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Embedded Categories: Three Studies on the Institutional Shaping of Categories and Category Effects

by

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Dedication

My dissertation is dedicated to my wonderful wife, Elaine – whose patience, support, and encouragement played a central role enabling this research – and to my amazing children, Kendall and Mackenzie, who are a constant reminder that my most important work does not lie in these pages.

I am also grateful to my parents, Nic and Judy, for instilling the belief that anything is possible with hard work; and to Mike Lounsbury, Dev Jennings, Royston Greenwood, and Mary Ann Glynn for the intellectual guidance that focused my hard work in a productive direction.

Also, for Gary McPherson, my dear friend and mentor who inspired me to become an academic but, very sadly, passed away before it came to pass.

Abstract

Over the past fifteen years, a rich program of research has emerged among scholars interested in the role of categories within fields and industries. In this context, studies have shown that categories shape organizational and market processes by grouping firms and products in ways that convey their identities, enable commensuration, and provide a basis for social conformity. However, this work reflects a general analytic strategy of studying individual categories and the ways that they constrain their members. Building on evidence that categories may be more or less distinctive from each other, I argue that category effects are contingent and can vary in important ways depending on how categories are related to each other within a system of classification.

My research context is the field for nanotube technology; an area where pan-disciplinary scientists, established firms, and new ventures are working to develop revolutionary commercial applications for carbon nanotubes. Analytically, I focus on the system of technology categories used by the United States Patent and Trademark Office to group nanotube inventions according to their primary attributes and functions.

My first paper explores mechanisms through which technology categories became linked together, giving structure to the category system. Adapting insights from complexity theory, I show how the activities of diverse and distributed inventors cohered into a dynamically evolving structure which shaped subsequent innovation trajectories. My second and third papers show that the evolution of this structure created temporal variance in the types of category effects observed in the field. Specifically, I find that as categories became similar to each other, innovation opportunities opened for the actors within them. Inventors in these categories were more likely to innovate across multiple categories, while those in more distinctive categories pursued narrower lines of innovation. I also show that startup ventures with patent portfolios crossing multiple categories were highly valued by investors, but only when specific categories were spanned at specific times. As such, my approach adds considerable nuance to the literatures on categories, innovation, and entrepreneurship by showing that category systems can shape outcomes of interest beyond the influence of the individual categories which comprise them. (349 words)

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INTRODUCTION

Given the complexity of the social world, actors rely on categories – bounded groups of items that are perceived to be similar to each other and different from others – to simplify thought and understanding by partitioning the social world. Categorization is a ubiquitous process that plays out across a wide variety of contexts. For instance, movies are categorized into genres, patents into technology classes, countries into first world and third world, and mutual funds into high and low risk. Through this act of grouping, categories set boundaries and create shared understandings about what appropriately lies within them (Douglas, 1986; Hsu, 2006; Zuckerman, 1999). Categories have been shown to play an important role in fields and markets because they organize knowledge and attention (Ocasio, 1997), enable commensuration and evaluation (Espland & Stevens, 1998; Zuckerman 1999), convey the identities of firms and products, and affect how external audiences react to these (Glynn, 2008; Hsu & Hannan, 2005; Lounsbury, Wry, & Jennings, 2011a; Navis & Glynn, 2011). Based on these properties, a rich organizational literature has emerged over the past fifteen years examining categories and their consequences, particularly for the organizations and products that challenge their boundaries (see Negro, Kocak, & Hsu, 2010 for a review).

Although efforts in this direction have generated a number of important insights, there is a general tendency to focus on individual categories and assume that they are rigidly bounded, discrete, and equally different from each other. Canonical findings about the constraining nature of categories and the consequences for spanning between them are based on studies where classes display these characteristics (e.g., Hsu, 2006, Zuckerman, 1999)[1].

However, evidence suggests that categories can be linked together in various ways and this may affect the properties that they display (e.g., Bowker & Star, 1999; Mohr, 1998; Rosch & Lloyd, 1978; White, 1965; Zerubavel, 1997). As inter-category relationships evolve, boundaries may become more or less potent, facilitating or frustrating inter-category mobility (Ruef & Patterson, 2009; Wry, 2010), new types of identities may be established (Lounsbury et al, 2011a), and audiences may react differently to these (Wry, 2011). Further, categories that are more deeply and persistently linked to others may become focal points for action and development within a field, while others are marginalized (Garud, 1994; Lounsbury et al, 2011b). Reflecting this, organizational scholars are beginning to recognize the importance of studying the dynamics of category systems (Kennedy, Lo, & Lounsbury, 2010; Kovacs & Hannan, 2010; Ruef & Patterson, 2009). Still, this endeavor is in its nascent stages and its repercussions are only beginning to be explored.

Building on a broader program of research (Lounsbury et al, 2011a, b; Wry, Greenwood, Jennings, & Lounsbury, 2010; Wry, Lounsbury, & Greenwood, 2010; Wry, Lounsbury, & Glynn, 2011), my dissertation focuses on the ideas that category constraints should be viewed as variable and that understanding the emergence and evolution of inter-category linkages is an important scholarly endeavor. Investigating this empirically in the field for nanotube technology – a

[1]Note that I use 'category/categorization' and 'class/classification' interchangeably through my dissertation

key area of nanotechnology – I undertook three studies that focus on the emergent and fluid structure of relationships among technology categories used by the United States Patent and Trademark Office to track nanotube inventions. Each study is at a different level of analysis, examining category structure at the field level and then exploring how it affects processes at the individual and organizational levels, respectively. Additionally, I endeavor to make micro-macro linkages within each paper in order to provide more nuanced insight into the relationships that inhere between actors, category structure, and outcomes of interest. As such, I help to establish a bulkhead for the integration of insights about category systems into multiple scholarly domains and signal novel research directions that I discuss more thoroughly in each paper.

My first study examines the evolution of the inter-category relationships which gave rise to structure within the nanotube category system. Although structure is a key variable in the cannon of institutional research, it is rarely measured directly and the few empirical studies in this milieu have focused on how structures emerge among stable groups of actors in well-delimited contexts (Barley, 1986; Barley & Tolbert, 1997). However, the field for nanotube technology was populated with a diverse and changing group of actors who adhered to different meaning systems and pursued varied lines of innovation. As such, a novel approach was required to understand how inputs from these diverse sources cohered into a meaningful structure. Building on insights from complexity theory, I derive a series of predictions about the ways in which stable patterns of inter-category relationships can emerge through mechanisms such as status, mimesis, efforts to increase fit, and self-reinforcing feedback loops that endogenously push a system toward order (Anderson, 1999; Drazin & Sandelands, 1992; Kauffman, 1993).

Using negative binomial and tobit regression models, I find support for my predictions and show that the resulting category structure fluidly directed innovation within the field as activity clustered around particular sets of linked categories. My findings add to the organizational literature on categories by contributing to discussions about the dynamics of category systems (Kennedy et al, 2010; Khaire & Wadhwani, 2010; Lounsbury & Rao, 2004; Rosa & Porac, 2002). In particular, I show the importance of mechanisms that make categories more or less similar to each other and show that novel insights can emerge by focusing on evolving patterns of inter-category relationships. In addition, my findings have implications for the institutional analysis of fields and markets by suggesting that the way in which processes such as structuration and change play out may vary with a field's complexity.

My second paper explores the effects of evolving category relationships on the types of innovations pursued among the full population nanotube inventors. I find that an actor's positioning within the category system plays an important role. Competing hazard rate models suggest that inventors who are active in structurally distant categories tend to innovate narrowly in a single technology class. However, inventors in categories that become more similar to others are much more likely to strike out and innovate in multiple classes. As such, I present strong evidence that category constraints are variable and shift in concert with inter-category relationships. Moreover, my findings point to macro forces that enable and constrain innovation opportunities, offering further evidence that innovation is not simply an individual or organizational level process. Further, I find that category structure conditions the influence of alternate explanations suggested by economics, strategy, and network analysis, thus pointing to its conceptual utility across multiple theoretical domains.

My last paper examines how category affiliations affect the ability of nanotube startup firms to attract venture capital. Pace existing studies, I suggest that multiple category affiliations will cause firms to be overlooked because this conveys an unclear identity. I extend understanding of this effect, however, highlighting how it is contingent on inter-category relationships. Using hazard rate and tobit regression models, I show that venture capital flows to firms depend on which categories are spanned and when. Notably, my results suggest that an identity which is perceived as inchoate at one point of a field's development may become comprehensible (and even valuable) depending on how relationships among the categories which comprise it evolve. Thus, my results suggest that understandings about relatedness are not a static feature of two entities, as is implied in the strategy literature. My findings also add nuance to the categories literature, showing that category constraints are temporally contingent and that multiple category affiliations can have positive as well as negative effects.

My empirical context is the nascent field for nanotube technology – a prominent area of nanotechnology. Nanotubes are extremely small, strong, and light carbon-based structures that have a number of novel properties related to electrical, thermal, and light emission (Meyyeppan, 2005). Their history can be traced to the discovery of carbon (C60)—a new carbon allotrope—in 1985 by a research team at Rice University. The C60 molecule is comprised of 60 carbon atoms arranged in hexagons and wrapped into a spherical shape that resembles the geodesic domes created by noted architect Richard Buckminster Fuller. In homage, C60 is more commonly referred to as a 'buckeyball' or 'fullerene' (Berube, 2006). Nanotubes are an elongated tubular derivative of C60 whose discovery in 1991 is credited to NEC research scientist Sumio Iijima. In the following years, commentators began to speculate about potentially revolutionary commercial applications for nanotubes in products as varied as batteries, lotions, lubricants, materials, drug delivery devices, transistors, flat panel displays, computer processors, data storage devices, and others (Lux Research, 2006). Reflecting this, nanotube technology quickly emerged as a robust site of technological development with over 1000 patents applied for between 1991 and 2005. Lux Research estimated the nanotube market in 2005 to be $43 million with an annual compound growth rate of 44% (Lux Research, 2006).

Given my interest in category systems, I focus on how patents are classified by the United States Patent and Trademark Office (USPTO). The USPTO classification system encompasses over 400 distinct categories covering all areas which are patentable under U.S. law (USPTO, 2009). As with other categories, USPTO classes group similar types of inventions and distinguish them from others. For example, class #204 is for 'wave energy chemistry', class #427 is for 'coating processes', and class #313 is for 'electric lamp devices'. When a patent application is made, it is reviewed by expert examiners (typically with a PhD in a related discipline) who discern appropriate classification based on the primary claimed attributes and functions of the invention. While the system is not perfect and is open to a variety of errors, patent classes are widely used in scholarly circles to distinguish between related vs. unrelated technologies and are assumed to capture meaningful distinctions among different types of inventions (Katila, 2002; Hall, Jaffe, & Trajtenberg, 2001; Rosenkopf & Nerkar, 2001).

Importantly for my purposes, each patent also includes a full inventory of 'prior art' citations: related patents and scholarly articles that a focal invention builds on (Hall et al, 2001). Thus, as with cognate efforts at the individual patent level (e.g., Podolny & Stuart, 1995), I'm able to track the stocks of knowledge that are relevant to each technology class where there are nanotube patents. Drawing on network analytic techniques (e.g., Breiger, 1974; Mohr, 1998), I use this data to create yearly structural measures that capture the extent to which categories draw on similar or different types of knowledge. Thus, while there is important future research to be done investigating the qualitative processes of structural emergence in the nanotube field (e.g., Phillips, Lawrence, & Hardy, 2004), my specific approach follows work that locates structure in the patterned quantitative links that exist among elements in a system (Breiger, 1974; Mohr, 1998; White, 1965). To be clear, USPTO categories are not specific to nanotube technology: the classification system is used to track all types of inventions. However, the specific categories utilized and patterns of prior art cited vary widely among different technologies (see Hall et al, 2001; Katila, 2002;

Rosenkopf & Nerkar, 2001). A category enters my estimation set when the first nanotube patent in that class is applied for.

My data includes comprehensive information on each patent, inventor, organization, and scholarly article in the nanotube field through 2005. My primary data source was Nanobank (Zucker & Darby, 2007) – an authoritative and comprehensive storehouse for information about all types of nanotechnology. To distill nanotube data from this larger set, I searched for 'nanotube' as well as related terms such as C60, buckeyball, buckeytube, and fullerene. This search yielded 1128 patents, the first of which was applied for in 1991. I also gathered information on each of the 11 249 patents and 8773 scholarly articles which these patents cited as prior art. Looking at the inventor names and organizational assignees listed on each patent allowed me to begin populating a database with information on each actor and corporation involved in nanotube technology. In total, I identified 715 unique inventors and 286 firms.

For each inventor, I gathered comprehensive information about their academic discipline from the Proquest Dissertation Database. From the Web of Science Database, I also collected information about the scholarly articles that they published between 1986 and 2005[2] (17 603 in total), and the number of times that these were cited. Based on co-authors and organization affiliations listed on each patent and publication, I created detailed career histories for each inventor tracking collaborator networks and career moves.

[2] I started to gather publication data in 1986 because the discovery of C60 was published in late 1985.

I used the Compustat Database to identify the size of each assignee corporation according to its sales. I considered firms with +$500 million in sales to be large firms – 132 in total. Looking at the remainder of assignees listed on nanotube patents, I used data from the Lux Nano Report (Lux Research, 2006), the Nanotube Site (Tomanek, 2009), and Understanding Nano (Boysen, 2009) to discern which were startup firms. This search yielded 57 firms. I gathered comprehensive information from the USPTO patent database on each firm's patents (large and startup) from 1986 to 2005, totaling 501 003 patents. For startups I also tracked venture capital investments using the Zephyr Database. In total, I found information on 68 completed deals totaling approximately $250m.

In sum, my dissertation, with well-developed theory and empirical analysis provides a detailed examination of the evolving category structure in the nanotube technology field. In doing so, I offer new insights into processes of structural emergence and change, showing how order can emerge at the field level – and consequentially shape action – based on the distributed and uncoordinated activities of diverse actors (paper 1). Set against the dynamically shifting backdrop of the nanotube category system, I also show how key findings from the extant categories literature are context dependent. The evolution (or dissolution) of inter-category relationships affects the types of innovations that actors pursue (paper 2), the identities which they stake out (papers 2 and 3), and how external audiences react to these (paper 3). My findings also point to a number of potentially interesting intersections between the literatures on categories, institutions, identity, and innovation which I discuss throughout the dissertation.

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BORN TO BE WILD? STRUCTURAL EMERGENCE IN THE FACE OF ENDURRING COMPLEXITY

Over the past decade, organizational theorists have become increasingly interested in categories. This work germinated with early efforts showing that categories partition fields and markets by setting boundaries and specifying what should appropriately fall within them (Polos, Hannan, & Carroll, 2002; Zuckerman, 1999; Zuckerman et al, 2003). Following from this, a series of studies elaborated the ways in which categories help audiences to understand a firm's identity (Hsu & Hannan, 2005; Navis & Glynn, 2011), enable commensuration and evaluation, and provide an important basis for social conformity by setting out behavioral guidelines which category members are sanctioned for violating (Hsu, 2006; Hsu, Hannan, & Kocak, 2009). While this work has generated a number of important insights, the prevailing focus on individual categories has largely elided consideration of broader category *systems*.

Recently, however, organizational scholars have begun to acknowledge that category effects are conditioned by the relational structure of the classification systems which embed them at the field level[3] (Kovacs & Hannan, 2010; Lounsbury, Wry, & Jenning, 2011b; Ruef & Patterson, 2009; Wry, 2010, 2011). Rather than assuming that categories are rigidly bounded, discrete, and equidistant—as is the norm in studies of individual categories—this work suggests that category systems exhibit unique structures and that incumbent

[3] Note that I use the terms 'category' and 'classification' interchangeably throughout the paper

categories are related in various ways and levels. This may affect the potency of category boundaries, allowing actors to move more easily among categories (Ruef & Patterson, 2009; Wry, 2010) as well as opening the door for new types of identities to be established (Lounsbury et al, 2011a; Wry, 2011). At the field-level, the relational structure of categories may also direct attention and action toward some categories and away from others as sites of activity and development (Bowker & Star, 1999; Porac & Thomas, 1990; Lounsbury, Wry, & Jennings, 2011b).

Still, we have little insight into the generative dynamics of category structure. Studies have presented snapshots of category structures at different times without probing their causal antecedents (Kovacs & Hannan, 2010; Ruef & Patterson, 2009) or have examined the emergence of individual categories without considering their broader systemic effects (Khaire & Wadhwani, 2010; Lounsbury & Rao, 2004; Rao et al, 2003). Others have focused on how categories are blended together, but the focus here tends to be on very limited sets of categories and the activities of a handful of relatively homogeneous actors (Durand, Monin, & Rao, 2007; Kennedy, 2008; Kennedy, Lo, & Lounsbury, 2010; Rao et al, 2005). Classification systems typically have multiple categories, however, and many fields are populated by actors with diverse interests and identities (Glynn, Barr, & Dacin, 2000; and see Fligstein, 1997, 2001; Garud & Karnoe, 2003; Greenwood et al., 2011; Powell et al, 2011 Rao, 1994 for examples), thus adding complexity to the task of understanding the emergence of inter-category relationships. My aim in this paper is to contribute insight into how meaningful patterns of inter-category linkage emerge and stabilize action in such contexts.

To this end, I build on extant studies of category blending (Kennedy, 2008; Kennedy et al, 2011; Rao et al, 2005), and adapt insights from complexity theory to make predictions about how patterned inter-category linkages can emerge at the intersection of diverse actors and multiple categories. Much like Giddens's (1979, 1984) theory of structuration, complexity theory views order as an emergent property of individual actions at lower levels of aggregation and anticipates the potential for structures to undergo continuous adjustment and change (Anderson, 1999). It's unique strength, however, is that it helps to account for how these processes play out among diverse and distributed actors (Anderson et al, 1999; Drazin & Sandelands, 1992). Further, the theorized end point is not an institutionalized structure of relationships (Barley, 1986; Phillips et al, 2004). Rather structure is viewed as a continuous variable where rigid and objectified is one possibility, but so too is a tenuous and shifting equilibrium (Anderson, 1999; Meyer et al, 2005).

Complexity theory is not a unified theoretical approach and organization scholars have drawn on various aspects to theorize particular outcomes of interest (e.g., Brown & Eisenhardt, 1997; Meyer et al, 2005; Powell et al, 2011). For my purposes, I focus on four insights which Anderson (1999: 219-220) suggests may be particularly germane for organizational research: *First,* structure is relational; it emerges and changes based on the linkages that actors make between a system's elements. *Second,* actors try to enhance their fitness within a system and, as such, its structural properties shape action within it. At the same time, the influence of structure is not hydraulic and actors are guided by individual knowledge schemas which shape action at time *t*, given their perception of the environment at *t-1*. Even when actors have divergent schemas, order may emerge within a system based on status, mimesis, and self-amplifying feedback loops—coordination is not required. *Third*, systems evolve through the entry, exit, and transformation of their members and this tends to reinforce emergent structural dynamic. *Fourth*, structures are unlikely to become fixed in the face of complexity because new actors, knowledge and innovations are constantly being introduced.

I develop my ideas in the context of nanotube technology; one of the most prominent and well-developed areas of commercial nanotechnology (Berube, 2006; Lux Research, 2006). Nanotubes are extremely small carbon-based tubes which are very strong and light and are excellent conductors of thermal and electric energy (Harris, 2005; Meyyeppan, 2005). Given these properties, efforts are underway to use nanotubes for new types of polymers, coatings, pharmaceuticals, lubricants, batteries, computers, and display devices (Lux Research, 2006). The nanotube field is an excellent site to investigate the relationship between complexity and structural emergence because it encompasses actors that adhere to scientific and market logics as well as sub-groups representing diverse scientific disciplines and product market foci. Boundaries are also porous, allowing for ongoing churn as actors enter, leave, or make ongoing commitments to the field. Finally, there is no coordinating authority or dominant actor to impose order or reduce complexity (Fligstein, 1997, 2001). Although these factors seem more conducive to chaos than order, structure emerged even as the field was gaining complexity and evolved, in large part, because of it.

To understand this, I focus on U.S. patent data from Nanobank (Zucker & Darby, 2007) to track the types of technologies being developed. Given my interest in category systems, I pay particular attention to how patents are categorized by the U.S. patent office (USPTO) (Halll, Jaffe, & Trajtenberg, 2001). The USPTO classification system provides a very detailed way of segregating technological developments, encompassing more than 400 classes (categories) which cover all subject matter patentable under U.S. law (USPTO, 2006). Patent classes group related technologies and distinguish them from others (Hall et al., 2001). As with other cultural elements, patent categories may become linked together in meaningful ways because each patent references ‘prior art’ (previous patents which it builds on) from its own class and others (Kennedy et al, 2010; Podonly & Stuart, 1995; Rosenkopf & Nerkar, 2001). Thus, I focus on the emergence of a relational structure among categories by examining mechanisms through which patterned linkages emerge among them and guide subsequent innovation trajectories

In the next section, I develop hypotheses about how diverse actors shape the structure of a category system, even as their actions are influenced by it. After this, I present my case on the development of nanotube technology. Drawing on negative binomial and tobit regression models, I provide evidence in support of my claims. Overall, I find considerable evidence that structure emerged from the actions of an increasingly diverse array of prominent actors, consequently shaping innovative activity within the field. However, the influence that these actors had was contingent on the degree to which their individual knowledge schemas fit with the emergent category structure. I conclude by discussing the implications of my findings for research on categories, structuration, and institutional theory.

THEORY AND HYPOTHESES

The power of institutional theory is that it focuses attention on how the behavior of actors is shaped by institutionalized structures that are enduring and often operate in taken-for-granted ways (Greenwood et al, 2008; Hugens & Lander, 2009). Despite widespread recognition that structures are constituted through action, structural emergence has received little attention and efforts in this direction have focused primarily on delimited contexts with stable sets of actors (Barley, 1986; Barley & Tolbert, 1997; Phillips et al, 2004; Ranson, Hinings, & Greenwood, 1980). This is mirrored in studies that show category systems evolving toward crisp sets with clear boundaries and settled meanings (Ruef & Patterson, 2009). However, there is increasing recognition that fields and markets can be quite complex, especially in their nascent stages where boundaries tend to be porous (Lamont & Molnar, 2002), authority decentralized (Rao, 1994), and membership fragmented among actors with different identities and interests (Glynn et al., 2000; Wry et al., 2011). On the surface, this seems more conducive to chaos than structure. Indeed, some commentators have suggested that complexity must be attenuated by skilled actors who impose their vision on a field before order can emerge (Fligstein, 1997, 2001). Still, it is clear that many fields exhibit enduring complexity yet operate in relatively predictable ways (Bartel & Garud, 2008; Glynn et al, 2000; Greenwood et al, 2010; Powell et al., 2011; Wry et al, 2011). While the presence of diverse actors, identities, interests, and meanings are not wholly incompatible with structuration theory (Giddens, 1979, 1984), extant studies have tended to portray a fairly linear relationship between action, structuration, and institutionalization that is unlikely to hold in more complex contexts (Barley, 1986; Barley & Tolbert, 1997; Lawrence & Phillips, 2004; Phillips et al, 2004; Ranson et al,1980).

In order to cultivate a richer and more nuanced approach to the emergence and ongoing evolution of structure in the face of complexity, I theorize nascent category systems as a type of complex adaptive system. Before deriving my hypotheses about how structure emerges in such contexts, however, it is important to note that fields and markets contain manifold structures and that any structurational analysis must foreground some and background others (Drazin & Sandelands, 1992; Giddens, 1979). Thus, I begin by defining the structure that I focus on and outlining its expected effects.

The Influence of Category System Structure

Consistent with both complexity and structuration approaches, I define structure as patterned linkages among elements within a system that are meaningful to participants and shape behavior by providing templates for appropriate action (Anderson, 1999; Barley, 1986; Giddens, 1979, 1984). While this can take a variety of forms (see Barley & Tolbert, 1997; Jarzabowski, 2008 for good reviews), I focus on the knowledge structure of a technological field as reflected in its category system and argue that its properties at time *t* will shape how actors behave in it at *t+1* (March et al, 2000; Simon, 1996).

Starting with Harrison White and some of his students (e.g., Breiger, DiMaggio), a rich tradition of network analysis has been developed mapping interdependence between actors and categories. This is present in the early notion of 'catnet' which focuses on the 'hidden' network structure that stabilizes relationships among actors enmeshed in category systems (White, 1965) and has been systematically elaborated through the study of category affiliation processes (e.g., Breiger, 1974), Blauspace (McPherson, 1983), and the use of blockmodeling, Galois lattices, correspondence analysis, and multidimensional scaling (see Mohr, 1998 for a discussion).

