No, the language of fields doesn't work there because there were new companies entering old fields in new ways so the definitions just don't work. We couldn't even agree on the definition of an M-instrument so the license is just a mess.

Larry: P-Co and S-Co [a large computer firm making the move into optical storage devices] and FMC are interested. I guess my thinking is that we should try to keep the technology open as much as possible. So, if Far East Co comes along and wants in they can still get a non-ex for display technologies.

Megan: Far East wants displays too? Who's on first?

Larry: They've got the printer field too, don't forget the printers. The technology works there as well.

Carrie: So is this why the docket is still up on the web [a signal that it's available for licensing] even though it has already been licensed.

Larry: Yes.

Megan: Doesn't that just force us to keep shopping it and responding to new companies?

Susan: We need better dispute resolution clauses in these field of use licenses.

Larry: You want me to add it to this?

Susan: Yeah, add a line or two about complex fields and prior licenses

Like the bioteam's discussion of a mechanism for blocking genetic expression, this physci team discussion centers on an ambiguous technology. But this discussion involves more complications. First, it highlights a licensing deal in mid-process rather than the prospective agreement at issue in excerpt 1. Second, the lens technology is more fundamentally ambiguous than the gene expression invention.

The latter was clearly defined. Its single use (blocking gene expression to kill bacteria) could be turned to disparate markets (heart drugs, tooth paste, and laundry detergent). It's primary indistinctness, then, revolved not around its technical characteristics or uses, but around legal definitions of ownership. In contrast, the EPU lens was patented for use in one type of product (holographic projection) and the state of the art in industrial technology changed (shifting toward photonics and optical information processing and storage). As a result, the lens suddenly became a valuable commodity in multiple existing and emerging markets. Here the fuzziness was technological not legal and the invention's equivocality resulted not from straightforward uses that crossed markets, but from divergent and mutually exclusive uses in emergent and transforming contexts.

Attempts to broadly license the gene expression technology, then, increased environmental complexity by reconfiguring stable but separate markets. Here the potential for cascades of change largely resulted from the indeterminacy of patent rights. Changes to licensing agreements under these conditions might be expected to ramify through the newly connected marketplaces, but the sources of such change would be exogenous (arising from the actions of the patent office) to the relationship between strategic manipulations of ambiguity and environmental complexity.

Contrast that with the tightly interwoven imagery of the second excerpt. Here indeterminacy and the evolution (spurred in part by ongoing research at EPU) of new uses resulted in a situation where strategic attempts to capitalize on technical ambiguities in support of multiple licensing arrangements resulted in the constitution of new markets and the recombinant transformation of old ones. Under these conditions, attempts to redefine one licensee's field of use had implications for diverse firms in the same and in parallel industries.

Taken together, these two examples provide several clues about the relationship between strategic manipulations of ambiguity and levels of environmental complexity. First, they suggest that complexity may be catalyzed by broadly licensing ambiguous technologies. Multiple deals for single objects increase the heterogeneity and connectivity of disparate clusters of developers. Second, the examples indicate ways that alterations in a strategic environment might create feedback loops, linking respones to changing conditions with further environmental transformations as modifications to one deal change the context of other agreements.

Finally, these examples suggest that there may be different types and levels of ambiguity. The implications of attempts to license these two technologies appears to vary with the type and degree of their ambiguity. Following a long tradition in literary theory (see, for instance Empson 1930) I identify multiple varieties of ambiguity in university innovations. I focus on two general categories, indistinctness and equivocality. In the examples I present, the former seems to have two sources, legal and technical, and the latter dual foundations. Equivocality, it appears, can result from multiple sources of value for a single process or use (as in the gene expression case) or from multiple sources of value for multiple processes and uses (as in the use of a single lens for projection, storage, and processing). Differing combinations of types and sources of ambiguity in new technologies may alter characteristics of the relationship between ambiguity and complexity.

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