Such network analytic approaches have been employed in a wide variety of settings, including the study of patents. Since patents are required to cite 'prior art'—scholarly articles and prior patents that a claimed invention builds on—researchers have been able to employ standard bibliometric techniques to analyze the relationship between patents and the overall structure of technological fields (e.g., Fleming & Sorenson, 2004; Podolny & Stewart, 1995). However, extant studies have yet to account for how patents are embedded in an elaborate system of categories that segregate different kinds of technological knowledge and practice. The USPTO classification system encompasses over 400 technology categories and covers all areas that are patentable under United States law. Each issued patent is assigned an original (primary) class by an expert examiner based on his/her assessment of its primary attributes and functions (Hall et al, 2001). To be clear, USPTO classes apply to all technological fields. However, the level of activity in each and the patterns of linkage among them vary considerably for different technologies (e.g., Fleming & Sorenson, 2004; Katila, 2002; Rosenkopf & Nerkar, 2001).

Based on this, I extend patent-level insights and suggest that patterned cross-citation linkages among categories will reveal a structure where some types of category-based knowledge are more central to the development of the field than others. My approach is based on the assertion that, by grouping patents together and detailing their intellectual history, USPTO categories communicate the types of inventions being pursued in a field and the knowledge that is relevant to them (see Phillips et al, 2004 for a similar argument about the relationship between discourse and texts). When patterned citation linkages emerge between categories, actors may view them as fitting together in meaningful ways. When a category has strong linkages to many others, it will occupy a structurally central position in a category system (Wasserman & Faust, 1994) and may thus be seen by field members as an important area of knowledge development. Categories with narrower appeal will be more thinly linked to other categories, occupy distant spaces in the category structure, and stimulate less activity. Thus, centrality in the knowledge structure of patent categories should be an important driver of patent creation. Hence,

H 1: The centrality of a category within a category system will have a positive effect on patent creation.

The Emergence of Category System Structure

A key contribution of complexity theory is that helps to account for the emergence of order based on the actions of distributed actors, each pursuing their own interests (Anderson, 1999; Gell-Mann, 1994: Meyer et al, 2005). Thus, rather than foregrounding overt power dynamics or centralized authorities (e.g., Fligstein, 1997, 2001), the focus is on how meaning emerges naturalistically and interactively through mimesis, adaptation, and selection (see also DiMaggio & Powell, 1983; Haveman & Rao, 1997). By attending to the ways in which different actors pursue their interest, link elements of a system together through their actions, and provide templates for imitation, insight can be gleaned into processes through which complex inputs create predictable outcomes (Kauffman, 1993; Gell-Mann, 1994). As such, my hypotheses focus on identifying high status actors, the variable schemas that they hold, and the ways that they catalyze knowledge interchanges among categories which are imitated and reinforced by others.

A foundational step in the analysis of complex systems is to identify the schemas—knowledge structures that provide blueprints for assessing situations and guiding action (Anderson, 1999: 221)—that agents possess. Complex systems encompass actors with many schemas and these may compete, be segregated, or symbiotic (Gell-Mann, 1994). Mirroring this conceptualization, institutional scholars have identified ‘logics’ as key cultural resources that provide blueprints for appropriate behavior, thus shaping an actor’s attention and decision-making (see Thornton & Ocasio, 2008). While early work on institutional logics focused on demonstrating the usefulness of the concept by correlating the existence of a dominant logic with behavior in a system (e.g., Haveman & Rao, 1997; Thornton & Ocasio, 1999), recent work has sought to develop a more nuanced and dynamic approach, showing that multiple logics may be co-present within a field, creating structural divisions between different classes of actors such as haute versus nouvelle cuisine chefs (Rao et al, 2003) or active versus trustee mutual fund providers (Lounsbury, 2007).

While logics may be fully embedded in established fields, they are less likely to be so in nascent ones where actors from a variety of institutional backgrounds enter an undefined space (Fujimura, 1997; McKendrick, Jaffee, & Carroll, 2003; Morrill, 2005; Weber et al, 2008). In such contexts logics may be used to justify a variety of practices rather than providing rigid guidelines for action (Boltanski & Thevenot, 1999; Sewell, 1992). In order to discern appropriate behavior in such contexts, complexity and organization theorists both suggest that actors will look to other agents for cues (DiMaggio & Powell, 1983; Drazin & Sandelands, 1992; Gell-Mann, 1994). High status alters may have a particularly strong influence because they are 'visible exemplars' of a logic (Wry et al, 2010, 2011) and tend to be targets of imitation (Haunschild & Miner, 1997). Indeed, a great deal of research emphasizes how the existence of high status actors can fuel increased activity in a category (e.g., Haveman, 1993; Podolny & Stuart, 1995). As such, identifying the logics at play within a field, as well as the activities of their high status exemplars, may provide insight into how attention and action are channeled toward particular categories, helping them to become more central in a category system.

In the carbon nanotube field, a distinction can be made between scientists whose schemas are shaped by a professional scientific logic and corporations who are more closely aligned with a market logic (Merton, 1968; Powell & Sandholtz, 2011; Trajtenberg et al, 1997). While this distinction is not absolute, there tend to be consistent differences in the types of patents taken out by these groups (see Trajtenberg et al, 1997). Based on this, I expect that categories with many patents from high status 'star' scientists or large corporations may be interpreted as important areas for other scientists and corporations to build on. According to Podolny and Stuart, "if actors working in a technological area expect that a technology will be superior, they will devote more resources to (it)… consequently, the technologies sponsored by high-status actors are more likely to be rapidly developed" (1995: 1233). Thus, patenting by star scientists and large corporations can enable relationships to develop between categories as others build on their patent in the course of pursuing inventions across a range of categories. Hence,

H2: The density of star scientist or large corporation patents in a category will have a positive effect on category centrality.

In addition to passively catalyzing inter-category relationships by providing a foundation for others to build on, complexity theory directs attention to the ways in which actors link elements in a system together more directly

(Anderson, 1999; Gell-Mann, 1994; Kauffmann, 1993). One way that this may happen is when actors span between multiple categories. Although a central finding in the categories literature is that actors are penalized for doing this (Hsu, 2006; Hsu et al, 2009; Rao et al, 2003; Zuckerman, 1999), the literature is replete with examples of actors shifting from one category to another or staking out positions across multiple categories (see Negro, Kocak, & Hsu, 2010 for a review). And, while actors who are fully embedded in a category system may also span categories, it is most likely when agents have links to other fields which expose them to new ideas and innovation possibilities (Greenwood & Suddaby, 2006; Hinings & Greenwood, 1996: 1028-1031).

Thus, for the nanotube field, one would expect scientists and large corporations to cross category boundaries as they import knowledge of scientific discoveries and evolving markets, respectively, into the category system on an ongoing basis (Podolny & Stuart, 1995; Stuart & Ding, 2006). While the nature of such shifts are difficult to predict a priori, making it unlikely that structure will emerge in a linear fashion (Anderson, 1999), spanning consequentially links categories together as actors carry knowledge and practices from one category and apply them in another (Lamont & Molnar, 2002: 187; Rao et al, 2005). For example, Rao and colleagues (2003, 2005) showed that as chefs spanned the boundary between haute and nouvelle cuisine—serving both types of dishes in their establishments and integrating elements of each to create new menu items—these previously orthogonal categories became understood as relationally linked and complementary.

I anticipate that the structural outcomes of category spanning will be most evident for high status actors. Structures are created through action (Anderson, 1999; Giddens, 1979, 1984) and strong category links only exist to the extent that many actors link the same categories together. Moreover, category systems—like all cultural structures—are dissipative and need to be maintained by reinforcing the linkages between elements on an ongoing basis (Drazin & Sandelands, 1992; Scott, 2008). High status actors are the most likely to catalyze such processes because their spanning is less likely to elicit scorn and their actions may be viewed by lower status actors as legitimate extensions of category-based knowledge, spurring them to make similar moves that reinforce emerging category links (Rao et al, 2005; Wry, 2010). Hence,

H3: High levels of spanning by star scientists or large corporations into a category will have a positive effect on category centrality

To here, I have focused on the potential for high status actors to contribute to the emergent structure of a category system. In fields with a single dominant logic, this may be sufficient to create an integrated structure that shapes the action of all members in similar ways. However, when multiple logics are co-present, the result may be a bifurcated structure where actors have divergent understandings about their individual and collective purpose (Glynn, 2000; Lounsbury, 2007; Scott et al, 2001). Collaboration across these groups is required to cultivate a more unified field level structure (Lawrence et al, 2002; Phillips, Lawrence, & Hardy, 2000; Wooten & Hoffman, 2008: 140). Through collaboration, actors negotiate meaning, import ideas and practices from disparate schemas, and lay the groundwork for new structures to emerge (Lawrence et al, 2002). Thus, when scientists and corporations collaborate, knowledge associated with each logic may be extended and transposed into a previously disparate set of categories. This type of collaboration can be difficult, however, and may be viewed as a type of category spanning that crosses greater 'distance' than simply extending extant knowledge into new domains (Kovacs & Hannan, 2010; Wry, 2011). For this reason, cross-schema collaborations initiated by low status actors may be overlooked or derided, while the same actions taken by high status actors may provide the groundwork for a deeper and ongoing interchange of knowledge among groups (Darby & Zucker, 1998; Powell & Sandholtz, 2010; Powell et al, 2010). Hence,

H4: The number of collaborations by star scientists or large corporations in a category with actors that are associated with other logics will have a positive effect on category centrality.

While attending to the multiple institutional logics in a field may reveal broad patterns of action that distinguish between groups (Lounsbury, 2007; Marquis & Lounsbury, 2007; Reay & Hinings, 2005), there may be considerable heterogeneity among their members. Indeed, evidence suggests that multiple sub-groups may adhere to a single logic (Glynn, 2008; Strauss, 1984) and these groups may be populated by heterogeneous members (Wry et al, 2011). As a result, there may be significant difference in the types of knowledge that sub-groups and their members possess (Anderson, 1999; Wooten & Hoffman, 2008). For instance, nanotube technology encompasses the efforts of physicists, chemists, biologists, mechanical engineers, and other scientists as well as corporations who are active across a wide range of product markets (Berube, 2006; Lux Research, 2006). This adds complexity to the field because these groups may work to pull the category system in a different direction based on the knowledge that they bring into the field by virtue of their institutionally plural identities (Kraatz & Block, 2008).

A key point in complexity theory is that actor' schemas are variously aligned with the structural properties of a system (Anderson, 1999; Drazin & Sandelands, 1992; Gell-Mann, 1994). As such, star scientists and large corporations will have schemas that contain knowledge that is more or less relevant to central categories within the classification system. When alignment is high, knowledge that is central within the category system occupies a similarly prominent position in an actor's schema. As a result, these actors should be more likely to draw on central knowledge in their patenting and have this reflected in the prior art citations that they make. In contradistinction, actors whose schemas are not well aligned may draw on structurally distant knowledge, even when they patent in the same category as their more well-aligned counterparts. To the extent that these prior art linkages are reinforced in subsequent patents, a category may be alternately draw into a central position in the category structure or pushed away (Anderson, 1999; Drazin & Sandelands, 1992). Hence,

H5: The degree of alignment between the structure of the category system and the schemas of star scientists or large corporations in a category will have a positive effect on category centrality.

The degree to which star scientists and large corporations have knowledge schemas that correspond with central categories may also have implications for understanding how their density, spanning, and collaborations affect an emergent category structure. For example, a higher number of well-aligned stars or large corporations in a category may send a strong signal about the relevance of this type of knowledge for development in the area. It also stands to reason that the impact of category spanning and collaboration across logics will have stronger effects when done by well-aligned actors who carry more central types of knowledge across category boundaries. Hence,

H6: The interaction between schema alignment and the density of star scientist or large corporation patents in a category will have a positive effect on category centrality.

H7: High levels of spanning into a category by well aligned star scientists or large corporations will have a positive effect on category centrality.

H8: The number of collaborations across logics by well aligned large corporations or star scientists in a category will have a positive effect on category centrality.

DATA AND METHOD

I examine structural emergence in the category system for nanotube technology – one of the most well developed domains of commercial nanotechnology (Berube, 2006; Lux Research, 2006). The history of nanotubes can be traced to the discovery of C60—a fundamentally new carbon allotrope comprised of 60 atoms arranged in a spherical shape—in 1985 by a team of research scientists at Rice University. Carbon nanotubes are the cylindrical variant of C60 and were discovered in 1991 by NEC research scientist Sumio Iijima. While only a few nanometers in diameter, nanotubes are extremely strong, light, and are excellent conductors of light, heat, and electricity (Harris, 2005; Meyyeppan, 2005). Based on these properties, commentators have theorized revolutionary applications for nanotubes in technologies as diverse as batteries, drug delivery devices, materials, lubricants, lotions, circuits, and display devices (see Lux Research, 2006). Nanotube patenting began almost immediately after their discovery and has grown rapidly with well over 100 patent applications per year in the new millennium. Given that the field has open boundaries, multiple logics, and a variety of scientific and corporate sub-groups, it is an excellent site to study structural emergence in the face of complexity.

Data and Data Sources

My patent data is from Nanobank; an authoritative and comprehensive storehouse for nanotechnology data (Zucker & Darby, 2007). To identify nanotube patents from this larger set, I searched for ‘nanotube’ and an array of related terms such as ‘C60’, ‘buckyball’, ‘buckytube’, and ‘fullerene’ which I identified by consulting nanotube research compendiums (Berube, 2006; Harris, 2006; Meyyeppan, 2005). My search yielded 1128 patents though 2005 (when the Nanobank data ends), the first of which was applied for in 1991. For each patent, I recorded the title, abstract, primary classification, secondary classifications (where applicable), inventor names, organization assignee, application date, and issued date. In a separate database, I recorded the prior art citations for each patent, totaling 11 249 patents and 8773 scholarly articles. I searched the USPTO patent database to identify the primary category affiliation for each cited patent (USPTO, 2009). I gathered additional data to determine which patents were issued to star scientists and large corporations, and the degree to which their schemas contained knowledge that was relevant to central categories: I discuss this data and its sources in the next section.

Variable Definitions

Dependent variables

My first dependent variable is the yearly count of patent applications per category year. This follows conventional practice in patent studies where variables are based on application dates, rather than when a patent was granted. This is considered to be a more accurate measure of when a patent was created and avoids bias associated with variation in USPTO processing times (Hall et al, 2001). Data structure is by category year with classes entering the estimation set the year of their first nanotube patent application. Based on the low number of patent applications through 1992, my analysis runs from 1993-2005.

My second dependent variable is the centrality of a category within the nanotube category system. Following approaches that analyze structure according to category clusters (Breiger, 1974; DiMaggio, 1987; Mohr, 1998), my variable captures similarities in the stocks of knowledge utilized in different patent categories. To calculate this, my first analytic step was to construct yearly two-mode matrices of focal patent classes by cited patent classes. While there is no established method to determine a structure's dissipative rate, studies suggest that a patent's influence begins to wane at three years and is significantly eroded by five years (Hall et al, 2001; Rosenkopf & Nerkar, 2001). Thus, my matrices track citations in rolling five year windows. As a robustness check, I also calculated centrality variables based on matrices with three year windows: similar results were obtained.

Next, I calculated what network theorists refer to as joint involvement or affiliation data (Breiger, 1974; Waserman & Faust, 1994) which I then transformed into similarity matrices using Pearson's correlation method – a typical technique for analyzing co-citation similarities (see Bensman, 2004). Finally, I used UCINET to calculate closeness centrality scores for each patent category (Borgatti, Everett, & Freeman, 1999). This is the most appropriate measure of spatial distance when not analyzing direct ties between actors as is the case with affiliation matrices (see Wasserman & Faust, 1997). Scores capture the degree to which a category is relationally similar to all others in the system. Data structure is by category year, with categories entering the estimation set the year when they received their first nanotube patent application. Analysis is from 1993-2005.

My approach also facilitates the visual mapping of the nanotube category structure through multidimensional scaling (MDS) plots. Based on the same matrices as my centrality calculations, MDS visually maps similarities among categories based on Euclidean distances in n-dimensions. When categories are close together it is because they share similar citation patterns, otherwise they are far apart. Stress levels for two-dimensional solutions ranged from 0.08 to 0.14; well within the limits considered to produce accurate plots (Kruskal & Wish, 1978). Figure 1 shows five well placed MDS panels plotting the evolution of the nanotube category structure.

Finally, in supplementary models, I investigated how the membership composition of the nanotube field might change depending on the properties of the category structure (Anderson, 1999; Haveman & Rao, 1997). I estimated separate models for star scientists and large corporations where the dependent variable is the yearly count of patents applied for by each actor. Data structure is by actor year, with actors entering the estimation set when they apply for their first nanotube patent: analysis runs from 1993-2005.

Independent Variables

Star and large corporation density. Star scientist density is a yearly updated count of the patents in a category issued to prominent scientists. I calculated this variable in four steps. First, I looked at the inventor names listed on each patent. From this, I identified 715 unique inventors. Second, based on evidence that scholarly citations are the most relevant measure of status in scientific fields (Stuart & Ding, 2006; Zucker & Darby, 1998), I searched the Web of Science database for each inventor's publications, beginning in 1986 (the discovery of C60 was published in November, 1985 (Kroto et al, 1985). To help ensure accuracy, I used a name matching algorithm which looked at name compatibility, co-authors, and article key words to assess the likelihood that similar named authors were indeed the same person (see Strotmann, Zhao, & Bubela, 2009 for a detailed discussion of the algorithm). In total, this search returned 17 603 scholarly articles. Based on the affiliations listed on each actor's patents and publications, I determined whether they were associated primarily with an academic institution (university or research lab) or a corporation. Third, I constructed cumulative yearly citation reports for each inventor using Web of Science citation data. I considered inventors with +1000 citations to be 'star scientists'; this worked out to 82 inventors—68 of whom were affiliated with academic institutions. Finally, I counted the number of patent applications made by academic star scientists per category year

Large corporation density is a yearly updated count of patents in a category issued to prominent firms. To identify these firms, I looked at the assignee organizations listed on each patent. Drawing on Compustat data, I coded firms with +$500 million in yearly sales as large corporations. In total, 132 firms met this criterion. I excluded patents from the 14 corporate-affiliated stars when calculating my density variables but included them when calculating collaboration variables.

Spanning and Collaboration. Star scientist and large corporation spanning are yearly updated counts of patents issued to these actors in a category that resulted from category spanning. I define category spanning as the first patent that an actor takes out in a new category after previously patenting in another category (or categories) (Hsu, 2006; Hsu et al, 2009; Zuckerman, 1999). Star scientist collaboration is a yearly updated count of patents in a category that star scientists have taken out jointly with corporate actors. To determine this, I looked at each star scientist patent. In cases where the assignee was a corporation (large or small) I coded them as collaborations. Large corporation collaboration is an equivalent measure tracking the extent to which prominent firms in a category collaborated across logics to patent with academic actors. In total stars collaborated with corporations 121 times and large firms collaborated with academics 203 times. There were 33 collaborations between stars and large firms which I counted as star collaborations *and* large corporation collaborations. In addition to my reported models, I estimated others where these collaborations were included as a discrete variable: this did not affect my results.

Schema alignment. These variables track the average degree to which the knowledge structures of star scientists and prominent firms in a category accords with the types of knowledge that are relevant to central categories in the classification system. For star scientists, I calculated this variable in four steps. I used scholarly articles as a knowledge proxy based on evidence that publications are a scientist's primary form of intellectual capital (Frickel & Gross, 2005; Stuart

& Ding, 2005). First, I drew on the 17 603 inventor articles in my database to create a publication profile for each star scientist. As with my category structure variable, a scientist's knowledge structure in a focal year is based on their previous five years of scholarly activity. Second, I assessed which publications were relevant to the development of nanotube technology by cross-matching each scientist's publications against the articles in my prior art database. When an article was referenced, I recorded the centrality of the citing category. Third, I calculated yearly measures of the average knowledge centrality for each publication and combined these into an aggregate yearly schema alignment measure capturing the overall degree to which a star scientist's publications were relevant to central areas of the category structure. Fourth, I aggregated these scores up to the category level, calculating the average schema alignment for all of the star scientists who were active in a focal category-year.

I assessed the schema alignment of large corporations following a similar procedure, but using patent data. Although some firms are active publishers, evidence suggests that the primary aim is typically to apply knowledge for commercial gain through patents (Dasgupta & David, 1994; Powell & Sandholtz, 2011). Drawing on the USPTO patent database, I gathered a complete inventory of each firm's patents from 1986 through 2005 (USPTO, 2009). In total, my search yielded 500 728 patents spread among 132 firms. I cross matched these patents against those in my prior art database and, when they were referenced, recorded the centrality of the citing category. From here, I followed the same procedure that I used to calculate star scientist schema alignment and aggregated up to the category level to construct the reported variable.

As a general data limitation, I acknowledge that actors may have relevant knowledge that is not captured in prior art citations. However, it is a criminal offense for inventors to withhold relevant citations that they are aware of and one of the primary roles of patent examiners is to utilize their expertise in the relevant prior art to ensure an exhaustive inventory is listed on each patent (Alacer, Gittelman, & Sampat, 2008). Patents also go through a series of reviews by senior examiners where citations are checked and edited (USPTO, 2009). As such, there is unlikely to be any systematic bias in my measure and citations likely capture a significant proportion of an actor's nanotube-related knowledge.

Schema alignment, density, spanning, and collaboration. To assess the interaction between schema alignment and the density of star scientists or large corporations in a category, I constructed interaction terms as follows: star schema alignment X star scientist density; Large corporation schema alignment X Large corporation density. To examine the joint influence of schema alignment and category spanning, I weighted my star and large corporation spanning variables according to the knowledge structure of the spanning actor. I assessed the joint influence of schema alignment and cross-logic collaboration in like manner.

Control Variables

I control for effects over the life-course of a category in two ways: 1) New category is a dummy variable set to '1' in the first of its first nanotube patent application; 2) Category age measures the number of years that a category has existed in the nanotube category system. I also control for the generality–or technological breadth—of a category (Benner & Waldfogel, 2008). While a patent's primary classification reflects its core attributes, secondary classes may be assigned to cover additional features (USPTO, 2009). Patents that make broad sets of claims are assigned a greater number of secondary classes. By summing the number of distinct secondary categories assigned to patents within a focal category and dividing by the total number of patents in the category, I control for the breadth of relevance that patents in a category have to patents in other categories (Benner & Waldfogel, 2008; Henderson et al, 1998). Category importance is the number of times that patents in a category were cited by other nanotube patents. Citation counts are a widely accepted proxy for the value of a patent (or patent category) and its importance for subsequent innovation (Hall et al, 2001; Harhoff et al, 1999). I summed the citation count of all patents in a category up to the prior year and divided by the number of patents in the category. I also control for the potential contribution of patent examiners to the category structure (Alacer et al, 2008) with a variable capturing the number of classes where they have examined patents over the past five years—and thus are thought to have expertise. The reported variable is the average number of examiner classes per category year.

In supplementary models predicting an actor's future participation in the nanotube field, I also include two controls specific to star scientists: 1) the academic discipline of each from the Proquest Dissertation Database; 2) yearly academic publications. I also include two large firm specific controls: 1) annually updated research and development expenditures from Compustat; 2) yearly non-nanotube patents. For both sets of actors, I include a dummy variable set to '1' if the scientist/firm is located in Boston, Houston, or the San Francisco Bay Area; the three top regions for nanotube research (Darby & Zucker, 2007; Wry, Greenwood, Jennings, & Lounsbury, 2010). I also control for the total number of nanotube patents issued to each actor.

Method of Analysis

For models predicting patent rates (Tables 2 and 5), I conceptualized patent applications as an arrival process based on a non-negative count variable. As such, model estimation was performed using negative binomial regression with a maximum likelihood estimation procedure. I chose the negative binomial approach over poisson regression because the distribution of my dependent variable shows evidence of over-dispersion (the conditional variance of the entry process is greater than the conditional mean) (Cameron & Trivendi, 1986). I included category and year fixed effects to help account for unobserved temporal and category level variance. In models predicting actor patenting, I included actor and year fixed effects. I used the *xtnbreg* command in STATA 11 for model estimation.

I used tobit regression for models predicting category centrality (Tables 3 and 4). Tobit regression is a non-parametric alternative to ordinary least squares regression and is typically used in cases where the dependent variable is continuous but skewed (or censored) on either side of the distribution. In my data, category centrality is left censored at zero and right censored at the maximum centrality point, making tobit regression an appropriate estimation strategy. Also, since my data include repeat category-year observations, I again included category and year fixed effects to control for unobserved temporal and category-level variance. Models were estimated using the *xttobit* command in STATA 11.

RESULTS

Table 1-1, provides the means, standard deviations, and correlations for the variables used in my analysis and shows that there are no correlation problems. Importantly, the correlation between the density of star scientists and large corporations in a category was quite low (.182), reinforcing my conceptual distinction between these two classes of actors. Indeed, star scientists tended to patent in categories linked to basic science advances (e.g., #204: wave energy chemistry , #252, compositions, #423: inorganic chemistry) whereas large corporations typically focused in more applied product categories (e.g., #313: electric lamp discharge devices, #361: electricity, systems and devices, #365: information storage and retrieval).

---------Table 1-1 about here---------

Category patent rates. Table 1-2 reports results for my analysis of category-year patenting: model 1 is a baseline with just controls, model 2 adds star and large firm density variables, and model 3 adds category centrality. Hypothesis 1 argued that the structural composition of the nanotube category system would affect how actors behaved within it. Model 3 provides strong support. Even after controlling for patent density, generality, and importance—variables which extant studies have suggested are important predictors of patenting (e,g, Hall et al, 2001; Harhoff et al, 1999; Henderson et al, 1998; Podolny & Stuart, 1995)—centrality has a strong and highly significant effect ($p<.001$) on subsequent patenting in a category.

---------Table 1-2 about here---------

Figure 1-1 presents MDS plots at three year intervals showing the structural evolution of the nanotube category system. As anticipated by complexity theory, plots show that the category structure is continually evolving at the same time that it shapes the behavior of actors within it. Initially, patenting was spread out among disparate categories with no clear pattern of linkage among them. By 1996, however, we can see visual evidence that structure is emerging with a core set of categories clustering together. This pattern continues through 1999, with the central cluster encompassing a growing number of categories. Around the turn of the millennium, however, there was a proliferation of actors entering all domains of nanotechnology, including nanotubes (Berube, 2006; Lux Research, 2006; Meyyeppan, 2005). By 2002, their effect on the category system is readily visible. While the emergent structure of core categories was reinforced and elaborated, many new categories also emerged and were spread across diverse structural positions. Notably, two 'fingers' started to separate from the core group of categories as the structure was pulled in new directions by actors who drew on central knowledge and integrated it with their broader schemas to stake out positions in new sets of categories. This general process continued through 2005, as tighter linkages emerged among categories in each ‘finger’, but dissipated among ‘core’ categories which began to comprise a more loosely packed set. I discuss these dynamics in more detail as I report on my category centrality models.

---------Figure 1-1 about here---------

Category centrality. Turning to the question of how structure emerges through the distributed actions of diverse agents, Tables 1-3 and 1-4 show the results of models predicting category-year centrality. Model 1 is a baseline with control variables, models 2 through 4 add hypothesized variables, and model 5 is the full model testing hypotheses two, three, and four. Table 4 tests the effects of schema alignment on category centrality with models 6 through 9 adding hypothesized effects. Model 10 is the full model of all hypothesized variables. As I report my findings, I provide details to help make contextual links to the structural plots in Figure 1-1. In doing so, I foreground particular actors and categories while backgrounding others. I also focus on the influence of certain explanatory variables in particular time periods, even though their effects are robust across the analysis period. As such, my discussion should be viewed as illustrative, and not an exhaustive account of the observed structural arrangements.

Hypothesis 2 argued that categories with a higher density of star scientists or large corporations would become more central within the category system. Model 2 shows some support for this. However, the effect is significantly diminished in model 5 when spanning and collaboration variables are included, and disappears entirely when schema alignment variables are introduced. Thus, I find weak and contingent support for the global effect of high status actors in a category. Hypothesis 3 focused on the effect of category spanning by prominent actors. Models 3 and 5 show that spanning by star scientists and large corporations has a marginally significant effect on category centrality ($p<.05$). Thus, I find some support for the argument that high status actors contribute to structural emergence by actively linking categories together. I fail to support hypothesis 4, however, suggesting that collaboration across logics has little effect on category structure when analyzed at the level of *all* star scientists and large firms.

Although I do not find strong support for the effects of star scientists and large firms on category structure, writ large, a different picture emerges when I account for the specific knowledge schemas that these actors possess. Model 6 shows that when star scientist or large corporations possessed knowledge that was relevant for development in central categories, their presence in a category has a strong effect on its subsequent centrality ($p<.01$). This effect is consistent throughout the models in Table 1-4, providing considerable support for hypotheses 5 and suggesting that the activities of well-aligned actors are an important predictor of category structure. Interestingly, however, the effect of schema alignment is not amplified with more well-aligned actors in a category, failing to support hypothesis 6. As such, the effect of prominent actors is strongest when they infuse knowledge from central areas of the category structure into a focal class: trait-based imitation seems to be more important than frequency-based imitation in this context (Haunschild & Miner, 1997).

---------Tables 1-3 and 1-4 about here---------

Examining the effects of schema alignment in more detail, the MDS plots for 1996 and 1999 show a cluster of central categories starting to emerge: many associated with nanotube synthesis and production (e.g., #204: wave energy chemistry, #423: inorganic chemistry, #585: hydrocarbon chemistry). Among the actors in these categories were prominent and well-aligned inorganic chemists and physicists, such as Richard Smalley of Rice University and Charles Lieber of Harvard, who were responsible for many of the foundational discoveries in nanotube science (Harris, 2005; Meyyeppan, 2005). Looking at the prior art cited in their patents, it is clear that they were drawing on knowledge that was central within the emerging category structure: this included many of their own patents (suggesting tight linkages with their knowledge schemas) as well as a broader range of patents from structurally similar and central classes. As a result, these categories emerged as prominent sites of patenting. Moreover, others tended to follow the general pattern of prior art linkages set out by Smalley, Lieber, and their high profile contemporaries, effectively reinforcing the emerging core. Tellingly, this basic dynamic was mirrored across central categories despite considerable variance in the number of patents from well-aligned stars. To wit, category #423 had more patents than #204, and many more than #585.

During the same time period, a number of prominent bio-scientists and organic chemists were working on projects attempting to utilize nanotubes for biotechnology and other organic applications (see Harris, 1999; Meyyeppan, 2005). Despite their prominence, these scientists' knowledge structures were comparatively misaligned with the emerging category structure. Consequentially, the categories where they were active tended to occupy structurally distant locations (e.g., # 434: molecular biology, #435: immunology, #514: drug compositions). This basic pattern was mirrored among large firms, such as DuPont, Exxon, and Goodyear, who were working on nanotube polymer applications (e.g., #524: synthetic resins, #548: organic compounds), but whose knowledge was not relevant for structures did not align well with the category structure. Interestingly, these categories were among the most active sites of early nanotube patenting. However, they did not converge on central areas of the category structure and actors began to desert them in the late 1990's. Interestingly, though, patenting re-emerged in the post-millennium years after well-aligned stars like Richard Smalley began spanning into these categories, thus drawing them into the category structure.

Reflecting this, empirical results support the hypothesized effect of category spanning by well-aligned actors. Models 8 and 10 show that category spanning by well aligned actors has a strong and significant influence on category centrality, providing considerable support for hypothesis 7. As such, the effects of category spanning appear to vary based on the types of knowledge that actors take across category boundaries: spanning by well-aligned actors draws a category into the emergent knowledge structure, while spanning by actors with incongruent schemas pushes a category away.

Indeed, the initial core of the category system appears to have been knit together in important ways through the spanning of well aligned scientists and corporations. In the initial years of nanotube patenting, star scientists were not only active patenters, but also category spanners. In addition to taking out some of the foundation patents for nanotube synthesis (classes #204, 423, 585), a number of well-aligned inorganic chemists and physicists worked to extend this knowledge into categories for basic materials and conductivity applications (e.g., #117: crystal growth, #257: transistors, #427: coatings, #428: stock materials). As they knit these classes together through their spanning, others followed, reinforcing the links that they had made (cross-traffic among categories 117, 204, 257, 423, 427, 428, and 585 accounted for over a third of all category spanning that took place between 1996 and 1999). Reflecting this patterned cross-traffic, these classes occupied structurally similar positions in the core set of categories: this is particularly evident in the 1999 MDS plot.

Likewise, firms such as Hitachi, Samsung, and Sony began to enter the nanotube field, making heavy investments in nanotube display devices around the millennium (see Lux Research, 2006). In the 1999 MDS plot, key categories in this pursuit (e.g., #313: electric lamp displays, #445, electric lamp manufacturing) are apparent just outside of the core set of categories. By 2002, these firms spanned a number of categories associated with nanotube displays and optics (e.g., #250: radiant energy, #352: optics, motion pictures, #353: optics, image projectors). Smaller and startup firms tended to follow into these categories—mirroring the broad citation patterns being made by the large corporations—and cultivating patent portfolios that spanned across many of the same categories. Indeed, a close examination shows that the horizontal ‘finger’ in the MDS plots for 2002 and 2005 is comprised of classes associated with optics and displays, many of which mirror the category spanning links made by prominent and well-aligned electronics firms.

I also find evidence in Models 9 and 10 supporting the idea that well aligned stars and large corporations contributed to the structural integration of the disparate categories where these groups patented. This is particularly evident when comparing the MDS plots in 1996 and 1999 with those in 2002 and 2005.

In 1996 and 1999, not only were star scientists and large firms patenting in different sets of categories, these occupied discrepant positions within the category structure. The bulk of star scientist patents clustered around the emerging core set of categories linked to nanotube synthesis and basic applications (e.g., classes #117, #204, #257, #423, #427, #428, #585). However, large firms were concentrating primarily in structurally distant classes for organic and polymer applications (far right of the 1996 and 1999 MDS plots). Indeed, when firms like DuPont, Exxon, and Goodyear were patenting in classes for organic and polymer nanotubes, not only were their schemas poorly aligned, the few scholarly collaborators that they had were similarly misaligned (e.g., JP McCauley, Long-Yee Chiang, Paul Fagan). While my data cannot say whether or not subsequent firms learned from this, many began collaborating with well-aligned star scientists, even as they drew on their own disparate expertise to pioneer new applications in display devices and memory chips. For example, startup firm Nanosys actively cultivated partnerships with Charles Lieber and other star scientists who had patented in classes related to nanotube synthesis and materials when taking out their foundational flash memory patents (Lux Research, 2006). This was mirrored by a variety of startup firms as well as large corporations such as AMD and Intel who capitalized on collaborations with academics in their memory-device patents. Looking at the MDS plots for 2002 and 2005, it is clear that the structural gap between star and large corporation patents had closed considerably, due at least in part to cross-logic collaborations among well-aligned actors. Tellingly, a closer look at the vertical 'finger' extending from the core group of categories in the 2002 and 2005 plots reveals categories associated with logic gates (#200, #335), storage devices (#360, #365, #369), and data processing (#700, #710).

Supplementary Analysis: Fitness and Participation

Given the effects of well-aligned actors on the category structure, I decided to investigate whether or not fit also affected the level of an actor's participation in the category system. A key point in complexity theory is that systems evolve through feedback loops: actors are aware of the systems that they are in, seek well-fitting positions, and commit more energy when they perceive a high level of fit (Anderson, 1999; Drazin & Sandelands, 1992; Kauffman, 1993). As such, the composition of actors in a system is expected to vary over time and reinforce emergent structuration as well-aligned actors make stronger commitments to the system while others demur. This mirrors the general point in organizational ecology that actors tend to be selected out of (or remove themselves from) systems that they are not well suited to (Hannan & Freeman, 1989; Haveman & Rao, 1997). Table 1-5 presents negative binomial models of the number of nanotube patents issued per year to each star scientist and large corporation in my sample. Overall, there is strong evidence that actors with more closely aligned schemas become more active in their patenting. Moreover, this finding is robust across star scientists and large corporations, even after controlling for individual factors associated with higher patenting such as academic publications, patent importance, and research and development expenses (Azoulay, Ding, & Stuart, 2007; Bound et al, 1982; Zucker & Darby, 1998).

---------Tables 1-5 about here---------

Indeed, evidence suggests that, in many cases, actors ceased patenting all together as their schemas and the category system evolved away from each other. As noted, in the 1996-1999 period firms like Exxon, DuPont, and Goodyear were active patenters, but poorly aligned with the category system. At the same time, comparatively well aligned inorganic chemists and physicists began patenting at increased rates, progressively bringing categories where they were active into central positions and pushing Exxon, DuPont, Goodyear (and others in their ilk) further out of alignment. Occupying distant posts in the category system while activity clustered in disparate areas, these firms began to withdraw from nanotube patenting in the late 1990s and stopped altogether by 2001. Table 1-5, models 2 and 3 suggest similar dynamics for successive streams of poorly aligned bio-scientists who were trying catalyze activity in categories for medical nanotube applications (e.g., classes #424, #435, #436, #514).

Conversely, in the post-millennium years, an array of new corporate entrants began to pull the category structure away from the core that was formed in its foundational years. Through this, some star scientists who were previously well-aligned with the category structure became less so. Indeed, between 2002 and 2005, categories for electronics and display devices moved toward the center—but did not draw heavily on basic science classes to do so—focusing on prior art from more applied classes instead (e.g., #117, #252, #257, #427, #428). Consequentially, classes such as #204 and #585 that contained some of the foundational nanotube patents shifted away from their structurally central positions. This basic pattern was mirrored among cognate basic science categories and is visually evident in the dispersion of previously core categories in the plots for 2002 and (especially) 2005. As the category structure evolved away from scientists with expertise in these areas, their patenting fell (to be clear, some—like Richard Smalley—evolved with the system and shifted their patenting to other categories) and some stopped all together.

As such, the co-evolution of schemas and category structure appears to reinforce emergent structural dynamics to the extent that well-aligned actors ratchet up their activities and crowd out misaligned actors who demur as their fitness within the system wanes (Anderson, 1999; Haveman & Rao, 1997). At the same time, however, new entrants can introduce diverse meanings which draw the category structure in novel directions, effectively setting the stage for new groups of actors to influence its structural dynamics.

DISCUSSION AND CONCLUSION

In this paper, I explored how order emerges from complexity. Although structure is a key independent variable in the institutional analysis of fields and markets, few studies have examined its emergence and those which have tend to focus on stable sets of actors operating in well-delimited contexts (Barley, 1986; Barley & Tolbert, 1997; Jarzabowski, 2008; Lawrence & Philips, 2004; Orlikowski, 2000). Although these studies offer a range of valuable insights, scholars are increasingly recognizing that complexity and plurality exist within many fields (Glynn et al, 2000; Greenwood et al, 2010; Greenwood et al, 2011; Kraatz & Block, 2008; Meyer & Scott, 1991; Pache & Santos, 2011a, b; Wry et al, 2011). Given that structure is characterize by the emergence of stable and repeated behaviors (Barley, 1986; Giddens, 1979, 1984), the existence of multiple logics, permeable boundaries, and diverse sub-groups within a field seem to be antithetical to structural emergence. Reflecting this, some commentators have suggested that reducing complexity is an important pre-condition of field emergence (Fligstein, 1997, 2001; Ruef & Patterson, 2009). Yet, it is clear that some fields exhibit enduring complexity without devolving into chaos (Greenwood et al, 2011, Pache & Santos, 2011a; Meyer et al, 2005).

To help resolve this apparent contradiction, I drew on complexity theory which suggests that order can emerge naturalistically through the distributed actions of diverse agents who are each pursuing their own interests (Anderson, 1999; Anderson et al, 1999; Drazin & Sandelands, 1992; Gell-Mann, 1994; Meyer et al, 2005). The central premise of this line of thinking is that complex systems naturally evolve toward stability (however tenuous) through non-coercive means. Showing how key insights form complexity theory mirror established premises in macro organizational theory, I theorized the category system for nanotube technology—a domain beset by multiple logics, diverse actors, and manifold product applications—as a complex adaptive system. Despite this complexity, the nanotube category system became structured in ways that consequentially shaped the behavior of actors within it. Exploring the emergent dynamics of this structure in more detail, I found that prominent scientists and corporations played a key role by linking categories together through their patenting, spanning, and collaborations, but only to the extent that their schemas were congruent with the category structure. Moreover, as the category system shifted over time, agents became more or less aligned. This affected their participation in the system and, in turn, the evolution of its structural arrangements.

Although my findings provide considerable support for my hypotheses, this research has some limitations. One general limitation is that my data does not account for the materiality of nanotubes or their relative strength compared to alternative technologies. While revolutionary applications for nanotubes have been theorized across a range of domains (Meyyeppan, 2005), they may not be equally suited to each. Moreover, other technologies may become more attractive development alternatives, diminishing the allure of some nanotube applications. For example, nanotube circuits compete with ongoing advances in silicon etching and lithography (Lux Research, 2006) and theorized biological applications for nanotubes may be better suited to other nanotechnologies such as quantum dots (Delerue & Lannoo, 2004). In addition, my schema alignment variable relied heavily on prior art citations in nanotube patents. While this measure had considerable explanatory purchase, it is not exhaustive of all of the relevant knowledge that actors may bring into a category system. For example, firms may have expertise in particular technologies which affects their nanotube patenting. Corporations and academics may also interact informally at conferences and tradeshows that are not captured in my patent analysis (Meyer et al, 2005). Thus, as with any study of complex adaptive systems, my analysis engages some aspects of complexity, but is by no means exhaustive (Anderson, 1999).

My findings are of interest to scholars studying complexity and institutions as well as those who examine the role of categories within fields and markets. For institutional theorists, my approach provides novel insights into issues of structural emergence and change. In particular, by drawing on complexity theory, I show that structuration can be a distributed process that sits at the intersection of diverse agents and schemas. As such, I show how actors can contribute to the structures that embed them by pursuing their own narrow interests rather that participating overt institution-building activities such as institutional entrepreneurship (DiMaggio, 1997; Lawrence & Phillips, 2004) or social movement advocacy (Schneiberg & Lounsbury, 2008; Weber et al, 2008). As such, complexity theory evokes an image of fields as 'systems of distributed decisions' rather than coordinated action.

To be clear, I do not discount the role of power, coercion, and coordination in structuration processes. While these were not apparent in the nanotube field, they are clearly prominent in other contexts: groups spar, conflicts exist, and actors work to impose their will on others. This is not inconsistent with my approach, however, and is directly theorized in complexity theory. To wit, there is widespread recognition among complexity theorists that systems may encompass multiple and competing schemata (Anderson, 1999; Gell-Mann, 1994). When groups compete, this creates additional complexity and structure may evolve in non-linear steps as groups abide temporary truces oriented around shifting power-positions (Hargrave & Van de Ven, 2006). As such, my study provides further support for the utility of a more nuanced and relational approach to institutional logics (Delbridge & Edwards, 2008; Reay & Hinings, 2005; Zhao & Wry, 2011). Indeed, the structure and stability of practices pursued by the groups which populate a field may be consequentially shaped through relationships with groups following different logics: contestation has different structural implications than partitioning (Lounsbury, 2007), symbiosis (Delbridge & Edwards, 2008), or domination (Thornton, 2002). As such, the interplay of logics is an important contextual factor which adds an additional level of complexity to be accounted for in future studies.

In addition, the level of complexity in a system may have implications for understanding how it changes. Although patterned structural arrangements emerged within the nanotube category system, they were never settled or objectified. Thus, while macro organizational theorists typically portray institutionalization as the end point of structuration (Barley, 1986; Lawrence & Phillips, 2004; Phillips et al, 2004) and focus on the effects of institutionalized structures on action (Heugens & Lander, 2008), my findings suggest a more subtle and recursively evolving relationship where structure and action co-evolve and change on an ongoing basis (see also Lawrence et al, 2002; Brown & Eisenhardt, 1997). Moreover, the ongoing and non-linear changes that I observed took place against the backdrop of stable institutional logics. As such, stability at one level may mask considerable dynamism at others, suggesting that institutional change may be a level of analysis issue as much as an ontological one (Lounsbury & Crumley, 2007).

Moreover, the type and level of change observed in a given field or market may be a function of its complexity. For example, my results suggest that complexity has an inverse relationship with institutionalization: ongoing innovation, membership churn, and knowledge importation prevent an emerging structure from settling. In such cases, ongoing, incremental, and non-linear change are likely the norm (Anderson, 1999; Hinings & Greenwood, 1996; Meyer et al, 2005). However, when there is less complexity, structures may become less fluid with a clear set of stable and recurrent practices evident across actors. Given the resilience and rigidity of institutionalized structures, change will likely require concerted efforts geared toward producing radical and stochastic shifts (see Barley, 1986; Barley & Tolbert, 1997; Greenwood & Suddaby, 2006; Rao et al, 2003).

In this way, my study also suggests looser links between logics and practices than is typically portrayed in the extant literature. While a number of studies implicitly recognize that a logic can support diverse practices—for example Lounsbury and Crumley (2007) showed that an active investing logic supported an incredible array of mutual funds—my approach makes this explicit and suggests that while logics may set the outer boundaries for acceptable action (Clemens & Cook, 1999), they allow leeway for structuration processes that bring some practices to the fore while others are neglected (Lounsbury et al, 2011). Theoretically, then, a single logic could serve as a 'logic of justification' for a multitude of practices which differ systematically according to context and potentially pave the way for groups to spar over the 'heart' of a logic (Boltanski & Thevenot, 1991; Sewell, 1992). As such, the structuration of practice in relation to a logic is an important research direction with the potential to more cleanly explicate the linkages between broad meaning systems and the behavior of actors who affiliate with them.

My findings are also of interest to scholars who study the role of categories within fields and markets. Whereas the majority of research in this milieu has focused on individual categories and the ways in which they shape commensuration and evaluation (Hsu, 2006; Hsu et al, 2009; Khaire & Wadhwani, 2010; Polos et al, 2002; Zuckerman, 1999), I direct attention to the importance of considering the shifting properties of category systems. My results suggest that, in addition to their individual effects, categories may have a combinatory influence on action as attention is directed to more central nodes in a category system. As such, category effects are not limited to their role in segmenting fields and markets: understanding how they function also requires attention to their relational structure at the broader field level. In this way, I draw out an important intersection between the literatures on categories and institutions which have proceeded largely independent of each other, despite sharing a common interest in culture and action. In addition, I show that not all classification systems evolve toward a stable structure with rigid boundaries and potent distinctions (Ruef & Patterson, 2009). Rather, categories may become meaningful in clusters and their effects on action may vary over time (Kennedy, Lo, & Lounsbury, 2010; Wry, 2011). Considering that canonical findings about categories, evaluation, and identities—and the imperative of single-category affiliations in this context—are based on stable category systems, my study provides further evidence of an important boundary condition for categories research. Studies should continue to investigate the variable effects of category spanning, multi-faceted identities, and innovation as they relate to different category structures (Glynn, 2008; Kennedy et al, 2010; Kovacs & Hannan, 2010; Ruef & Patterson, 2009).

In sum, my study shows the utility of complexity theory for understanding the emergence of order in the face of significant countervailing pressures. In particular, I build on emerging insights about complexity within fields and markets and show its implications for foundational concepts in macro organization theory such as structuration and change. As such, I provide a unique lens on structural emergence and show how it can guide action in consequential ways without ever becoming fixed or objectified.

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TABLES AND FIGURES

TABLE 1-1.
Means, Standard Deviations, and Correlations

Variables	Mean	St Dev	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. New Category	.102	.303	-.457	-.132	-.097	-.209	-.162	-.199	-.137	-.096	-.150	-.140	-.060	-.081
2. Category Age	5.29	3.17	---	.268	.301	.069	.298	.192	.307	.167	.254	.255	.130	.182
3. Breadth	.718	1.23		---	.369	.080	.222	.196	.276	.214	.205	.158	.145	.224
4. Importance	.052	.181			---	.175	.249	.300	.528	.290	.391	.240	.333	.415
5. Examiner Effect	.485	.734				---	.167	.193	.209	.174	.154	.219	.140	.224
6. Star Sci Density	1.17	2.42					---	.182	331	.216	.381	.203	.167	.211
7. Large Corp Density	3.42	5.79						---	.254	.239	.150	.255	.135	.302
8. Star Sci Spans	.493	1.22							---	.322	.363	.269	.392	.316
9. Large Corp Spans	.777	.274								---	.224	.344	.177	.274
10. Star Sci Collabs	.188	.575									---	.169	.286	.204
11. Large Corp Collabs	.216	.542										---	.118	.202
12. Star Schema Align	.450	1.01											---	.314
13. Corp Schema Align	.305	2.56												---

TABLE 1-2.
Negative Binomial Regression Models, Category-Year Patenting: 1993-2005

Variables	**(1)**	**(2)**	**(3)**
New Category	.016 (.060)	.023 (.062)	.018 (.062)
Category Age	.171 (.031)***	.147 (.030)***	.091 (.030)***
Breadth	.151 (.040)***	.085 (.040)**	.067 (.040)*
Importance	.187 (.231)	.116 (.226)	.137 (.211)
Star Scientist Density		.098 (.018)***	.074 (.018)***
Large Corp. Density		.039 (.008)***	.027 (.008)***
Centrality			.188 (.029)***
Year Fixed Effects	Y	Y	Y
Category Fixed Effects	Y	Y	Y
Log-likelihood	-961.13	-936.63	-838.09
LR X^2	117.64	184.99	198.11

Standard errors in parentheses, one-tailed tests for hypothesized variables
*p<.10; **p<.05, ***p<.01

TABLE 1-3.
Tobit Regression Models, Category-Year Centrality: 1993-2005

Variables	(1)	(2)	(3)	(4)	(5)
Controls					
New Category	-.042 (.021)**	-.045 (.020)**	-.043 (.020)**	-.044 (.021)**	-.042 (.020)**
Category Age	-.001 (.006)	-.003 (.006)	-.004 (.006)	-.002 (.005)	-.004 (.006)
Breadth	.056 (.010)***	.026 (.011)**	.028 (.011)***	.041 (.011)***	.028 (.011)***
Importance	.072 (.036)**	.045 (.035)	.048 (.035)	.076 (.036)**	.045 (.035)
Examiner Effect	.029 (.008)***	.020 (.008)**	.020 (.008)**	.027 (.008)***	.020 (.008)**
Hypotheses 2-4					
Star Sci Density		.013 (.004)***			.006 (.005)*
L. Corp Density		.010 (.003)***			.002 (.006)
Star Sci Spans			.024 (.013)**		.018 (.011)**
L. Corp Spans			.027 (.019)**		.022 (.016)**
Star Sci Collabs				.134 (.153)	-.120 (.157)
L. Corp Collabs				.057 (.061)	-.026 (.067)
Year Fixed Effects	Y	Y	Y	Y	Y
Category Fixed Effects	Y	Y	Y	Y	Y
Log-likelihood	208.33	226.84	233.09	208.24	233.67
LR X^2	325.09	376.63	393.92	324.33	395.69

Standard errors in parentheses, one-tailed tests for hypothesized variables;
*p < .10; **p < .05, ***p < .01

TABLE 1-4.
Tobit Regression Models of Category-Year Centrality: 1993-2005

Variables	(6)	(7)	(8)	(9)	(10)
Controls					
New Category	-.036 (.020)*	-.037 (.020)*	-.036 (.020)*	-.037 (.020)*	-.037 (.020)*
Category Age	-.005 (.006)	-.005 (.006)	-.005 (.006)	-.006 (.006)	-.006 (.006)
Breadth	.020 (.011)**	.020 (.010)**	.021 (.011)**	.018 (.011)*	.021 (.011)**
Importance	.046 (.035)	.044 (.035)	.043 (.034)	.037 (.035)	.033 (.035)
Examiner Effect	.016 (.008)**	.017 (.008)**	.015 (.008)*	.016 (.008)**	.014 (.008)*
Hypotheses 2-4					
Star Sci Density	.006 (.006)	.006 (.005)			.008 (.006)
L. Corp Density	.001 (.006)	.001 (.006)			.003 (.006)
Star Scientist Spans	.010 (.011)		.004 (.011)		.007 (.011)
L. Corp Spans	.015 (.008)**		.005 (.009)		.017 (.025)
Star Sci Collabs	-.068 (.154)			-.092 (.154)	-.100 (.155)
L. Corp Collabs	.006 (.037)			-.004 (.037)	-.006 (.038)
Hypotheses 5-8					
Star Sci Schema Alignment	.350 (.082)***	.301 (.104)***	.266 (.090)***	.345 (.082)***	.186 (.081)***
L. Corp Schema Alignment	.140 (.029)***	.128 (.033)***	.136 (.031)***	.137 (.030)***	.138 (.031)***
Star Alignment X density		-.016 (.021)			-.015 (.021)
Corp Alignment X density		-.034 (.043)			-.037 (.044)
Weighted Star Spans			.207 (.087)***		.216 (.087)***
Weighted L. Corp Spans			.151 (.067)***		.142 (.075)**
Weighted Star Collabs				.024 (.014)**	.024 (.014)**
Weighted L. Corp Collabs				.023 (.013)**	.024 (.013)**
Year Fixed Effects	Y	Y	Y	Y	Y
Category Fixed Effects	Y	Y	Y	Y	Y
Log-likelihood	253.62	254.29	256.60	256.53	257.56
LR X^2	454.05	455.83	462.94	462.52	465.89

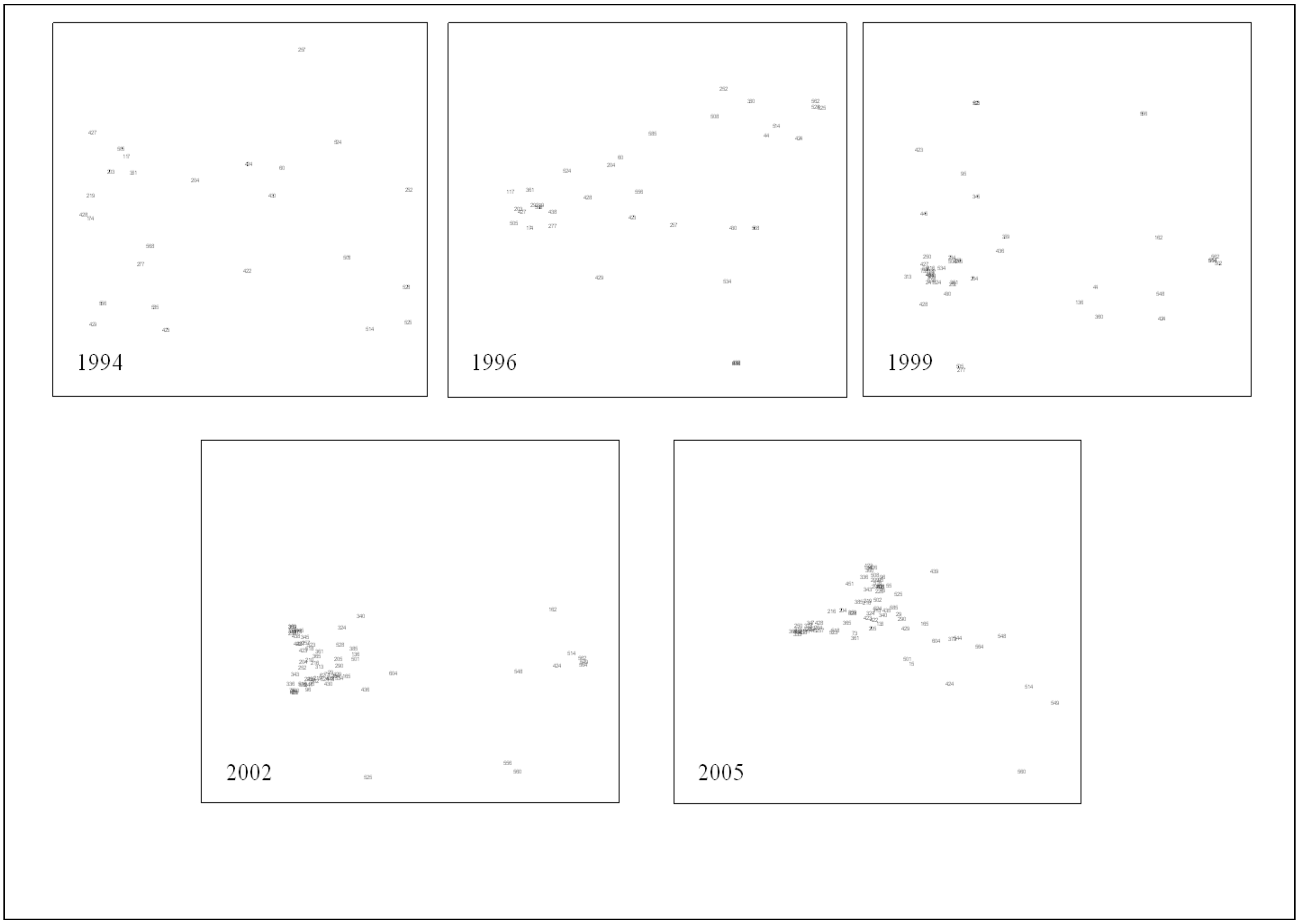
Standard errors in parentheses, one-tailed tests for hypothesized variables
*p < .10; **p < .05, ***p <. 01

TABLE 1-5.
Negative Binomial Regression Models of Actor-Year Patenting: 1993-2005

	Star Scientists			*Large Corporations*		
Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Controls						
Years Active	-.347 (.053)***	-.289 (.049)***	-.239 (.058)***	-.292 (.043)***	-.307 (.039)***	-.340 (.042)***
Bos, Hou, SF	.360 (.180)**	.541 (.189)***	.425 (.201)**	.043 (.240)	.054 (.215)	-.011 (.216)
Nanotube patents	.061 (.038)	.028 (.040)	-.006 (.038)	.134 (.020)***	.116 (.017)***	.107 (.017)***
Importance	.217 (.080)***	.182 (.080)**	.139 (.084)*	-.026 (.030)	-.007 (.028)	-.020 (.032)
Star Sci						
Physics		.143 (.242)	.119 (.250)			
Chemistry		.191 (.102)*	.198 (.130)			
Bio-Chem		-.268 (.129)*	-.220 (.131)*			
Engineering		.425 (.201)**	.359 (.229)*			
Publications		.016 (.010)*	.017 (.009)*			
L. Corp						
R&D Millions					.076 (.037)**	.054 (.031)*
All patents					.008 (.001)***	.007 (.001)***
Schema Alignment			2.083 (.454)***			.749 (.301)***
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Actor Fixed Effects	Y	Y	Y	Y	Y	Y
Log-likelihood	-1122.35	-463.69	-449.85	-667.51	-650.27	-607.58
LR X^2	238.33	65.00	87.00	68.40	151.69	185.85

Standard errors in parentheses, one-tailed tests for hypothesized variables
*p < .10; **p < .05, ***p < .01

FIGURE 1-1.
Multidimensional Scaling Plots of the Nanotube Category System



TO BUILD OR BREAK AWAY: EXPLORING THE ANTECEDENTS OF CATEGORY SPANNING NANOTECHNOLOGY INNOVATION

Given the complexity of the social world, actors rely on categories to simplify thought and understanding by lumping similar things together. Through this act of grouping, categories set boundaries and create shared understandings about what appropriately lies within them (Douglas, 1986; Hsu, 2006; Zuckerman, 1999). As such, they are key cultural nodes which organize knowledge (Powell & Snellman, 2004), focus attention (Ocasio, 1997), and provide a foundation for commensuration, conformance, and sanctioning (Espland & Stevens, 1999; Zuckerman 1999). Given these properties, categories and categorization have emerged as prominent themes in organizational theory. The dominant thrust in this research has been on the constraining effect of categories; a focus that is particularly acute in institutional and ecological accounts where categories are generally viewed as discrete and obdurately bounded entities. Studies in this milieu have clustered around two themes: 1) the role of categories in shaping interests, identities, and actions (Hsu & Hannan, 2005; Kraatz & Zajac, 1996; Sutton & Dobbin, 1996) and; 2) the penalties for challenging category constraints by taking actions that result in multiple category affiliations (Hsu, 2006; Hsu et al, 2009; Zuckerman 1999).

There is a persistent finding that category spanning actors suffer economic and social disadvantages. Whereas being positioned discretely within one category makes an actor’s identity clearly recognizable, evidence suggests that multiple category memberships make identities inchoate, resulting in ostracization, derision, or other forms of marginalization (Hsu, 2006; Rao, Monin, & Durand, 2003, 2005; Zuckerman, 1999). Actors may also dilute their expertise and focus by engaging in practices that span multiple categories, thus compromising their ability to perform strongly in any one (Hannan, Carroll, & Polos, 2003). While negative sanction is typically most pointed when oppositional categories are spanned (e.g., Carroll & Swaminathan, 2000; Kovacs & Hannan, 2010; Rao et al, 2005), Hsu and colleagues (2009: 151) argue that the threat of external sanction constitutes a significant barrier to spanning amongst less sharply opposed categories as well.

Despite its potentially detrimental consequences, category spanning is relatively common across a range of contexts (see Hsu, 2006; Hsu et al, 2009; Rao et al, 2003; Kennedy, Lo, & Lounsbury, 2010; Lounsbury & Rao, 2004; Zuckerman, 1999). It is also an important driver of innovation (Hargadon & Sutton, 1997) and has implications for the emergence, evolution, and redirection of institutional fields (Greenwood & Suddaby, 2006; Lounsbury & Rao, 2004; Rao et al, 2003, 2005). However, the prevailing focus on the detriments to category spanning has elided detailed consideration of its causal antecedents. Recognizing this paucity of understanding, Lamont and Molnar (2002: 187) argue that identifying key mechanisms which enable actors to span between categories more or less easily is an important aim which scholars should pursue vigorously. Heeding this call, I take inspiration from studies that show the cultural conditioning of innovation and identities (e.g., Glynn, 2008; Lounsbury & Glynn, 2001; Powell et al, 2009) and show how category spanning is shaped by the institutional context which embeds it.

Unlike extant approaches in organization theory which focus on the influence of individual categories, my approach argues for the consideration of a field's broader category system (Bourdieu, 1984; Bowker & Star, 1999; DiMaggio, 1987; White, 1965). In particular, I argue that categories can become linked together in meaningful ways (Mohr, 1998; Mohr & Duquenne, 1997) and that these patterns of linkage constitute a key mechanism which facilitates category spanning. Also, while my primary aim is to show how the relational structure of categories at the field level affects spanning, I look across levels of analysis and consider the influence of actor and category level variables as well (Lounsbury & Glynn, 2001; Navis & Glynn, 2010; Rao et al, 2003, 2005). At the individual level I investigate the effects of work experience, networks, and status (Aldrich, 1999; Shane, 2000; Stuart & Ding, 2006) and at the category level, I examine social influence (DiMaggio & Powell, 1983; Haunschild & Miner, 1997) and category fertility (Carroll & Swaminathan, 2000; Chang, 1996; Hannan & Freeman, 1989). Also, to the extent that the relational structure of categories makes spanning more or less difficult, I argue that it may condition the influence of actor and category level variables by providing the field level infrastructure which enables their efficacious functioning.

Empirically, I focus on category spanning amongst the 715 scientists who comprised the full population of inventors in the field of nanotube technology – an important area of nanotechnology (nanotech) – between 1993 and 2005. While the definition of 'nanotech' is amorphous and disputed (Kaplan & Radin, 2009), nanotube technology comprises a relatively well bounded and cohesive area within this larger domain (Harris, 2005; Meyyappan, 2005). Nanotubes are extremely small and strong cylinders that are usually carbon based and have novel electrical and light emission properties. Given their promise to revolutionize technological development in areas such as drug delivery, display devices, materials, and computer chips (Lux Research, 2006) nanotube technology has become a robust domain of commercial innovation with 1128 patents applied for between 1991 and 2005, when my data ends.

To examine category spanning, I pay particular attention to the patents taken out by nanotube inventors and where these are positioned within the classification system at the United States Patent Office (USPTO). Each USPTO patent is assigned into one of over 400 technology classes (categories) which reflect its primary attributes and distinguish it from other types of inventions. This process involves multiple expert examiners who follow an assiduously laid out method for determining appropriate categorization, as well as a series of checks by senior staff designed to ensure that the process plays out consistently across patents (see USPTO, 2009). As with other category systems, evidence suggests that actors incur penalties for spanning between technology categories (Wry, 2011). Still, over the period of my analysis 127 nanotube inventors engaged in category spanning by patenting in multiple technology categories while 218 innovated repeatedly in their home category.

Competing hazard rate models for category spanning and home category patenting show that inventors were likely to span between closely linked categories but innovate repeatedly in disparate ones. Moreover, supplementary analysis shows that the category structure was not fixed; rather, its early emergence was shaped by star scientists who fluidly redirected innovation activities. Results further show that while actor and category level variables have no discrete influence, hypothesized effects show up when conditioned by the structure of the overall category system. Thus, I find strong support that category spanning owes to the synergistic interplay of individual, category, and field levels factors.

THEORY AND HYPOTHESES

Categories are key cultural elements that allow actors to understand and make sense of the social world. In this way, categories provide widely shared understandings about the similarity and distinctiveness of various entities (e.g., Bowker & Star, 1999; Douglas 1986; Zerubavel, 1997). While social categorization processes such as those related to making distinctions based on race, gender, sexual preference, and other dimensions that distinguish groups of actors provide cultural material to help constitute identities and guide behavior, classification efforts are also abundant in the construction of markets where products, services, technologies and organizations are differentiated (e.g., Bowker & Star, 2000; Mohr & Duquenne 1997). Most research on categorization to-date, however, has emphasized the constraining force of categories and the rigidity of their boundaries (see Lounsbury & Rao, 2004).

There is a persistent finding that category spanning actors suffer social and economic disadvantages. One reason for this is that audiences have difficulty understanding the identities and expertise of actors who are not positioned neatly within a single category. As a result, these actors tend to be ignored, devalued, or otherwise marginalized. This basic dynamic has been illustrated in studies of oppositional categories such as haute vs. nouvelle cuisine (Rao et al, 2003, 2005), trustee vs. growth mutual funds (Lounsbury & Rao, 2004), and industrial vs. craft beer (Carroll & Swaminathan, 2000) as well as within more nuanced category systems such as feature film genres and eBay product categories (Hsu, 2006; Hsu et al, 2009; Zuckerman, 1999; Zuckerman et al, 2003). In addition to the threat of external sanction, spanning is thought to be detrimental because it dilutes an actor's focus, compromising their ability to perform strongly in a single category (Hannan et al, 2003).

Beyond the material consequences for category spanning, a focus on categories as constraint suggests that actors are disinclined to span between categories by virtue of their position within a home category. More specifically, category spanning can be considered an example of the paradox of embedded agency (Seo & Creed, 2002). That is, how is it possible for an actor to conceive of opportunities in divergent categories when their interactions, experiences, and thought processes are tied to the skills, resources, and cognitive codes of their home category (Aldrich, 1999; DiMaggio & Powell, 1983; Sutton & Dobbin, 1996)? Thus, in the parlance of Scott (2008), there are both regulatory and cognitive impediments to category spanning. Still, category spanning has been observed across a wide range of contexts and has been shown to be a key driver of innovation (Gilsing et al, 2008; Hargadon & Sutton, 1997; Rosenkopf & Nerkar, 2001) as well as a catalyst for the emergence of new roles, collective identities, and organizational forms which shape processes of institutional emergence and change (Greenwood & Suddaby, 2006; Lounsbury, 2007; Lounsbury et al, 2003; Lounsbury & Rao, 2004; Rao et al, 2003, 2005; Stuart & Ding, 2006).

At the individual level, one possible explanation for category spanning is that an actor is exposed to new information which makes them aware of opportunities outside of their home category (Aldrich, 1999; Greenwood & Suddaby, 2006; Romanelli & Schoonhoven, 2001). Indeed, a considerable body of literature shows that the information an actor has access to influences the opportunities which they recognize. As Ozen and Baron (2007: 175) note, "to identify viable opportunities… (actors) must somehow perceive, gather, interpret, and apply information about industries, technologies, markets… and other factors". Work experience is a prominent source for such information because it allows an actor to accrue detailed information about a specific market category or industry (Aldrich, 1999; Romanelli & Schoonhoven, 2001; Shane, 2000). As Shane (2000) has shown, actors with different work experiences perceived divergent opportunities from the same technological breakthrough. Following this logic, it reasons that an inventor who changes work contexts may be exposed to information which helps them overcome cognitive constraints of their home category and see opportunities in new categories. Thus,

H1: Inventors are more likely to engage in category spanning when they make a number of career moves after patenting in a focal category

Another potential source of information about category spanning opportunities is inter-personal contact. Social network research shows that inter-personal contacts serve as important conduits for the dissemination and diffusion of novel practices (Davis, 1991; Powell, Koput, & Smith-Doer, 1996; Stuart & Ding, 2006). As such, to the degree that novel information flows through an actor's network, it may be an important mechanism which helps them overcome the cognitive constraints of their home category and recognize opportunities in others. While it is possible that the information flowing through a network can change endogenously, it is most likely to occur when the composition of the network changes (Stuart & Ding, 2006; Uzzi, 1999). In particular, I expect that the addition of collaborators who have patented in a different category than a focal inventor will be particularly influential. Thus,

H2: Inventors are more likely to engage in category spanning when inventors with patents in disparate categories enter into their collaboration network.

Beyond the types of knowledge that an actor accrues through their personal and organizational affiliations, a considerable body of literature suggests that their status position within a field may affect their propensity for category spanning. Studies show that actors with very high and very low status are the most likely to diverge from institutional norms (Greenwood & Suddaby, 2006; Miner, 1997; Stuart & Ding, 2006). The former are likely to engage in radical innovation because they are disadvantaged by prevailing arrangements and have relatively little to lose by doing so (Podolny, 1993). Conversely, high status actors have more leeway to innovate in novel directions because their expertise is unquestioned and their elevated position shields them from negative sanction (Merton, 1968; Podolny, 1993; Rao et al, 2005). Anecdotal accounts suggest that high status actors are particularly likely to cross category boundaries in techno-scientific fields such as nanotube patenting (Darby & Zucker, 2003). Indeed, studies have shown that it is typically star scientists who work to bridge disparate research traditions (Clarke, 1990; Fujimura, 1987), foment new scientific movements (Frickel & Gross, 2005), and reshape professional norms (Powell et al, 1996; Stuart & Ding, 2006). Thus,

H3: Star scientists are more likely to engage in category spanning than scientists with lower scientific standing.

In addition to its influence at the individual level, status may also be an important category level mechanism which catalyzes spanning. More specifically, I consider the possibility that, to the extent that star scientists engage in category spanning, this may induce broader diffusion of the practice amongst other category members. Mimesis is a key concept in neoinstitutional analysis, and high status actors tend to be targets of imitation (DiMaggio & Powell, 1983; Haunschild & Miner, 1997). The underlying logic is that actors are highly attentive to their high status alters and look to them as role models for appropriate behavior (Haunschild & Miner, 1997; Podolny, & Stuart, 1995; Stuart & Ding, 2006). To wit, Haveman (1993) showed that new market categories attracted entrants when large, successful firms demonstrated the fruitfulness of opportunities in a new category. Rao and colleagues (2003, 2005) similarly showed that French chefs imitated their high status contemporaries who had spanned the categories of haute and nouvelle cuisine. Thus,

H4: Inventors are more likely to engage in category spanning when star scientists in their home category engage in spanning.

Another potential category level mechanism that drives spanning is the relative resource richness of an actor's home category vis-à-vis other options. Economists and organization ecologists agree that, all things being equal, economic activity will tend to cluster in fertile resource spaces (Schumpeter, 1934; Hannan & Freeman, 1989). Economists see few constraints on this process, assuming that actors are rational (or boundedly rational) maximizers who attempt to shift resources into areas with the strongest yield potential (Chang, 1996; Evans & Jovanovic, 1989; Khilstrom & Laffont, 1979). Organizational scholars disagree about the practical ability of actors to make such moves but agree that fertile categories are attractive, regardless of whether or not the resulting attempts at category spanning are successful. For example, Carroll and Swaminathan (2000) showed that when the craft brewing market category became highly fertile, industrial brewers attempted to break with their extant offerings and create new products for the craft brewing category. Rao and colleagues (2003, 2005) similarly showed that haute cuisine chefs were more likely to span categories of haute and nouvelle cuisine when they saw reputational gains accruing to nouvelle cuisine chefs.

In addition to the potential for fertile categories to exert a pull on actors, membership in a low performing category may push actors toward spanning. Studies show that firms are most likely to introduce new products or enter new markets when their extant product or market orientation provides limited growth opportunities (Calori & Harvatopoulos, 1988; Kotler, 2007). Evidence also suggests that actors are more likely to break from established ways of doing things and innovate in novel directions when they suffer bouts of low performance not easily rectified through simple search or incremental innovation (Cyert & March, 1963; Greve, 2003; March, 1991). Thus,

H5: Inventors are more likely to engage in category spanning when their home category has low resource endowments relative to other categories.

In addition to the influence of individual and category level factors, literature on the relational nature of categories also suggests that the properties of a category system may affect the likelihood of spanning. Scholars fomenting the ‘new’ structuralism in organizational theory (Lounsbury & Ventresca, 2003) have argued that the relational structure of categories in a field plays a key role in how their contents are understood (Bourdieu, 1984; Breiger, 1974; Mohr, 1998). This idea germinated with Harrison White’s (1965) notion of ‘catnet’ and has been elaborated through the study of category affiliation processes (e.g., Breiger, 1974), Blauspace (see McPherson, 1983) and the development of techniques such as blockmodeling (DiMaggio, 1987) and correspondence analysis (Bourdieu, 1984). A central observation is that relationships between categories reveal clusters that occupy similar areas of institutional space linked to higher order meaning systems such as organization forms (Mohr & Duquenne, 1997), collective identities (Wry, Lounsbury, & Glynn, 2011), and institutional logics (Mohr & Friedland, 2008). For example, Mohr and Duquenne (1997) showed how linkages amongst categories defining the targets and tactics of charity coalesced into stable notions about acceptable poverty relief practices that were embodied in specific organizational forms.

A related stream of literature emphasizes that the actors and practices tied to a category are fluid and subject to negotiation as opposed to being fixed and exogenous. Indeed, evidence suggests that a category's contents and boundaries are socially constructed and subject to alterations based on the actions of high profile actors (Becker, 1978; White, 1992; Zhou & Ventresca, 2009). One possibility is that actors can shape the relations between categories so that the knowledge and practices which they encompass becomes more or less similar (Hannan & Freeman, 1989). As categories become less sharply defined, the penalties for spanning are reduced because the boundary between them loses potency (Lamont & Molnar, 2002; Rao et al, 2005). This is particularly true when categories become complementary (Rosa et al, 1999). For example, the history of cancer research shows a schism between the research programs pursued by different categories of researchers (Fujimura, 1987). However, in the early 1980's proponents of recombinant DNA actively showed the utility for oncagene therapy across unrelated research programs. As a result, while each pursued a distinct line of inquiry, a common focus on oncagenes led researchers to see their previously opposed research categories as complimentary, thus paving the way for increased inter-disciplinary mobility and interaction without the prospect of professional sanction or ostracization (Fujimura, 1987, 1997).

It also stands to reason that when the knowledge and practices associated with different categories become similar, actors should be able to cross between them without significantly diluting their home category focus and expertise (Hannan et al, 2003). Put another way, category similarity should relax the tradeoff between specialized affiliation with a single category and a more general, category spanning, orientation (Hsu, 2006; Kovacs & Hannan, 2010). To wit, Lounsbury and Rao (2004) showed that the mutual fund industry evolved rich and variegated product categories that combined elements of previously orthogonal stewardship and growth categories. The result was a category system where similar categories clustered in specific areas of a risk continuum rather than oppositional poles. This allowed organizations to leverage a common pool of knowledge in order to offer products associated with multiple categories.

For this paper, I pay particular attention to how patent categories become linked together in a relational structure. The knowledge base which underpins innovative activity in a category is comprised of related patents, or ‘prior art’, which incumbent patents make reference to (Hall, Jaffee, & Trajtenberg, 2001). Accordingly, the emergence of thick patterns of cross-citation between categories will reveal those which are more closely related in terms of the stocks of knowledge which they draw on. To the extent that a patent category becomes similar to other categories, inventors may be more aware of opportunities across category boundaries and perceive less risk in pursuing them. Thus,

H6: Inventors are more likely to engage in category spanning when their home category features a knowledge base that is similar to other categories.

While I expect that similarity is a key mechanism that enables category spanning, I also anticipate that its effects will be magnified in combination with individual and category level variables. More specifically, to the extent that similarity helps actors to overcome the cognitive embeddedness of their home category and attenuate the detrimental outcomes to spanning, it may unlock barriers to the unencumbered functioning of other mechanisms. For example, an actor may acknowledge the resource richness of a disparate category, but demur from spanning because they fear negative sanction or because they cannot conceive of how their extant knowledge stocks might translate across category boundaries. This prediction can be extended with little revision to the interaction between similarity and new information as well as the imitation of high status alters. Hence,

H7: Inventors are more likely to engage in category spanning when their home category is similar to others but resource poor.

H8: Inventors are more likely to engage in category spanning when their home category is similar to others and they experience workplace or collaboration network changes.

H9: Inventors are more likely to engage in category spanning when their home category is similar to others and its high status members engage in category spanning.

DATA AND METHOD

Empirically, I explore category spanning in one key area of nanotech – nanotubes; the most common of which are carbon based. While the broad field of 'nanotech' is somewhat ambiguously defined (Kaplan & Radin, 2009), nanotube technology comprises a relatively well bounded and cohesive sub-field (Harris, 2005; Meyyappan, 2005). Nanotubes consist of graphitic layers seamlessly wrapped in a cylindrical shape and capped with pentagonal rings. While only a few nano-meters in diameter, they are extremely strong and have unique properties related to electrical and thermal conductivity, and electronic transmission (Meyyappan, 2005). Applications for nanotubes are wide ranging and include new kinds of diodes, transistors, probes, sensors, field emission arrays, and flat panel displays. Lux Venture Capital estimated the nanotube market in 2005 to be $43 million and projected a five year annual compound growth rate of 44 percent (Lux Research, 2006). Nanotube patenting began almost immediately after Sumio Iijima (1991) illustrated carbon nanotube synthesis and has grown rapidly, with well over 100 patents issued per year in the new millennium.

To explore category spanning, I pay special attention to how nanotube patents are classified by the USPTO. Each patent issued by the USPTO is assigned into one of over 400 technology classes (categories). This classification system is an extraordinarily detailed way of segregating technological developments and covers all subject matter that is patentable under US law (USPTO, 2009). Each category is mutually exclusive and contains a title and description which detail its boundaries. For example, class #427 is for 'coating processes,' and class #438 is for 'semiconductor device manufacturing,' (USPTO, 2006). In this way, patent categories group related technologies and distinguish them from others. In order to ensure consistent and accurate classification, each patent application is assigned to an examiner with relevant expertise (often in the form of a PhD in a related discipline) who follows an assiduously laid out process for determining its primary technology class (USPTO, 2009). This categorization is reviewed by a series of supervisors before a patent is granted (or not) [4].

As previous studies have shown, it is relatively common for actors to take out patents in multiple technology categories (Gilsing et al, 2008; Kennedy et al, 2010; Rosenkopf & Nerkar, 2001). As such, nanotube patenting is not an extreme case to test category spanning in the vein of studies that focus on opposing categories (e.g., Carroll & Swaminathan, 2000; Rao et al, 2003, 2005). However,

[4] As a new domain of technology development, there may be some concern about the ability of USPTO examiners to classify nanotube inventions accurately. However, nano-research and technology are not novel disciplines, but rather extensions of established areas of chemistry, physics, biology, materials science, and engineering (Meyyeppan, 2005) – all areas where USPTO employs relevant experts. Also, the claims listed on a patent application (which are the basis for categorization) relate to an invention's attributes and functions. The level of expertise required to distinguish whether or not a nanotube invention is claiming to be a coating process (class 427), for instance, is quite different than the expertise needed to judge whether a journal submission advances a highly specialized line of nanotube research.

spanning is still far less common amongst nanotube inventors than in other contexts where scholars have explored category spanning. My data show that about 20% of nanotube inventors engaged in category spanning. In comparison, the average film spans almost three genres and about half of all eBay sellers span multiple product categories (Hsu, 2006; Hsu et al, 2009). There is clear evidence of category spanning penalties in these contexts (Hsu et al, 2009) and recent work suggests similar dynamics in nanotech patenting (Wry, 2011). Because nanotube technology is well-defined field with a moderate amount of category spanning – despite evidence of penalties for doing so – it is a germane context to investigate the antecedents of category spanning innovation.

Data and Data Sources

My data includes the full population of nanotube inventors, scholarly articles, and patents found in the Nanobank database – a National Science Foundation funded storehouse for all scientific and technological activity in nanotech (Zucker & Darby, 2007). I began by searching the title, abstract, and claims of Nanobank patents for the term ‘nanotube’ and related terms which I identified by reviewing nanotube research compendiums (e.g., Harris, 2005; Meyyeppan, 2005). Additional terms included, ‘carbon 60 (C60)’, ‘carbon 70 (C70)’, ‘buckeyball’, and ‘fullerene’. This yielded 1128 patents through 2005 (when the Nanobank data ends), the first of which was applied for in 1991. For each patent, I recorded inventor names, title, issue year, abstract, primary classification, secondary classifications (where applicable), assignee organization, assignee country, and examiner. From the inventor names listed on each patent, I identified 715 unique inventors. In a separate sheet, I recorded the full inventory of 'prior art' citations listed on each patent.

I also gathered information about each inventor's scholarly publications. To do this, I entered each inventor's name into the Web of Science database to identify their publications between 1986 and 2005. To ensure accurate results, I used a name matching algorithm which looked at name compatibility, co-authors, and key words to assess the likelihood that similar named authors and inventors were indeed the same person (see Strotmann, Zhao, & Bubela, 2009 for a detailed discussion of the algorithm). This search returned 17 603 scholarly articles authored by 640 nanotube inventors. I removed the 75 non-publishing inventors from my dataset since many of the covariates in my analysis are culled from publication data. The proportion of publishing and non-publishing inventors who had engaged in category spanning was almost identical (0.198 vs. 0.207) suggesting that no significant bias was introduced. I also used the Web of Science database to create a citation report for each inventor that recorded cumulative yearly citations to their scholarly articles for each year of my analysis.

Finally, I searched the Proquest Dissertation Database to determine the academic discipline that each inventor was trained in. For missing cases (typically non-North American and non-PhD scientists), I used the department affiliation listed in an inventor's first publication since many scientists first publish as graduate students. This is an established bibliometric technique (e.g., Schummer, 2004).

Variable Definitions

Dependent variables. My primary dependent variable is *category spanning*, a yearly count of the new technology classes that an inventor patents in. My secondary dependent variable is *home category patenting*: a yearly count of an inventor's patents in their home category.

Independent variables**.** I used information recorded in the 17 603 articles written by nanotube inventors to construct a detailed career history and egocentric co-authorship network for each inventor. *Career moves* is a yearly updated count of the number of times an inventor has switched institutional affiliations since being issued a nanotube patent. To assess the role of an inventor's social network, I calculated *new network class* as a count of new collaborators who have patented in a different USPTO class than an inventor as well as those who patent in a different category after entering an inventor's network.

Consistent with studies showing that an actor's scientific stature is the most relevant status measure in fields where patents rely on scientific discovery (Darby & Zucker, 1999; Powell et al, 1996; Stuart & Ding, 2006), I calculated an inventor's status based on a yearly updated count of citations to their scholarly articles. I dummy coded inventors as *star scientists* when they had received +1000 citations. *Star scientist spanning* is the cumulative yearly count of the number star scientists from an inventor's home category who engaged in category spanning.

I measure the resource richness of a category according to the degree that it contains important patents. Researchers studying patents have shown that the demand for certain technologies can be understood by assessing the importance of patents via citation analysis (Henderson, Jaffe, & Trajtenberg, 1998; Rosenkopf & Nerkar, 2001; Wartburg, Teichert, & Rost, 2005). That is, to the extent that a patent is cited by other patents, it becomes a building block for the development of related technologies. As Podolny and Stuart (1995: 1231) note, highly cited patents are of great economic or at least prestige benefit to their owners. Extending this logic to the category level, a patent category can be understood as more important – and resource rich – if its patents are highly cited. I calculated the importance of a patent based on Henderson and colleagues' measure (1998: 123), which summarizes the number of direct and indirect citations to a focal patent per year. Category *importance* is the yearly average patent importance in an inventor's home category.

My category structure variable captures similarities in the stocks of knowledge utilized in different nanotube patent categories. The USPTO requires that every patent application include a list of related patents (prior art). Inventors and their advocates (technology transfer officers, patent lawyers, etc.) include citations that they are aware of and patent examiners can also add citations. Patent researchers generally consider prior art to be the knowledge stock that an invention builds on (e.g., Katila, 2002; Rosenkopf & Nerkar, 2001). Still, for some studies, citations that are not directly attributable to an inventor are problematic. However, my interest is in the knowledge base of a technology category and additions by multiple actors are helpful because they serve as a check that all relevant prior art is included.

The procedure I followed to calculate similarity scores is as follows. I began by constructing yearly two-mode matrixes of focal patent classes by cited patent classes with cells in the matrix containing the number of citations from patents in a given 3-digit patent class going to patents in a receiving 3-digit class. Based on evidence that patents have a useful life of about five years (Hall et al, 2001; Rosenkopf & Nerkar, 2001), the matrix for a focal year includes patents from the previous five. Using UCINET (Borgatti, Everett, & Freeman, 1999), I calculated joint involvement or affiliation data (e.g., Breiger 1974) which I then transformed into a similarity matrix using Pearson's correlation method – the most appropriate technique for analyzing co-citation similarities (see Bensman, 2004). I then used UCINET to calculate closeness centrality scores which I used for my category *similarity* variable: this measure captures the degree to which a category is similar to all others in the category system in a focal year (Wasserman & Faust, 1994). I then used non-metric multidimensional scaling (MDS) to plot the relational structure of categories for each year based on Euclidean distances in n-dimensions. When two nodes are close together it is because they share similar citation patterns, otherwise they are far apart. Stress levels for two-dimensional solutions ranged from 0.08 and 0.14; well within the limits considered to produce accurate plots (Kruskal & Wish, 1978). Figure 2-1 shows four well placed MDS panels plotting the evolution of the nanotube category structure.

-------- Insert Figure 2-1 about here --------

Control variables. I include several controls in my models. I include a full complement of dummy variables for scientific disciplines to control for differences amongst inventors with different academic training. Work context dummies for *academia* and *industry* are also included to control for potentially varying institutional pressures related to category spanning. Based on evidence that high levels of activity help to legitimate areas of entrepreneurship and innovation (Aldrich, 1999; Aldrich & Fiol, 1994; Hannan & Freeman, 1989), I also include a category *density* variable. In addition, evidence suggests that the size of an actor's collaboration network may affect the number of opportunities which they identify (Singh, 2000). To account for this I control for *network size* as well as *network additions* as a base count of new collaborators entering an inventor's network.

I also control for a number of variables related to an inventor's patent and publication history. Evidence suggests that patenting tracks quite closely with scientific productivity (Azoulay, Ding, & Stuart, 2007). As such, I control for an inventor's yearly number of *publications*. Also, many USPTO patents are classified into multiple secondary categories which can differ from their primary category. To control for the possibility that inventors may be more likely to span categories when their previous patents include attributes related to other categories, I include patent *breadth* as a count of the number of secondary categories which an inventor's patents have been assigned to. Finally, because there are repeat observations in my analysis, I include an inventor's *previous* *spanning* and *previous home category patents*. All variables are calculated by inventor year and lagged one year.

Statistical Method

To investigate the causal antecedents of category spanning versus further patenting in a home category, I constructed competing risk hazard rate models (Blossfeld, Golsch, & Rohwer, 2007) using the Cox model for estimation (Cox, 1972). Unlike parametric models which make strong assumptions about the shape of a hazard rate, the Cox model calculates the proportional influence of covariates but leaves the base hazard rate unspecified. The model can be written as

$$r(t) = h(t)\exp(A(t)\alpha) \qquad \text{Eq.1}$$

where the transition rate, *r(t)*, is the product of an unspecified baseline rate, *h(t)*, and a second term specifying covariates, *A(t)*, expected to produce proportional shifts in the transition rate. The proportionality assumption of the Cox model makes it particularly attractive for analyses such as mine where: 1) the primary focus is the magnitude and direction of influence for hypothesized covariates and; 2) the researcher lacks strong theoretical assumptions about the shape of the transition rate (Blossfield et al, 2007: 224). Model estimation is based on the method of partial likelihood where Y*i*(t) indicates if actor *i* experiences an event at *t*, and Y*k*(t) specifies if actor *k* is at risk at *t*.

$$\prod_{t} \frac{\mathrm{Y}i(\mathrm{t})\exp(Aí\ (t\ í\ )\ \alpha)}{\Sigma = 1\quad \mathrm{Y}k(\mathrm{t})\exp(AI\ (t\ k\ )\ \alpha)} \qquad \text{Eq.2}$$

I consider an inventor to be at risk for category spanning or further home category patenting after they are issued their first nanotube patent. Using STATA

11, I began by declaring my data as survival time data using the *stset* command and specified *category spanning* and *home category patenting* as failure occurrences. Then, following the procedure outlined by Blossfeld and colleagues (2007), I modeled competing hazard rates for *category spanning* and *within category patenting* using the *stcox* command. Finally, since my theoretical interest includes all instances of spanning and home category patenting, I included repeat occurrences in my models using the *robust cluster* option with 'inventor' specified as the grouping variable, as per the procedure outlined by Cleves and Cañette (2009). I also include year fixed effects to help account for unobserved temporal variance.

One issue with using the Cox model is that many of my variables can only be tracked yearly, meaning that my data are organized in discrete, rather than continuous, time. Consequently, there are a number of tied events in my data where multiple failure occurrences are recorded in a year. I used the Breslow method to account for such ties because it has been shown to produce reliable estimates when the ratio of tied events to all observations at risk is low – as it is in my data (Petersen, 1991).

RESULTS

Table 2-1, which provides variable means, standard deviations, and correlations shows that there are no correlation problems. Table 2-2 reports the results of my competing hazard rate models. Model 1 provides a baseline with just control variables. Model 2 adds hypothesized variables and Models 3 adds the interaction terms. For parsimony, I excluded the 7 scientific discipline dummies from the presented results. All models with hypothesized variables show improvement in fit over the baseline model.

-------- Insert Tables 2-1 and 2-2 about here --------

Looking at Table 2-2, it is apparent that different factors affect the hazard rates for category spanning and home category patenting. Amongst control variables, a few results are worth noting. Models 1 and 2 show that category spanning has a negative effect on home category patenting and vice versa, suggesting that actors tend to follow one path or the other. I also observe that industry affiliated inventors are more likely to engage in category spanning, providing further evidence that corporate science tends to be more speculative than university-based research (James, 2006). One surprising result is that the breadth of an inventor's patents has no effect on spanning, but a significant effect on home category patenting. While it seems counter intuitive that inventors with patents that integrate attributes from multiple categories would innovate incrementally within their home category but not span categories, there may be a simple explanation. Studies have found that drawing on bits of knowledge from multiple domains is a common and potentially lucrative strategy for technology innovation (Gilsing et al, 2008; Nerkar, 2003; Rosenkopf & Nerkar, 2001). As such, integrating new attributes into a given technology may provide an inventor with a germane path for intra-category innovation, rather than spurring more radical moves into new categories. The influence of network additions, *in toto*, on home class patenting may owe to a similar explanation with information from new collaborators being used for more incremental types of innovation.

My first and second hypotheses focused on the influence of information from an inventor's workplace and collaboration network on category spanning. As Model 2 shows, I fail to find support for either hypothesis. The marginal effects for career moves and cross category network additions are negligible for both category spanning and home category patenting. I did find support for hypothesis 3, however, with Model 2 showing that high profile 'star' scientists were significantly more likely to engage in category spanning. Considering the typical role of star scientists in catalyzing novel research directions (Frickel & Gross, 2005) and the reduced penalties they are likely to suffer for category spanning (Merton, 1968; Stuart & Ding, 2006), this is unsurprising. What is surprising, however, is that category spanning amongst star scientists had a significantly negative influence on the diffusion of the practice amongst members of their home categories. Indeed, I fail to find support for hypothesis 4. Yet, as I discuss later in this section, a more detailed examination suggests that while star scientists mimesis played a minor role in category spanning, star scientists played a central and constitutive part in enabling category spanning by undertaking the cultural work of linking disparate categories together.

My fifth hypothesis was that category spanning is more likely when an inventor's home category is resource poor. The results in Model 2 fail to support this hypothesis. The coefficient for category importance is not in the hypothesized direction, nor is it significant. As such, it appears that economic explanations, in isolation, do not hold much sway for predicting category spanning innovation.

Consistent with my argument that category spanning is enabled when a category becomes similar to others, Model 2 shows considerable support for hypothesis 6. In fact, the marginal effect for category similarity is the only hypothesized variable other than inventor status that has a significant influence on category spanning. Moreover, its effect on home category patenting is significant and negative. Taken together, these results suggest that inventors are more likely to innovate incrementally within distant categories but span between similar ones. Thus, I find strong evidence that the emergence of thick and patterned links between categories constitutes a key mechanism that affects category spanning by shifting the relational composition of the field level category structure.

To further explore the effects of similarity on category spanning, Figure 2-2 plots the proportion of category spanning and home category patenting as a proportion of all nanotube patents per year. There is a clear pattern where category spanning increased while home category patenting fell as the category system became more tightly packed. Figure 2-3 plots the distance travelled by category spanning patents each year. After an initial spike, a clear downward trajectory is apparent beginning around 1996. As categories began to cluster, inventors engaged in more spanning and crossed shorter distances in doing so. In sum, I find strong evidence that the structure of the category system affected the type of innovation that actors pursued within it.

-------- Insert Figures 2-2 and 2-3 about here --------

While the marginal influence of category similarity is noteworthy in its own right, its effect in tandem with my other hypothesized variables is striking. Indeed, similarity appears to be the enabling mechanism which unlocks the influence of economic and social variables. Hypothesis 7 predicts that inventors will be more likely to span between categories when their home category is similar to others, but resource poor. As Model 3 shows, when category importance is combined with similarity it has a negative influence on category spanning and a positive influence on home category patenting. This suggests that while the marginal effect of category importance is negligible, it operates as expected amongst similar categories: actors pursue incremental innovations in resource rich categories but break with past lines of innovation in poorer categories when there are similar ones they can shift into. To check that category spanning indeed followed a pattern where inventors moved into more fertile categories, I calculated the average importance of sending and receiving categories. The average importance of a receiving category was 0.44 standard deviations higher than the sending category, thus providing further support for hypothesis 7.

I also find support for hypothesis 8. Inventors are significantly more likely to engage in category spanning when their home category is similar to others and they add collaborators with experience in other categories. The magnitude of this effect on the hazard rate is very high. Thus, while collaborators may convey information about patent opportunities in disparate categories, this does not appear to have much influence if the subsequent innovation would take an inventor far from their home category. The interaction between changes in work experience and category similarity has no discernable effect, however. This may be due to the high proportion of transitions within academe and industry as compared to transitions across institutional domains. As Models 1 and 2 show, corporate employment is significantly associated with category spanning. Thus, it reasons that a sub-set of career moves tracking shifts into industry should produce a significant result. To investigate, I constructed a variable of transitions from academe to industry; however, the number of observations was too low to produce meaningful results (21 occurrences in 2874 inventor year observations).

Finally, while the two way interaction between category similarity and star scientist spanning does not support hypothesis 9, supplementary analysis shows a more nuanced, time inflected relationship. As Figure 2-3 shows, star scientists tended to reach out to more distant categories than other inventors in their spanning. However, the distance spanned fell more precipitously as the category system began to cohere. To investigate how this affected mimetic explanations for category spanning, I modeled a three way interaction between star spanning, similarity, and a dummy variable set to 1 in years post 2000 (when the average Euclidean distance spanned by star scientists began to settle at around .85). As Model 3 shows, the result supports hypothesis 9 (all composite 2-way interactions were included but are not reported for issues of parsimony).

While competing hazard rate models suggest that star scientist mimesis played a comparatively minor role in enabling category spanning, a deeper look shows that star scientists actually played a central role in driving this process. To wit, a detailed examination of category spanning amongst star scientists combined with analysis of archival documents shows that these inventors were key in shaping the overall terrain of the nanotube category structure. While by no means an exhaustive list, for illustrative purposes I focus on the activities of Richard Smalley from Rice, Dieter Gruen at the Argonne National Laboratory, Charles Leiber from Harvard, Chad Mirkin at Northwestern, and Richard Haddon from the University of Kentucky; all among the most highly cited scientists over the duration of my analysis.

Analysis of the 'prior art' sections of early patents issued to these scientists yields a consistent pattern of category linkages comprising a clearly identifiable knowledge core for nanotube innovation. Collectively, over 80% of patents issued to star scientists in the first three years of nanotube patenting fell in categories related to chemistry (#204), inorganic chemistry (#423), and, to a lesser extent, hydrocarbon chemistry (#585). Each of Smalley, Gruen, Lieber, Mirkin, and Haddon cut their nanotube patenting teeth in these categories. Moreover, there was a consistent pattern of cross citation between these categories which created a meaningful knowledge core linked to the 'new carbon science' approach to nanotube technology (Meyyeppan, 2005; Smalley, 1995; Smalley Institute, 2009).

As the field developed, star scientists actively extended core knowledge from the new carbon science into disparate technology categories. Indeed, star scientists were among the first to open new categories of technological advance: as Figure 3 shows, the average distance between categories spanned by star scientists was notably higher than other category spanners, especially in the field's formative years[5]. Beginning in 1995, star scientists began to take out patents in categories for crystal growth (#117), compositions (#252), coatings (#427), and stock materials (#428). Tellingly, the prior art citations in these patents show consistent links to the original set of categories where these stars were active (#204, #423, and #585), as well as inter-linkages amongst each other, resulting in a kernel of similar knowledge relevant to each.

This basic pattern repeated in subsequent years as star scientists began to take out patents in a broader array of technology categories. For example, drawing on prior art from categories #204, #423, #252, and #427, Charles Lieber branched out into patent classes related to electronics (#505) and transistors (#257). Likewise, Robert Haddon built on prior art from categories #204, #252, #423, and #428 for patents in categories related to semi-conductors (#257) and data storage devices (#369). Further, as subsequent inventors began to enter these categories, they followed similar patterns of prior art linkage, resulting in the solidification of a broadly similar knowledge base amongst these categories. As Figure 1 shows, by 1996 classes #117, #252, #257, #369, #427, #428, and #505 had begun to occupy similar locations in the nanotube category system and, by 1999 they anchored a tightly packed cluster.

[5] Distance scores are based on MDS solutions which produced yearly coordinates for each category year in 2-dimensional space. I used these coordinates to calculate Euclidean distances between each category pair.

DISCUSSION

In this paper, I explored how individual, categorical, and institutional factors influence an actor's propensity to incrementally innovate in their home category versus breaking away to patent in a new technological domain. My results support arguments about the need to consider the characteristics of a field's overall category system in order to apprehend the dynamics that play out within it (Bourdieu, 1984; DiMaggio, 1987; Mohr, 1998; White, 1965). Moreover, whereas traditional approaches in this vein provide a rather static image of the relationships among categories, I show how the nanotube category system was shaped by star scientists who established a core kernel of knowledge which they extended into multiple categories.

Competing hazard rate models show that between 1993 and 2005, nanotube inventors increasingly recognized opportunities to innovate in new categories and this was largely attributable to the evolving composition of the field's category structure. When a category became more similar to others, its inventors were much more likely to pursue innovation opportunities in multiple categories. In contradistinction, inventors in dissimilar categories continued to pursue incremental, within category, innovations. I also find support for individual and category level explanations for innovation. Results show that a category's resource richness, an inventor's collaboration network, and the behavior of a category's high profile members all affect the type of innovation that an actor pursues. However, the influence of these variables was only apparent when conditioned by the overall category structure. This supports my contention that understanding the types of innovation which actors pursue necessitates the joint consideration of strategic and cultural factors (Oliver, 1997; Lounsbury & Glynn, 2001).

My findings are of interest to scholars who study the role of categories in shaping field and market dynamics, especially those who focus on category spanning. By aligning with sociological approaches to categories and category systems (Bourdieu, 1984; Mohr, 1989; White, 1965), I depart from typical accounts which conceptualize categories as rigid, discrete, and obdurate entities with externally imposed meanings. Rather, I show the importance of considering the structural relationships among categories. Scott (2004: 13) has stressed the utility of such a conceptualization:

> Although still a minority position, a growing number of scholars have begun to embrace a *relational* or process conception… if structures exist it is because they are continually being created and recreated, and if the world has meaning, it is because actors are constructing and reconstructing intentions and accounts.

As such, my study establishes a bulkhead for relational approaches in the organizational literature on categories. I also provide further evidence that categories undergo constant recalibration (Rosa et al, 1999) and highlight one avenue through which this takes place.

A focus on the relational structure of a field's category system has implications for our understanding of the causes and consequences of category spanning. While authors have dedicated considerable energy to showing the detrimental outcomes of spanning (e.g., Hannan & Freeman, 2003; Hsu, 2006, Hsu et al, 2009; Zuckerman, 1999), its antecedents have received considerably less attention (but see Kovacs & Hannan, 2010; Rao et al, 2003, 2005 for exceptions). By showing that spanning is significantly more likely amongst similar categories, I show that the emergence of thick patterned linkages amongst categories is a key mechanism which enables spanning. Moreover, my results suggest the opposite of ecological arguments which hold that category spanning is an attractive option in tumultuous environments (Hannan & Freeman, 1977; 1989). To wit, I find that it is the settling of the category system which enables spanning because this reduces barriers to crossing between specific nodes. Moreover, the interplay I observe between individual, categorical, and institutional factors suggests that category spanning is causally complex and requires further research. One particularly promising avenue would be to examine how institutional forces work with cognitive processes (e.g., Kaplan, Murray, & Henderson, 2003; Kaplan, 2008) to shape innovation dynamics.

My results also suggest that as categories become similar, the relevant level of cultural influence can shift from away from individual categories and toward category clusters. In this way, my results are broadly supportive of recent work which discusses the possibility of penalties varying according to the categories which an actor spans (Hsu et al, 2009; Kovacs & Hannan, 2010). It would be useful for future research to investigate the potential for the relational structure of a category system to not only affect which categories get spanned, but the consequences for doing so. Also, while conflict was not apparent in my research context, another potentially fruitful line of inquiry would be to examine how category spanning innovation is affected when groups compete to impose their preferred category ordering or actively resist changes to the category structure (Hargrave & Van de Ven, 2006; Marquis & Lounsbury, 2007).

In addition to its implications for the study of categories, a key contribution of my paper is that it embeds processes of opportunity recognition within a broader cultural milieu. My study thus reaffirms arguments in the entrepreneurship literature which hold that opportunities are not identified objectively but, rather, are rooted in interpretive processes shaped by individual characteristics, social networks, and past experiences (Aldrich, 1999; Shane et al, 2003; Shane, 2000; Singh, 2000). I extend this literature by showing the direct influence of culture on opportunity recognition as well as illuminating the potential for extant explanations to be culturally contingent. In this way, my results also support recent arguments about the institutional conditioning of innovative activity (Lounsbury & Glynn, 2001; Powell et al, 2011) and extend them by showing how the types of opportunities an actor pursues are shaped by the interplay of cultural, economic, and social factors. Given the paucity of research about the role of culture in guiding opportunity recognition, let alone its interaction with economic and social variables, my study provides an important direction for future research.

My findings may also be of interest to scholars who focus on organizational exploration and exploitation. Consistent with the types of innovation analyzed in my paper, exploitation is the incremental innovation of extant products and services while exploration constitutes an attempt to break away and innovate more radically (see Baum, Li, & Usher, 2000; Benner &

Tushman, 2002; March, 1991). Much of this research focuses on research and development, organizational competencies, as well as search processes and their timing (e.g., Gilsing et al, 2008; Katila, 2002; Rosenkopf & Nerkar, 2001). Although my findings are at the actor level, they point to potentially interesting avenues for organizational research in this domain. For instance, it may be useful to examine the ways in which institutional forces shape which types of exploratory inventions a firm decides to actively cultivate and pursue – or, put another way, how field-level dynamics affects decisions about when to begin exploiting the fruits of exploration. The issue of alignment between exploration and field dynamics also warrants consideration. Is it beneficial for exploration to track with the relational composition of a field's category system? If a firm sits in a distant category, what are the consequences of exploring in more central categories versus continuing to develop extant offerings? And, what are the strategic consequences for exploring in distant categories?

Finally, my results point to a potential second-order benefit of exploration. Given its speculative nature, the link between exploration and the introduction of viable products and services can be tenuous (March, 1991). A good example is exploration linked to basic scientific research where questions persist about why firms engage in this behavior at all (e.g. Ding, 2008). In addition to the remote possibility of a radical breakthrough, my findings suggest that this very speculative form of exploration may contribute to the shaping of innovation trajectories. While more research is clearly needed, it reasons that speculative forms of exploration such as basic science research may contribute to a firm's non-monetary capital stocks. To the extent that scientific prestige converts into relational influence (Bourdieu, 1984), it may help a firm shape innovation paths to enable the success of subsequent exploration activities that are geared more discretely toward market applications.

In sum, my study helps to cast light on the mechanisms which lead actors to pursue novel lines of inquiry as opposed to innovating incrementally. In doing so, I support arguments that emphasize both the institutional shaping of innovation as well as its more micro antecedents while extending each in novel directions. My findings help reorient the organizational literature on categories away from a focus on constraint and homogeneity by showing how the more active uses of culture can shape the dynamics of innovation within a field. I also highlight the value of a cultural sensibility for scholars of entrepreneurship and strategy by showing how the micro underpinnings of innovation may not only be shaped by institutional forces, but quite dependent on them in some contexts. As such, I show that our understanding of category spanning can be greatly enriched by the joint consideration of individual, categorical, and institutional factors.

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TABLES AND FIGURES

TABLE 2-1.
Means, Standard Deviations, and Correlations

	Variables	Mean	St. Dev.	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Academia	.68	.287	-.023	.039	.018	.504	-.012	.291	.057	.044	.131	.017	.059	.196	.194
2	Industry	.24	.116	---	.057	.026	.119	.021	.001	-.001	.017	-.025	.015	.000	.100	-.016
3	Prev. spanning	.082	.310		---	.113	.053	.209	.072	.056	.063	.071	.235	.090	.051	.027
4	Prev. home category	.097	.450			---	.069	.154	.001	.179	.128	.048	.287	.057	.054	.016
5	Publications	.512	1.51				---	-.025	.344	.061	.100	.154	.029	.031	.429	.128
6	Breadth	1.90	3.25					---	-.015	.025	-.026	-.054	.027	-.083	.026	-.012
7	Network additions	.073	.126						---	.007	.001	.045	.021	.020	.208	.052
8	Density	3.39	3.98							---	.496	.064	.471	.295	.088	.028
9	Importance	.232	.273								---	.057	.299	.258	.101	.050
10	Star scientists	.399	.533									---	.064	.039	.071	.053
11	Star sci. spanning	1.24	2.26										---	.239	.044	.065
12	Similarity	.352	.237											---	.035	.036
13	New ntwk category	.035	.184												---	.076
14	Career moves	.016	.126													---

TABLE 2-2.
Competing Hazard Rate Analysis of Category Spanning (1) and Home Category Patenting (2): 1993-2005

Variables	Model 1 (1)	Model 1 (2)	Model 2 (1)	Model 2 (2)	Model 3 (1)	Model 3 (2)
Controls						
Academia	-.058 (.354)	-.141 (.352)	-.137 (.393)	.061 (.358)	-.235 (.408)	.096 (.324)
Industry	1.170 (.411)***	.192 (.603)	.844 (.448)*	.220 (.591)	.784 (.465)*	.263 (.585)
Prev. spanning	.336 (.351)	-.494 (.153)***	.245 (.356)	-.487 (.158)***	.289 (.334)	-.459 (.150)***
Prev. home category	-.072 (.260)	.195 (.076)**	-.413 (.295)*	.091 (.079)	-.587 (.389)*	.013 (.079)
Publications	.084 (.044)*	.089 (.042)**	.061 (.047)	.064 (.052)	.074 (.047)	.057 (.051)
Breadth	.041 (.031)	.074 (.182)***	.032 (.030)	.073 (.019)***	.037 (.030)	.095 (.020)***
Network additions	.184 (.566)	.437 (.346)	.150 (.580)	.475 (.283)*	.039 (.579)	.412 (.274)
Density	-.004 (.006)	.166 (.014)***	-.008 (.008)	.157 (.019)***	-.006 (.008)	.111 (.057)**
Home Category						
Importance			.403 (.331)	.420 (.366)	-1.259 (.676)**	6.516 (1.956)***
Star scientist spanning			-.103 (.074)*	-.002 (.004)	.149 (.261)	-.007 (.026)
Similarity			.313 (.121)***	-.300 (.083)***	.481 (.166)***	-.352 (.093)***
Inventor						
Star scientist			.121 (.071)**	-.241 (.201)	.147 (.074)**	-.334 (.198)*
New network category			.069 (.178)	.019 (.171)	2.513 (1.138)**	.062 (.233)
Career moves			.307 (.590)	.506 (.441)	.409 (.603)	.205 (.167)
Interactions						
Importance x Similarity					-1.376 (.416)***	5.994 (2.129)***
New ntwk.cat. x Similarity					2.574 (1.239)**	.031 (116)
Career moves x Similarity					-.731 (.988)	.835 (1.371)
Star signals x Similarity					.280 (.289)	-.006 (.021)
Star sig x Sim. x Post 2000					.697 (.414)**	
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Log-likelihood	-667.563	-1011.889	-633.999	-933.189	-626.397	-919.914
LR X^2	45.50	80.58	72.12	217.11	87.33	335.70

Standard errors in parentheses; 2-tailed tests for hypothesized variables; *p < .10; **p < .05; p < .01***

FIGURE 2-1.
Multidimensional Scaling Plots of the Nanotube Category System

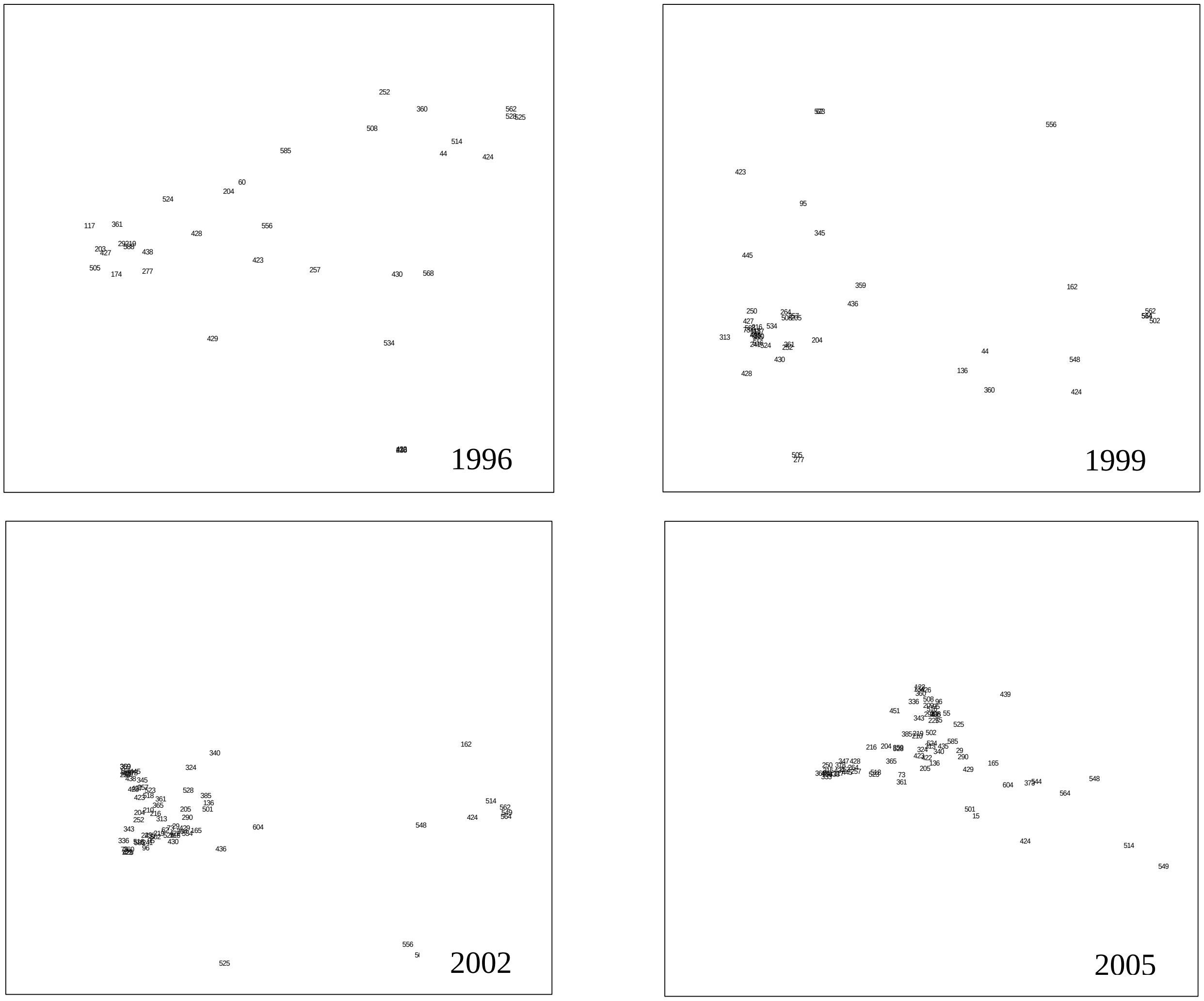


FIGURE 2-2.
Proportion of Category Spanning and Repeat Category Patents per Year

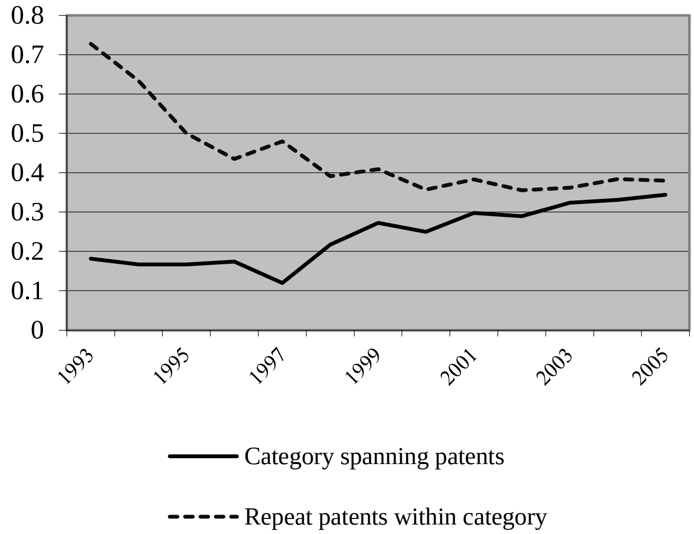
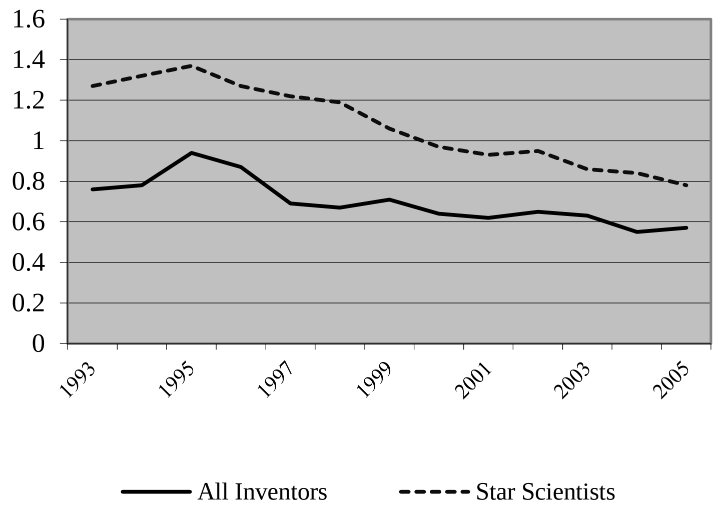


FIGURE 2-3.
Average Euclidean Distance
Between Categories Spanned per Year



CONTEXTUALIZING THE CATEGORICAL IMPERATIVE: CATEGORIES, CONVEYED IDENTITY, AND RESOURCE ACQUISITION IN NANOTECHNOLOGY ENTREPRENEURSHIP

Attracting resources from external providers is critical to the survival and growth of an entrepreneurial venture (Aldrich, 1999; Brush, Greene, & Hart, 2001; Sahlman et al, 1999; Shane, 2003). Yet, gaining positive attention from audiences such as customers, ratings agencies, potential employees, and investors is a difficult task. Without an established track record, reputation—or even product in some cases—there is considerable uncertainty about a new venture, and this makes resource providers reluctant to invest (Brush et al, 2001; Shane, 2003; Stinchcombe, 1965). Given the importance of resource acquisition, scholars have dedicated considerable energy to identifying factors that help firms to overcome these barriers. While studies have focused on firm-level attributes such as founding team composition and business plans, or relationships such as third-party affiliations and endorsements (see Shane, 2003 for an overview), our understanding of the role played by cultural dynamics in resource acquisition is limited (Martens, Jennings, & Jennings, 2007; Navis & Glynn, 2011; Rao, 1994).

I aim to contribute to the emerging literature on culture and resource acquisition—and help to strengthen the bridge between micro and macro perspectives on entrepreneurship—by examining how cultural factors influence which firms receive venture capital investment. Following extant research, I define culture as the interpretive frameworks that actors use to make sense of their own behavior and that of others (e.g., Lounsbury & Glynn, 2001; Scott & Lane, 2000; Wry, Lounsbury, & Glynn, 2011). While culture exists at multiple levels of analysis, one important level is the category systems which structure attention, action, and valuation within an organizational field (Hsu, 2006; Hsu, Kocak, & Hannan, 2009; Kennedy, 2005, 2008; Khaire & Wadhwani, 2010; Lounsbury & Rao, 2004; Zuckerman, 1999). Actors rely on categories to simplify thought and understanding by lumping similar things together and distinguishing them from others (Zerubavel, 1997). Through this act of grouping, categories set boundaries and create shared understandings about what appropriately falls within them (Douglas, 1986; Rosch & Lloyd, 1978). Because of these properties, categories such as film genres (Hsu, 2006), industry categories (Zuckerman, 1999), and technology classes (Kennedy, Lo, & Lounsbury, 2010) shape perceptions by providing audiences with a comparison set and specifying evaluation criteria for category members (e.g., Khaire & Wadhwani, 2010; Rao, Monin, & Durand, 2003; Zuckerman et al., 2003).

There is an established consensus that organizations are viewed less favorably when they span multiple categories—a phenomenon known as the 'categorical imperative' (Hsu, 2006; Hsu et al, 2009; Zuckerman, 1999). Two explanations have been advanced: 1) performing well in a category requires distinct skills and, as a result, spanning multiple categories dilutes attention and expertise; and 2) audiences have difficulty understanding the identities of category spanning organizations, making it unclear where they fit within a field and how they should be valued (Hsu et al, 2009; Rao et al, 2003). While penalties are strongest when oppositional categories are spanned (Kovacs & Hannan, 2010), evidence shows that the categorical imperative is robust to wide range of contexts (see Hannan, 2010 for a review). Given the high uncertainty of a nascent entrepreneurial venture, this research suggests that category affiliations may be an important factor in resource acquisition. Affiliation with a limited number of categories may help a firm to convey a more focused identity and clear expertise: two important factors in venture capital investment decisions (Chen, Yao, & Kotha, 2009; Fried & Hirsch, 1994; Navis & Glynn, 2011; Sahlman et al, 1999).

I suggest that the category affiliation(s) of a new firm will affect its likelihood of attracting venture capital, but not necessarily in the ways suggested by extant studies. Most studies examining the implications of category spanning assume that categories are rigidly bounded, stable, equidistant, and discrete (but see Ruef & Patterson, 2009 for an exception). Yet, evidence shows that this is not always the case: new categories can emerge (Khaire & Wadhwani, 2010; Lounsbury & Rao, 2004), categories can become similar or different (Rao et al, 2005), and boundaries can become sharper or more ambiguous (Fleischer, 2009; Ruef & Patterson, 2009).

I build on these insights and take a relational approach which emphasizes that the meanings associated with a category are affected by its position vis-à-vis others in a category system (Emirbayer, 1997; Scott, 2008). More specifically, I argue that categories may become linked together at a superordinate level of analysis (Bourdieu, 1984; Rosch & Lloyd, 1978) or when the perceived expertise needed to compete in different categories becomes similar (Rao et al, 2005). In either case, the implication is that certain categories may be seen as fitting together, fostering perceptions that firms which bridge them have a comprehensible identity and focused expertise. While categories may be more or less closely related in all classification systems (Kennedy, 2008), these effects are likely to be more pronounced in nascent or tumultuous fields where order is an emergent property and inter-category relationships are prone to shift and solidify in real time (Rao et al, 2005; Ruef & Patterson, 2009)

My research context is the nanotube technology field; one of the first domains of commercial nanotechnology, spawned by the discovery of a new form of carbon (C60) in 1985 (Berube, 2006). Nanotubes are nano-scale structures with hexagonally arranged carbon atoms wrapped into a cylindrical shape. They are very strong, rigid, and are excellent conductors of light and energy. Based on these properties, there has been speculation about revolutionary commercial applications for nanotubes in optics, materials, medicine, energy, and computing (Lux Research, 2006; Meyyeppan, 2005). Commercialization efforts began almost immediately after nanotubes were discovered and the first patents were applied for in the early 1990's. While patenting was initially led primarily by prominent scientists and large corporations, nascent firms began to emerge in the mid-1990's. By 2005 the field encompassed almost 60 startup firms and the overall market for nanotube products was estimated to be $43m with a 44% compounded annual growth rate (Lux Research, 2006). As with cognate fields like biotechnology and semiconductors (Aldrich, 1999; Martens et al, 2007) venture capital was an important resource for nascent CNT firms and helped many firms take applications from the lab to the market (see Lux Research, 2006).

To assess how the category affiliation(s) of nascent entrepreneurial firms affected their likelihood of attracting venture capital, I examined how their patents were categorized by the United States Patent and Trademark Office (USPTO). In high technology fields, the identity and expertise of a startup firm are reflected in the technologies which they patent (Kennedy, 2008; Podolny & Stuart, 1995; Powell et al, 2011; Powell & Sandholtz, 2011; Stuart & Ding, 2006). To be clear, a firm's identity is not limited to the technologies it is developing (Glynn, 2008). Still, the 'technological identity' which I'm referencing may be an important piece of a firm's self definition (Darby & Zucker, 2010) and is an important way that high technology firms present themselves to external parties (Powell & Sandholtz, 2011). The USPTO distinguishes between different types of technologies with a classification system comprised of +400 categories[6]. Based on the claims listed on a patent application, expert examiners at the USPTO follow an assiduously laid out classification protocol and assign the patent to a primary category that reflects its chief attributes and functions (USPTO, 2009). Categories are mutually exclusive and have extensive criteria detailing the types of inventions that can be placed within them. As such, USPTO categories are widely used in academic studies to differentiate between related and unrelated inventions (e.g., Gilsing et al, 2008; Hall, Jaffe, & Trajtenberg, 2001; Rosenkopf & Nerkar, 2001). Industry actors, including venture capitalists, also use them to understand patterns of technology development and the position of various firms in this context (Chicock, 2002; Lux Research, 2006).

While there is a general consensus that USPTO categories capture meaningful distinctions amongst areas of technological development, I find

[6] Note that I use 'category' and 'class' interchangeably throughout the paper.

limited support for the categorical imperative in the nanotube field. Hazard rate models show that firms developing technologies across multiple categories were less likely to receive investment, but this effect disappears for firms who stake out identity positions across related categories. Additional analysis suggests that the evolving relational structure of categories in the nanotube field also facilitated the emergence of combinations that were viewed as coherent and valuable identity positions. After developing my hypotheses in the next section, I provide details about the CNT field and the nascent firms that emerged within it. I analyze venture capital investments reported in the Zephyr database from 1994 (when the first CNT firm emerged) through 2005 to shed light on how category affiliation(s) affected resource acquisition amongst the full population of startup firms. I conclude by discussing the implications of my findings for the resource acquisition and categories literatures, and for research at the interface of micro and macro approaches to entrepreneurship, more generally.

VENTURE CAPITAL AND THE CATIGORICAL IMPERATIVE

Cultural and institutional processes are becoming increasingly important to our understanding of entrepreneurial dynamics. Studies have shown that the shared understandings which exist in particular fields, communities, and time periods shape the entrepreneurial ventures that emerge within them (Cornelissen & Clarke, 2010; Lounsbury, 2007). Recent work has also begun to examine the active shaping of culture (Khaire & Wadhwani, 2010) and how this enables the emergence of completely new types of organizations (Lounsbury, Ventresca, &

Hirsch, 2003; Sine & Lee, 2009; Weber, Heinze, & DeSoucey, 2008). While this work typically examines the relationship between culture and entrepreneurship at a fairly broad level of analysis, scholars have also suggested that cultural factors may influence the ability of individual firms to secure resources (Lounsbury & Glynn, 2001; Navis & Glynn, 2011; Martens et al, 2007). I contribute to this burgeoning literature by integrating and extending insights about a firm's category affiliation(s) and the assessments of external resource providers.

I suspect that a firm's categorization plays an important role in venture capital investment decisions. Scholars have long recognized the difficulty that nascent organizations face in gaining positive attention from resource providers. The newness of a venture, while a central and highly lauded feature of entrepreneurship, is also a significant liability (Stinchcombe, 1965). Resource providers are faced with decisions about how to allocate their investments and there is typically high uncertainty about the potential and quality of a nascent firm (Shane, 2003). While venture capitalists have a higher risk tolerance than many other investors, they still look for 'safe bets': firms with potentially valuable opportunities as well as the expertise to capitalize on them (Chen et al, 2009; Fried & Hirsch, 1994; Navis & Glynn, 2011). Evidence also suggests that nascent firms are unlikely to receive investor attention when their identities are unclear (Glynn, 2008; Lounsbury & Glynn, 2001; Navis & Glynn, 2011). Perceptions of identity and expertise both relate to category affiliations.

Categorization is a ubiquitous social process where actors group like things together. When categories are widely agreed upon, they create shared understandings about the similarity and distinctiveness of various entities and provide criteria for evaluating their members (Douglas, 1986; Rosch & Lloyd, 1978; Zerubavel, 1997). As such, categories provide a foundation for identification within fields and help observers to evaluate category members (Espland & Stevens, 1999; Khaire & Wadhwani, 2010; Zuckerman 1999). When a firm is affiliated with multiple categories, studies consistently show that observers have difficulty making sense of its identity and infer lower levels of expertise in each category as compared to competitors with more focused identities (e.g., Hsu, 2006; Hsu et al, 2009; Zuckerman, 1999)—a phenomenon that Zuckerman (1999) termed 'the categorical imperative'.

Discounted evaluations for category spanning have been shown in a range of contexts. For example, films that span multiple genres are seen as having unclear identities, making them less appealing to critics and moviegoers (Hsu, 2006; Hsu et al, 2009). Likewise French chefs that bridged categories of haute and nouvelle cuisine received lower ratings because Michelin Guide critics could not easily identify them as members of a particular category (Rao et al, 2005). While it is possible that the poor performance of category spanners results from the difficulty they face in allocating scarce resources across multiple domains (Freeman & Hannan, 1989), perceptions of an organization's identity and expertise affect evaluations regardless of their accuracy (Hsu & Hannan, 2005). For example, 'craft' brews produced by large industrial brewers were poorly evaluated, independent of their quality, because audiences saw the identity and expertise of these firms as inconsistent with making craft beer (Carroll &

Swaminathan, 2000). Following this logic, I expect that, at a general level, affiliation with multiple technology categories will result in an unfocused identity for a nascent CNT firm, creating ambiguity about what *type* of firm it is and how its expertise relates to the manifold technologies it is developing. Because of this, I expect that venture capitalists will be less likely to invest in such firms.

H1: Entrepreneurial ventures will be less likely to receive venture capital when they convey unfocused identities through a portfolio of inventions that bridge multiple technology categories.

CONTEXTUALIZING THE CATEGORICAL IMPERATIVE

Although I agree that an organization is likely to be viewed less favorably when its category affiliations create ambiguity about its identity and expertise, I suggest that this is moderated by the relationships between the categories being spanned (Emirbayer, 1997; Kovack & Hannan, 2010). In particular, categories may become understood as fitting together, thus blunting the identity ambiguity created by category spanning and enabling perceptions that expertise across categories is symbiotic. Taking this broader context into account has potentially important implications in terms of scope conditions for the categorical imperative and may provide a very different view on the hazards of category spanning. I suggest two ways that categories might be understood as fitting together: 1) when they are linked at a superordinate level of analysis; and 2) when their underlying knowledge and expertise become similar.

Category Linkages at a Superordinate Level

Most studies of category spanning assume that categories are rigidly bounded, stable, equidistant, and discrete (but see Rao et al, 2005; Ruef & Patterson, 2009 for exceptions). This flat topography suggests that the meanings associated with each category are similarly potent. However, studies in cognitive psychology show that categories can be arranged hierarchically, in which case the types of distinctions implied by the categorical imperative may operate at a higher level of analysis (Rosch et al, 1976; Rosch & Lloyd, 1978; Porac & Thomas, 1990). When audiences perceive meaningful distinctions at a superordinate level of analysis, it becomes more important and culturally potent than the lower level categories which comprise it (Rosch et al, 1976; Rosch & Lloyd, 1978; Porac & Thomas, 1990). For instance, differences across product categories may become muted when higher level industry category differences are focalized (Lounsbury & Rao, 2004). As such, this research suggests that the relevant level of cultural distinction in category studies should be treated as an empirical question.

One important way that categories may become meaningfully linked together is through common association with a specific type of actor. Indeed, a central contribution of Bourdieu's theorizing was to show that different classes of actors distinguish themselves through habitual affiliation with configurations of categories that cross domains of food, clothing, furniture, and entertainment (Bourdieu, 1984). Extending this insight to an organizational context, Lounsbury (2007) showed that Boston and New York money managers created linkages among mutual fund product categories associated with conservative versus aggressive investing respectively, and accentuated the differences across these two classes of categories. Mohr and Duquenne (1997) also illustrated this type of identity-consistent category spanning among New York City Poorhouses: identities were built on configurations of categories related to the actors served and practices used to serve them. Likewise, Porac and Thomas (1990: 229) presented evidence that the identities of different categories of Scottish knitwear providers were comprised of lower-level categories such as 'knitwear, fashion knitwear, and fully fashioned knitwear'.

Moreover, this type of distinction can apply even when a group of actors affiliate with different, but overlapping, category configurations. According to Wittgenstein's (1953) theory of family resemblances, audiences can associate a group of categories with a group of actors even if its members affiliate with various categorical combinations—potentially not sharing membership in any one category. Thus, when different categories are associated with a similar type of actor, spanning between them may be seen as an identity consistent – or even an identity verifying – act. I expect that this will have two implications for venture capital investments:

H2: Entrepreneurial ventures will be less likely to receive venture capital when they convey unfocused identities—that is, a portfolio of inventions that bridge categories which are associated with different types of actors.

H3: Entrepreneurial ventures will be more likely to receive venture capital when they convey focused identities—that is, a portfolio of inventions in categories which are associated with similar types of actors.

Category Linkages through Common Expertise

The mechanisms leading to discounted evaluations for category spanners might also be conditioned by the similarity of expertise associated with the categories being spanned. While category studies typically assume that the skills and abilities required to compete effectively in one category are distinct from others (Hannan & Freeman, 1989), this need not be the case. Within many classification systems, there are categories which are more and less similar (Bowker & Star, 1999; Fleischer, 2009; Rao et al, 2005). As such, while categories may be associated with distinct outputs, there can be various degrees of overlap in the skills and abilities required to produce the elements that comprise them. For example, there is growing agreement amongst organizational scholars that 'institutional' and 'social movements' research categories share a number of underlying similarities, even as they pursue different types of research questions (Campbell, 2005; Schneiberg & Lounsbury, 2008).

Moreover, category relationships are not static; they evolve as actors build bridges, borrow across boundaries, and advocate for the appropriateness of such blending (Hannan & Freeman, 1989; Rao et al, 2005). As consensus emerges about the similarity of various categories, it can attenuate perceptions that actors who span between them are diluting their expertise or engaging in identity-inconsistent activities (Lamont & Molnar, 2002). For example, Rao and colleagues (2005) showed that mixing techniques associated with haute versus nouvelle cuisine initially resulted in discounted evaluations for French chefs. However, as audiences began to see these categories as fitting together—with chefs equally adept at producing haute and nouvelle dishes as well as combining their elements directly—this type of hybrid identity became viewed as appropriate by groups such as Michelin Guide critics and the punishments for spanning largely disappeared. Similarly, Lounsbury and Rao (2004) showed that before the 1970's mutual fund providers held identities as 'growth' or 'trustee' investment houses based on their affiliation with one of these orthogonal investment categories. Subsequently, the field began to evolve an array of product categories encompassing varying degrees of risk. This allowed firms to cultivate new types of identities – which audiences perceived to be focused and legitimate – as purveyors of diverse investment options (Lounsbury, 2007). In the context of technological knowledge and patent categories, when patents across different categories build on common knowledge, or when knowledge flows develop between particular categories, they may be viewed as similar because they share a common base of expertise (Hall et al, 2001; Jaffe et al, 2000). As such, I think that when the expertise considered relevant to different technology categories becomes similar, venture capitalists may view spanning between them as an identity-consistent act, well suited to exploiting a nascent firm's expertise. Thus,

H4: Entrepreneurial ventures will be more likely to receive venture capital when they convey focused identities—that is, a portfolio of inventions in categories that build on similar types of knowledge and expertise.

DATA AND METHOD

My empirical context is the nanotube technology field. Nanotubes are nano-sized structures comprised of hexagonally arranged carbon atoms that are wrapped into cylinders. They are very small, strong, and light with novel thermal, optical, and electro-conductive properties (Harris, 2005; Meyyeppan, 2005). Nanotubes are derived from a completely new form of carbon (C60) which was discovered in 1985 and rewarded with a Nobel Prize (Smalley, 1995). There has been considerable speculation about the commercial potential of nanotubes, with some observers predicting that they will revolutionize areas such as optics, materials, medicine, computing, energy transmission, and display devices (Berube, 2006; Lux Research, 2006). Patenting began almost immediately after Sumio Iijima (1991) illustrated nanotube synthesis and the field quickly developed into one of the most prominent domains of commercial nanotechnology (Lux Research, 2006).

In the mid-1990's entrepreneurial firms began to emerge, pursing opportunities related to nanotube production and nanotube-enabled products. As Figure 1 shows, only a handful of firms were active through 2000. However, this jumped considerably in subsequent years. By 2005 the field encompassed 57 startup firms, collectively accounting for almost 250 patents. While venture capital was not the exclusive source of financing for these firms (the US government also played a key funding role by providing research grants), it provided large capital infusions as well as strategic expertise for bringing products from the lab to the market (Lux Research, 2006). Between 1994 and 2005, 26 firms received venture funding with 68 completed deals totaling approximately $250m. Notably, the median size of these deals ($6m) was over 10x larger than a typical government grant (Lux Venture Capital, 2006; Zucker &

Darby, 2007).

------Figure 1 about here------

I used the United States Patent and Trademark Office (USPTO) classification system to examine category affiliations amongst nascent firms, thus capturing the extent to which their identities were more or less focused. Each patent issued by the USPTO is assigned into one of over 400 primary technology classes. These categories are mutually exclusive and contain detailed guidelines about what types of inventions should be placed within them (Hall et al., 2001). While patents are categorized by USPTO examiners, category affiliations are largely voluntaristic. Each patent application contains an inventory of claims detailing an invention's attributes and functions; these claims provide the basis for its categorization (USPTO, 2009)[7]. To help ensure accurate interpretation of patent claims – and thus appropriate classification – patent applications are assigned to examiners with expertise relevant to the focal invention, often in the form of a PhD in a related area. Examiners follow a detailed classification protocol designed to ensure consistent and accurate categorization (see Hall et al, 2001; USPTO, 2009). While the potential exists for a patent to be placed in a category not intended by its inventor(s), there is a general consensus that patent categories capture meaningful distinctions among the technologies that a firm is developing (see Gilsing et al, 2008; Katila, 2002; Rosenkopf & Nerkar, 2001). Further, actors such as venture capitalists use the USPTO category system to map out trajectories of innovation within a field and to assess the competitive position

[7] In addition to examining official USPTO documents pursuant to classification, I conducted five interviews with patent examiners. Each told a consistent story of classification as a mechanistic process guided by the claims made in a patent application.

of various firms in this context (Chicock, 2002; Lux Research, 2006).

My patent data is from Nanobank – an authoritative storehouse of nanotechnology patents, grants, and articles (Zucker & Darby, 2007). To identify nanotube patents from this larger set, I searched for 'nanotube' and related terms such as 'fullerene', 'buckeyball', and 'carbon 60' that I identified from research compendiums (e.g., Harris, 2005; Meyyeppan, 2005). This search yielded 1128 patents through 2005 (when the Nanobank data ends), the first of which was applied for in 1991. I recorded information about the original—or primary—category for each patent as well as its inventor(s) and organizational assignee. I also kept an inventory of the 'prior art' citations made by each patent as a way to track the expertise considered relevant to patents in each category.

To identify nascent firms, I examined the assignees listed on each patent and matched this against a list of startup firms compiled from sources including the Lux Nanotechnology Report (Lux Reserach, 2006), the Nanotube Site (Tomanek, 2009), and Understanding Nano (Boysen, 2009). The Lux Report was particularly useful because it lists the type of nanotechnology that each firm is working with (e.g., nanotubes vs. quantum dots). Given that Nanobank does not include patents that were applied for, but not granted, before 2005, the Lux Report helped me to identity firms that were not picked up in my original sample. In total, I identified 57 unique firms that were active in the field through 2005, the first emerging in 1994. To ensure my patent data was comprehensive, I searched for each firm's patents directly in the USPTO database. Interestingly, this search showed a handful of firms with non-nanotube patents in their portfolios (four firms and twelve patents). I tried to account for this in two ways: 1) as a distinct variable; 2) as another instance of category spanning, equivalent to spanning between USPTO classes with nanotube patents. The first was not significant in any model and neither affected the magnitude, direction, or significance of reported results. As such, I dropped these patents from my analysis and confined my category spanning measure to nanotube patents.

Venture capital information is from Zephyr, a database that tracks organizations receiving venture capital over the years of my analysis. Data is organized by firm-year and includes 332 observations between 1994 and 2005.

Variable Definitions

*Dependent variable***.** My dependent variable is venture capital investment. I track this in two ways. Primary analysis treats investment as a binary variable set to 1 for the year that a firm receives funding and 0 in all other years. This allows me to model the factors that help a nascent firm to secure venture capital. In supplementary analysis, I also explore differences in the level of funding which firms received. Here, venture capital is modeled as a continuous variable reflecting the amount of each investment in millions of dollars.

Independent variables. Category spanning is calculated using a modified herfindahl measure (where larger values represent dispersion rather than concentration so as to match the directionality of my hypotheses) that captures the extent to which a firm's patents are focused in a limited number of USPTO classes, or are spread out amongst many. The equation is written as:

$$H(\mu(x, y, t)) = 1 - \sum_{l \in p(t)} \mu^2_{i(l)}(x, y, t), \qquad \text{Eq.1}$$

where $\mu_{i(l)}(x, y, t)$ is the proportion of the firm's category memberships that come from *l*. As per the convention in patent studies, my category spanning variable is based on patent application dates (see Hall et al, 2001).

Hypotheses 2 and 3 argue that venture capital investment will be affected when firms affiliate with categories associated with a specific type of actor. Along these lines, I think that venture capitalists may perceive a coherent identity for nascent firms when they bridge categories that are the focus of patenting by high profile 'star' scientists *or* large corporations. Early nanotube patenting was led primarily by these actors and, mirroring the divide between academic science and corporate development, star scientists tended to take out patents related to nanotube synthesis and materials, while large corporations worked to integrate them into consumer product platforms (Lux Research, 2006; Meyyeppan, 2005). Reflecting this, my data show a fairly low correlation (.182) between star scientist and large corporation patent density across all category-years of my analysis. Further, while over 100 categories contained nanotube patents between 1991 and 2005, the majority of star scientist and large corporation patents clustered in a small subsection – the top 10 categories for star and corporation patenting comprised between 64% and 78% of all patents issued to these actors in a given year. Models reported elsewhere also suggest that categories where star scientists or large corporations focused were the most likely to emerge as prominent sites of nanotube patenting (Lounsbury, Wry, & Jennings, 2010), and that other actors tended to follow one or the other – not both – in their own patenting (Wry, 2010).

Thus, I think that categories where star scientists versus large firms focus may provide a relevant level of distinction beyond individual technology categories.

To track a nascent firm's affiliation with categories that were the focus of star scientist and large corporation patenting, I began by identifying patents issued to these actors. I considered an inventor a star when his/her scholarly articles were cited +1000 times[8] (see Zucker, Darby, & Brewer, 1998 for a related approach). Firms with +$500m in sales were considered large corporations[9]. From this, I calculated the cumulative proportion of all star scientist and large corporation patents in each category per year. A nascent firm's affiliation with star scientist categories is the average proportion of star scientist patents in the categories where the firm has patented. Affiliation with large corporation categories is the average proportion of large corporation patents in categories where the firm has patented. I interacted these variables with category spanning to see how they affected the outcomes of multiple category affiliations.

Hypothesis 4 argued that venture capitalists might perceive coherent identities for nascent firms that span between categories where similar expertise is relevant. To assess this, I began by examining the 'prior art' citations listed on the patents in each category. Similar to references in an academic article, each patent issued by the USPTO includes a list of related patents that it builds on (Hall et al, 2001). Technology categories that cite similar prior art are considered to build on like expertise (Hall et al, 2001; Jaffe et al, 2000; Katila, 2002;

[8] To calculate this, I gathered information about an inventor's scholarly publications from Nanobank. From this, I created yearly citation reports for each inventor based on information from the Web of Science database.
[9] Sales figures are taken from Compustat and are updated annually.

Rosenkopf & Nerkar, 2001). To formally assess the knowledge similarity among patent classes, I began by creating yearly matrices with citing category in the rows and cited category in the columns. Given evidence that patents have a useful life of about five years, each matrix includes data on the previous five years of patents (Hall et al, 2001; Rosenkopf & Nerkar, 2001). Next, using UCINET (Borgatti, Everett, & Freeman, 2002), I calculated joint affiliation data by multiplying each matrix by its inverse (e.g., Breiger, 1974) and then transformed the results into similarity scores using Pearson's correlation method. From this, I calculated closeness centrality scores in UCINET which track the degree to which a category is relationally similar to all others in a given year. I interacted category similarity with category spanning to assess its impact on venture capital funding.

Control variables. I include a number of controls related to the availability of venture capital and quality signals which might help a firm to access it. Evidence suggests that venture capital was more plentiful in the nanotube field in the years after the US National Nanotechnology Initiative (NNI) (Lux Research, 2006). The NNI was passed in 2001 and, backed with over $1 billion in annual funding, provided a strong signal of the U.S. government's commitment to fostering commercial nanotechnology (Berube, 2006). I control for the resulting spike in venture capital with a dummy variable set to 1 in the post-NNI years. Certain regions may also be more fertile for venture capital than others (Chen et al, 2010; Saxenian, 1994). For nanotechnology, commercial activity and venture capital are most prominent in Boston, Houston, and the San Francisco Bay area (Wry et al, 2010). I control for this by assigning a 1 to firms based in these regions. Also, because venture capital funding often results in further financing (Lerner, 1995), I include a dummy for firms that have secured a previous investment round.

Studies also suggest that resource providers look to signals about a firm's quality when making investment decisions (Sahlman et al., 1999; Zott & Huy, 2009). I controlled for four variables generally thought to reflect the quality of a high technology firm: 1) intellectual property (IP); 2) IP value; 3) affiliation with established organizations; and 4) founder status (e.g., Martens et al, 2007; Powell & Sandholtz, 2011; Stuart, Hoang, & Hybels, 1999; Zucker et al, 1998). Intellectual property is the cumulative yearly count of patents owned by a firm or pending approval. IP value is the cumulative yearly sum of citations to a firm's patents in the prior art section of other patents; a widely accepted measure of quality and importance in the patent literature (Hall et al, 2001; Harhoff et al, 1999)[10]. I also controlled for one important type of third-party affiliation—being spun-out of a university or existing corporation (Richards, 2009; Zahra, 1996). Lastly, based on evidence that firms in cognate industries, such as biotechnology, were more likely to secure investment when founded by high profile actors (Powell & Sandholtz, 2011; Zucker et al, 1998), I include a dummy variable for firms launched by a star scientist.

Statistical Method

[10] Using patent citations is complicated somewhat, however, because more recent patents are cited less and patents in different years and categories are not equally likely to be cited (see Hall et al., 2001). To correct for this, I scaled the citations for each of a firm's patents according to the average yearly citations for all nanotechnology patents issued in the same category year (see Mariani, 2004 for a similar approach). Citation rates were calculated using data on each of the patents included in Nanobank.

I modeled the effects of category spanning on the likelihood of receiving venture capital with hazard rate models (Blossfeld, Golsch, & Rohwer, 2007) using the Cox method of estimation (Cox, 1972). Unlike parametric models which make strong assumptions about the shape of a hazard rate, the Cox method controls for temporal effects, but leaves the base hazard rate unspecified. The model is written as:

$$r(t) = h(t)\ \exp(A(t)\alpha) \qquad \text{Eq.2}$$

where the transition rate, *r(t)*, is the product of an unspecified baseline rate, *h(t)*, and a second term specifying covariates, *A(t)*, expected to produce proportional shifts in the transition rate. Model estimation is based on the method of partial likelihood where Y*i*(t) indicates if actor *i* experiences an event at *t*, and Y*k*(t) specifies if actor *k* is at risk at *t*:

$$\prod_{t} \frac{Y_i(t)\exp\left(A_i\left(t_i\right)\alpha\right)}{\Sigma_{=1}\ Y_k(t)\exp\left(A_l\left(t_k\right)\alpha\right)} \qquad \text{Eq.3}$$

Firms enter my risk set the year that they apply for their first patent and leave when they are acquired or fail. I include repeat observations in my analysis to model all instances of venture capital investment. I used STATA 11 for all models. After declaring my data as survival time with the *stset* command I created models using the *stcox* command. Finally, since my data contain repeat observations of individual firms, I used the *cluster* option with ‘firm number’ as the grouping variable to help account for unobserved in-group correlation. Presented results show coefficients rather than hazard rates for ease of interpretation. I also included year fixed effects to help account for any unobserved temporal variation.

In addition, based on results suggesting that some types of category spanning were more likely to result in venture capital investment, I constructed supplementary tobit regression models to explore which category affiliations were associated with larger investments. Tobit regression is a non-parametric alternative to ordinary least squares regression and is typically used in cases where the dependent variable is continuous but skewed (or censored) on either side of the distribution. In my data, investment values are bounded at the low end by zero – and are thus left censored – making tobit regression an appropriate estimation strategy. Also, since my data include repeat firm-year observations, I controlled for unobserved variance by estimating models with year fixed effects and firm random effects. Models were estimated using the *xttobit* command in STATA 11.

RESULTS

Table 3-1 provides variable correlations, means, and standard deviations and shows that there are no correlation problems. Table 3-2 reports the results of my hazard rate models. Model 1 is a baseline model with just control variables. Models 3 to 8 add hypothesized variables and show improved fit over the baseline model.

-------Tables 3-1 and 3-2 about here-------

My first hypothesis argued that firms spanning multiple technology categories would be less likely to receive venture capital: results show strong support for this argument. The coefficient for category spanning is negative and highly significant across most models, providing support for the categorical imperative at a broad level of analysis. Hypothesis 2 suggested that this effect would be magnified for firms that spanned between categories associated with different types of actors; in my case, star scientists and large corporations. However, Table 3-2 – models 4 and 6 – show that there is no support for this hypothesis. Affiliation with both star scientist and large corporation categories has no effect on venture capital investment, regardless of the extent of this spanning. Table 3-2, models 3 and 5, also show that affiliation with star scientist *or* large corporation categories does not moderate the effect of category spanning on venture capital investment as suggested in hypotheses 3. Firms affiliated with large corporation categories were more likely to secure investment, but this dissipated when they spanned multiple categories. Note, however, that while I fail to support for the influence of categories associated with star scientists and large corporations when considered alone, I delved further into this relationship in additional models and found they are actually quite important for understanding venture capital when considered in tandem with category knowledge similarity.

Hypothesis 4 argued that venture capitalists would perceive coherent identities for firms that bridged categories where similar knowledge was relevant, making investment in these firms more likely. I find considerable support for this hypothesis. Table 3-2 – models 7 and 8 – show that firms with intellectual property portfolios comprised of similar categories were much more likely to receive venture capital, regardless of the number of categories that they spanned. As such, the emergence of thick, patterned, knowledge links among categories appears to eviscerate the negative outcomes associated with category spanning and thus has considerable implications for the ability of nascent nanotube firms to attract venture capital.

Supplementary Analysis: Category Configurations and Deal Sizes

Given that firms which spanned between related categories were the most likely to receive venture capital, I decided to look more deeply to see if certain combinations of these categories were seen as more valuable, resulting in larger investments. Also, I was struck by the moderately high correlation between affiliations with star scientist and large corporation categories among funded firms (.341) – something that is counterintuitive to the logic of hypotheses 2 and 3. As such, I deepened my investigation, examining in more detail the role played by category similarity, as well as by star scientist and large corporation categories.

As a starting point, I created maps detailing the category affiliations for each firm, noting deal sizes as well as affiliations with classes where stars and corporations were most active. Given the generally low activity of nanotube firms leading up to the millennium, Figures 3-2 and 3-3 show the category affiliation maps for 2002 and 2005. For illustrative purposes, the figures distinguish between the top 10 classes where stars were active and the top 10 where large corporations were active. Collectively, these categories capture a large majority of star scientist (2001=.746, 2005=.720) and large corporation (2001=.698, 2005=.715) patents.

-------Figures 3-2 and 3-3 about here-------

To map the evolving knowledge similarities among patent categories, I created non-metric multi-dimensional scaling (MDS) plots for the entire nanotube category system in five well-spaced panels: Figure 3-4. MDS plots provide a visual representation of category similarity based on Euclidean distances in 2-dimensions (Kruskal & Wish, 1978). When categories are close together they are relationally similar, otherwise they are far apart. I marked the top ten star scientist and large corporation categories on these plots, (eight on the 1996 plot because of the smaller number of categories with nanotube patents at that time).

-------Figure 3-4 about here-------

Taken together, Figures 3-2 and 3-4 provide an illuminating picture of category spanning as it relates to star scientist and large corporation categories and to deal sizes. As Figures 3-2 and 3-3 indicate, star scientists and large corporations focused on developing different types of nanotube applications. The former were most active in classes related to synthesis and basic materials applications (e.g., class #204: wave energy chemistry, #423: inorganic chemistry; #252: compositions). The latter tended to concentrate in areas of commercial application: initially, developing novel conductive structures and basic imaging applications (e.g., classes #257, #430) and moving toward flat panel displays (e.g., classes #313, #315), computers (e.g., classes #257, #438) and energy transmission (e.g., class #250) in the post millennium years. While the types of applications pursued by star scientists and large corporations were distinct throughout my analysis, their underlying knowledge similarities changed dramatically. Figure 3-4 shows that, through 2002, large corporations and star scientists utilized very different types of knowledge in their patenting. By 2005, however, this schism had largely disappeared. While a full account of the reasons for this convergence are beyond the scope of this paper, it is clear that the expertise relevant to star scientist and large corporation dominated categories had become much more similar. Specifically, post 2002, firms began to draw much more heavily on expertise related to synthesizing nanotubes and related materials as they worked to integrate these into consumer product platforms. As Figure 3-4 shows, by 2005, the knowledge profiles of many large corporation dominated categories had converged on those where star scientists were most active.

The evolving knowledge dynamics among star scientist and large corporation categories appears to have played an important role in both category spanning amongst nascent firms and in the level of investment that they attracted. Looking at Figure 3-2, it is striking that up to 2002 only two of 21 firms spanned between star scientist and large corporation categories and neither attracted venture capital. As such, it appears that the knowledge differences between star scientist and large corporation categories in this period may actually have presented a strong barrier to both spanning and venture capital investment; a finding that lends a degree of support to hypothesis 2. By 2005, however, very different dynamics are apparent. Concurrent with the convergence in knowledge among star scientist and large corporation categories, nascent firms began to span between them at a much higher rate. Moreover, as Figure 3-3 shows – while some firms that affiliated with star scientist *or* large corporation categories attracted funding – many large deals were for firms that straddled these areas.

To analyze this empirically, I constructed a series of periodized tobit regression models with 'deal size' as the dependent variable: Table 3-3. I used 2002 as a temporal divider because it is apparent that the dynamics of category spanning and venture capital investment began to change around this time[11]. Table 3-3 shows that, other than category similarity which has a positive influence across all models, there were a number of differences among the factors predicting deal sizes in the early and late periods. Most notably, models 3 and 4 show that the effect of spanning between star scientist and large corporation categories was opposite. Before 2002 – when star and large corporation categories drew on different expertise – firms that spanned between them were viewed less favorably by venture capitalists as evidenced by significantly smaller deal sizes. However, as the underlying knowledge among these categories converged in the later period, nascent firms that affiliated with both were significantly more likely to attract large investments – especially when they spanned between the most similar of them.

-------Table 3-3 about here-------

Overall, my supplementary analysis suggests that the evolving relationships among star scientist and large corporation categories enabled firms to bridge between them successfully. As such, a group of firms created a unique space between the field's most prominent players. As per arguments that firms are most attractive to investors when their identities resemble – but are distinct from – a field's existing players, my results suggest that this type of identity

[11] I also ran models shifting the period effect by one year in either direction; results were similar to those reported

position was quite lucrative (Lounsbury & Glynn, 2001; Navis & Glynn, 2011)[12], but only when star scientist and large corporation categories were similar. Mirroring this, the deal rationale provided by venture capitalists suggests that they perceived coherent identities for firms that spanned between such categories. For example:

> *"As (corporate) customers continue to aggressively shrink geometries and adopt new materials and novel device structures, we believe Epion's unique (CNT) technology will find its way into several high volume production applications,"* (Zephyr, 2010)
>
> *"The application of NanoGram's nano materials solution to the solar sector opens up an extremely exciting frontier in the development of cost-effective solar technology... Given the enormous promise of their technology, we are more than pleased to have a technology leader such as NanoGram in our portfolio."* (Zephyr, 2010)
>
> *"Nantero has developed a process for creating (CNT) junctions that is compatible with existing silicon fabrication. Its nanotube junctions can store a bit of information (and)… the company could find its NRAM (memory chips) in a leading position, achieving revenues of double-digit millions"* (Lux Research, 2006)

Thus, while the knowledge distance between star scientist and large corporation categories made them a bridge too before 2002, their evolving similarities appear to have facilitated perceptions that spanning between them was a coherent and highly valued identity position in the post-millennium years.

DISCUSSION AND CONCLUSION

In this paper I investigated how the category affiliation(s) of nascent firms affected their likelihood of attracting venture capital. Pace existing arguments about the categorical imperative, I suggested that firms would be less attractive to

[12] I also investigated the influence of a firm's position vis-à-vis other firms. Results were not significant: a finding that is not terribly surprising considering that firms with the biggest deals shared a similar orientation bridging between star and corporation categories.

venture capitalists when they were affiliated with multiple technology categories because this would lead to perceptions of unclear identities and unfocused expertise (Hsu, 2006; Hsu et al, 2009; Rao et al, 2003; Zuckerman, 1999; Zuckerman et al, 2003). While I found support for this, overall, my analysis suggests that such broad analysis misses important nuance in the relationship between category spanning and venture capital in the nanotube field. Some nascent firms which spanned multiple categories were less likely to attract investment, but this hazard was blunted amongst firms that bridged similar categories. Moreover, I showed that as the expertise being utilized for basic science advances and corporate development began to converge, firms that spanned between these categories were the most likely to attract large investments. Thus, category spanning was both rewarded and punished, depending on which categories were being spanned and when. As such, I identify a significant scope condition for the categorical imperative and show the importance of considering inter-category relationships. If my analysis had stopped at the same point as most extant studies, I would have missed key pieces of the relationship between category spanning and entrepreneurial resource acquisition.

My findings contribute to the literatures on entrepreneurship and on categories. In particular, while existing studies of resource acquisition have focused primarily on the implications of entrepreneurial actions and enabling conditions (e.g., Delmer & Shane, 2003; Eisenhardt & Schoonhoven, 2001; Zott & Huy, 2007), I show that cultural factors are also important. By situating a firm within its field and conveying its identity and expertise, category affiliations affect which firms are most likely to receive venture capital and in what amounts. As such, I contribute to research at the intersection of culture and entrepreneurship. Moreover, while most studies in this milieu have focused on the influence of culture in predicting the types of firms that are founded – especially within specific communities and regions (e.g., Lounsbury, 2007; Marquis et al, 2007; Weber et al, 2008) – my approach links culture to an important entrepreneurial outcome. Thus, I provide further evidence of the cultural embeddedness of entrepreneurship as it applies to individual firms (Lounsbury & Glynn, 2001; Martens et al, 2007; Navis & Glynn, 2011).

My findings also have implications for the organizational literature on categories. Building on work that highlights the evolving nature of categories and category systems (Fleischer, 2009; Kennedy, 2008; Khaire & Wadhwani, 2010; Lounsbury & Rao, 2004; Ruef & Patterson, 2009), I advocated for a relational approach to category spanning. In particular, I showed that technology categories in the nanotube field were embedded in a structure of shifting relationships and that this was associated with specific patterns of spanning and specific outcomes for category spanners. For example, key areas of development such as nanotube synthesis (category #423: inorganic chemistry) and flat panel displays (#313: electric lamp discharge devices) are associated with very different outputs; yet, as they began to share elements of underlying expertise, nascent firms were able to span between them without conveying unfocused identities. As such, my findings offer further evidence that category systems evolve over time (Fleischer, 2009;

Ruef & Patterson, 2009). Moreover, I show that the relationship between category spanning and organizational outcomes is contextualized within specific fields: the categorical imperative should not be assumed and requires empirical investigation on a case-by-case basis.

I also show that evolving relationships among categories can facilitate the emergence of highly valued combinations. This is a novel finding in the organizational literature on categories. However, scholars in other traditions have long recognized the hierarchical nature of categories and the potential for organizational identities to be comprised of lower-level categories (Glynn, 2008; Porac & Thomas, 1990; Rosch & Lloyd, 1978; Whetten, 2006). Further, firms that make credible claims to comprehensible yet distinct identities are generally thought to be the most attractive to resource providers (Lounsbury & Glynn, 2001; Navis & Glynn, 2011; Martens et al, 2007). While this research has yet to intersect the literature on category spanning, my results suggest a bridge between them. Specifically, it appears that evolving category relationships may enable actors to assemble configurations that are recognized by external audiences as coherent identities. When these identities combine categories associated with prominent field members with novel—but similar—categories, firms may be able to cultivate identities that are distinctive yet comprehensible and highly valued. This stands in contrast to the traditional argument in organizational ecology which suggests that category spanning is best suited to tumultuous and uncertain environments (Hannan & Freeman, 1989). Indeed, unlike category systems where the distinctiveness of individual categories is institutionalized over time (e.g., Ruef & Patterson, 2009), the nanotube field saw progressively deepening inter-category relationships which appear to have enabled perceptions that certain combinations fit together. While it is speculative at this point, such dynamics may play a role in the emergence of higher order categories such as new organizational forms if combinations are repeated and become institutionalized among important audiences (Berger & Luckman, 1966; Ruef, 2000).

I envision a number of intriguing directions for further research. One of the most obvious is to explore my findings in different contexts. The nanotube field exhibits a high degree of complexity (Greenwood et al, 2011) and USPTO categories comprise a specific category system. It would be useful to investigate if category similarity affects the categorical imperative in fields with different levels of complexity and different category systems. Such investigation may also help to illuminate factors that lead some category systems to trend toward similarity and integration, while others become more rigidly segregated over time (Ruef & Patterson, 2009). Further, venture capitalists are only one audience and others may perceive category spanning firms differently. Examining the perceptions of different audiences may help to provide a more robust understanding of the relationship between category spanning and resource acquisition.

I also foresee possibilities to build on my findings through qualitative research. While a quantitative approach is typical of category studies (e.g., Hsu, 2006; Zuckerman, 1999), it required that I infer the perceptions of venture capitalists from their investments. Future research should examine these perceptions directly. In addition to providing nuance and depth, this might help to tease out the influence of expertise versus identity-based explanations for the categorical imperative; something extant studies have had difficulty doing (see Hsu et al, 2009).

Along these lines, it would also be useful to investigate how audience perceptions are affected by the narratives that firms use to describe their category affiliations. While it is generally assumed that audiences react to category spanning in a relatively unmediated way, such judgments are unlikely to take place in a vacuum (Wry et al, 2011). Category spanners can advocate for the appropriateness of their position and this may affect how they are perceived (Rao et al, 2005). As such, the categorical imperative may be attenuated based not only on the categories being spanned, but also by the social skill of the actor doing the spanning (Fligstein, 1997). Entrepreneurial ventures are a germane context for such investigation because these firms dedicate considerable energy to crafting narratives about their identity and expertise (e.g., Martens et al, 2007; Navis & Glynn, 2011; Zott & Huy, 2007).

In sum, I find that category affiliations have a significant effect on entrepreneurial resource acquisition. However, my results suggest that there is folly in assuming that all types of categories and category systems are alike. While I find support for the categorical imperative at a broad level of analysis, it masks important nuances that only become apparent when considering the relationships that develop between categories. Thus, while some nascent firms are punished when they affiliate with multiple categories, those which bridge similar categories fare much better. Moreover, when a field is characterized by evolving relationships that bring constellations of categories together, it appears to lay the groundwork for highly valued combinations to emerge. In such cases, affiliation with a single category may be an impairment, not an imperative.

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TABLES AND FIGURES

TABLE 3-1.
Means, Standard Deviations, and Correlations of Variables

	Variables	Mean	St. Dev	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1.	NNI	.670	.471	.120	.068	.094	.092	.073	-.062	.257	.383	.237	.222
2.	Nano Region	.400	.491	---	-.01	.123	-.020	.136	.408	.056	.225	.217	.334
3.	Previous Investment	.672	.356		---	.060	.239	.153	.024	.153	.154	.020	.046
4.	IP (patents)	5.076	2.312			---	-.007	-.006	-.081	.315	.186	.012	.070
5.	IP Value	.734	2.025				---	.075	.154	.103	.182	.079	.113
6.	Spinout	.052	.221					---	-.133	-.068	.147	-.110	-.112
7.	Star Founder	.121	.327						---	-.188	.224	.532	.379
8.	Spanning	.386	.277							---	.188	.080	-.052
9.	Corp. Categories	.154	.141								---	.182	.271
10.	Star Categories	.193	.260									---	.288
11.	Similarity	1.409	1.267										---

TABLE 3-2.
Cox Hazard Rate Models of Venture Capital Investment: 1994-2005

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NNI	-.345 (.263)	-.242 (.264)	-.365 (.285)	-.354 (.287)	-.326 (.283)	-.426 (.290)	-.342 (.326)	-.334 (.324)
Nano Region	.997*** (.278)	.902*** (.279)	.958*** (.285)	.961*** (.286)	.960*** (.280)	.969*** (.283)	.455 (.325)	.526* (.311)
Previous Investment	1.677*** (.233)	1.889*** (.240)	1.805*** (.244)	1.796*** (.246)	1.798*** (.243)	1.797*** (.248)	1.465*** (.281)	1.421*** (.282)
IP (patents)	.002 (.082)	.167* (.093)	.169* (.094)	.171* (.094)	.172* (.093)	.166* (.093)	.199** (.097)	.236** (.100)
IP Value	.056 (.095)	.119 (.098)	.107 (.103)	.105 (.104)	.098 (.105)	.069 (.109)	.096 (.102)	.108 (.105)
Spinout	.488*** (.136)	.287** (.140)	.329** (.164)	237** (.122)	.205** (.141)	.292*** (.145)	.561*** (.211)	.616*** (.239)
Star Founder	.271 (.324)	.070 (.341)	.129 (.440)	.068 (.491)	.077 (.465)	.225 (.542)	.072 (.396)	.048 (.404)
Spanning		-.252*** (.073)	-.281*** (.077)	-.244*** (.077)	-.108 (.112)	-.153 (.140)	-.141** (.081)	-.256** (.112)
Star Category Affiliation			.001 (.013)	-.012 (.047)	-.018 (.036)	-.126 (.099)		
Large Corp. Category Affil.			.068*** (.029)	.065** (.031)	.170*** (.062)	.146** (.067)		
Similarity							.327*** (.124)	.684*** (.260)
Star x Corp Affiliation				.001 (.004)		.012 (.011)		
Star Affiliation x Spanning					.006 (.008)	.022 (.022)		
Corp Affiliation x Spanning					-.052** (.027)	-.026* (.020)		
Stars x Corp. x Spanning						-.002 (.003)		
Similarity x Spanning								.177*** (.062)
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Log-likelihood LR X^2	-374.02 94.21	-369.31 94.21	-366.42 109.42	-366.38 109.50	364.72 112.81	-363.96 114.36	-264.60 78.02	-263.70 79.83

Standard errors in parentheses, one-tailed tests for hypothesized variables
*p<.10; **p<.05, ***p<.01

TABLE 3-3.
Tobit Regression Models of Venture Capital Investment Size (millions): 1994-2001 (A), 2002-2005 (B)

Variables	(1) A	(1) B	(2) A	(2) B	(3) A	(3) B	(4) A	(4) B
Constant	-10.479*** (3.402)	-18.316** (8.626)	-2.307 (4.111)	-11.260* (7.935)	-4.284 (3.701)	-7.342* (6.476)	-4.425 (3.760)	-5.656* (5.708)
Firm age	.261 (.486)	.656 (.872)	.217 (.634)	.463 (.977)	.113 (.551)	.354 (.910)	.089 (.616)	.169 (.921)
Nano Region	1.966 (2.357)	.608 (1.911)	3.004 (2.931)	-.778 (2.029)	2.210 (2.185)	-1.580 (1.959)	3.719 (2.452)	-.833 (1.936)
Previous Investment	7.196*** (2.673)	3.526* (2.090)	11.721*** (4.175)	-.190 (2.156)	8.293*** (2.948)	-.851 (2.033)	6.476** (2.984)	-1.135 (2.057)
IP (patents)	-.027 (.911)	.697*** (.245)	-.540 (1.072)	.296 (.234)	-.377 (.996)	.278 (.219)	-.674 (1.048)	.110 (.229)
IP Value	-.678 (1.612)	.065 (.332)	1.734 (1.976)	-.121 (.345)	.218 (1.627)	.120 (.343)	.786 (2.129)	.255 (.337)
Spinout	2.251 (4.076)	1.224 (3.549)	.175 (4.403)	2.118 (3.877)	-.569 (4.078)	2.104 (3.662)	-.487 (4.362)	1.386 (3.828)
Star Founder	1.105 (3.089)	7.701*** (2.521)	5.274 (4.827)	7.950*** (2.923)	7.874 (5.035)	9.415*** (2.978)	10.944** (5.397)	9.282*** (2.938)
Spanning			-.979 (1.053)	.807* (.550)	-.918 (.890)	.811* (.518)	-.912 (1.339)	.462 (.553)
Star Category Affiliation			-.747** (.437)	-.250*** (.095)	-1.620** (.802)	-.925*** (.304)	-1.540* (1.032)	1.485*** (.472)
Large Corp. Category Affil.			1.078* (.682)	.558** (.310)	.242 (.539)	.377* (.290)	.123 (.674)	1.092** (.531)
Similarity			2.586** (1.465)	4.620*** (1.492)	2.036** (.938)	4.655*** (1.383)	2.242** (1.032)	5.016*** (2.748)
Star x Corp Affil.					-.154* (.108)	.063*** (.026)	-.188 (.200)	.106** (.050)
Star x Corp x Similarity°							.089 (.173)	.072* (.052)
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Log-likelihood	-160.21	-179.06	-156.77	-140.89	-155.17	-137.87	-151.50	-135.32
LR X^2	13.62	27.05	20.81	39.92	24.02	45.97	31.34	51.06

Standard errors in parentheses, one-tailed tests for hypothesized variables
*p<.10; **p<.05, ***p<.01
°composite 2-way interactions included in estimation, but excluded for parsimonious presentation

FIGURE 3-1.
Active Nanotube Firms and Venture Capital Deals per Year: 1994-2005

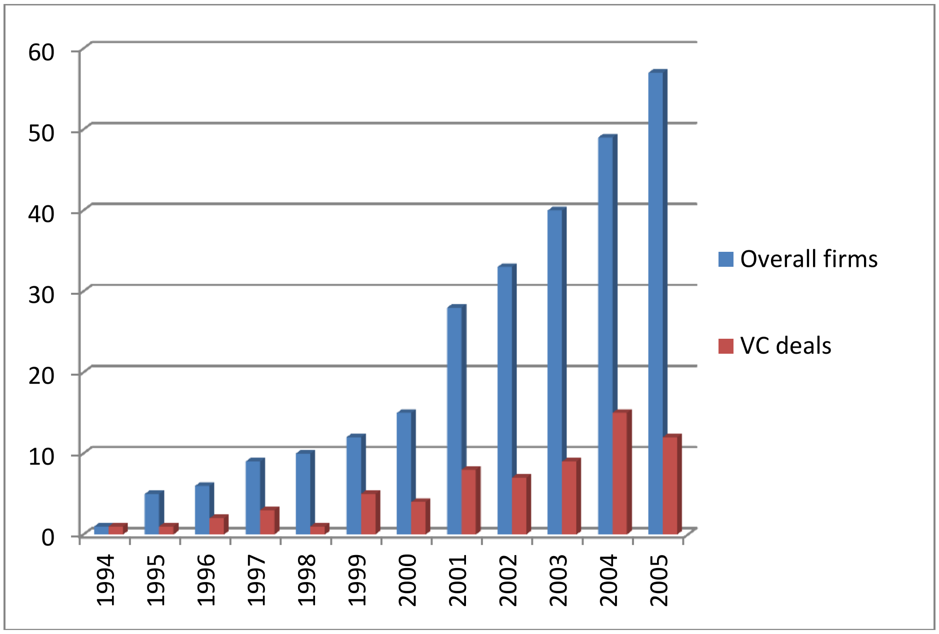

FIGURE 3-2.
Category Affiliations and Venture Capital Investments: 1994-2001

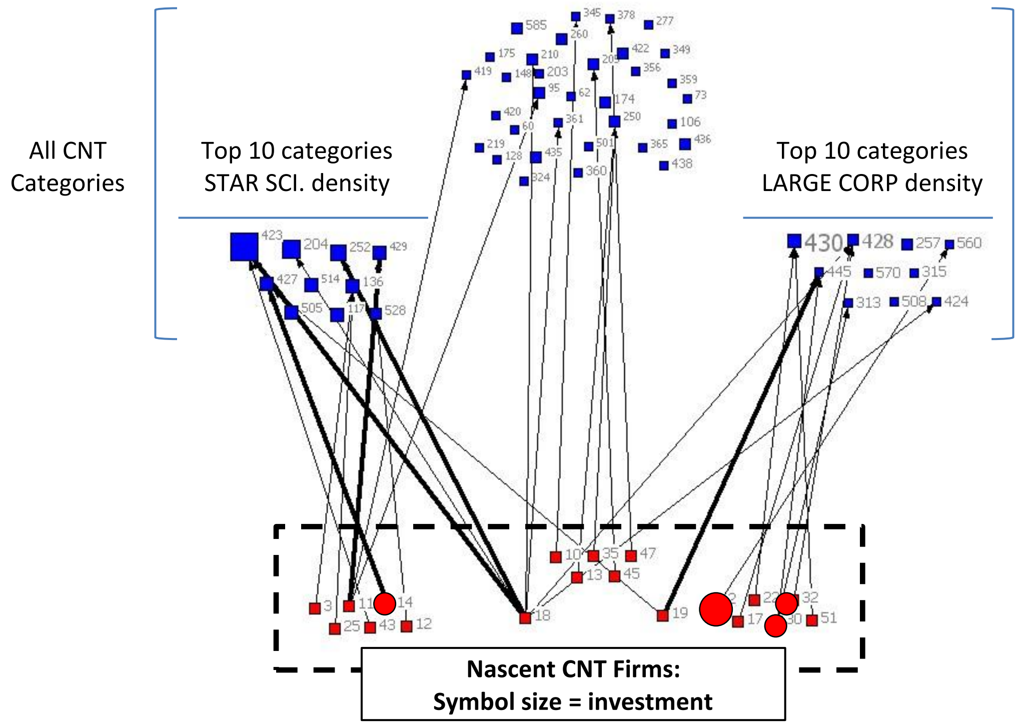

FIGURE 3-3.
Category Affiliations and Venture Capital Investments: 2002-2005

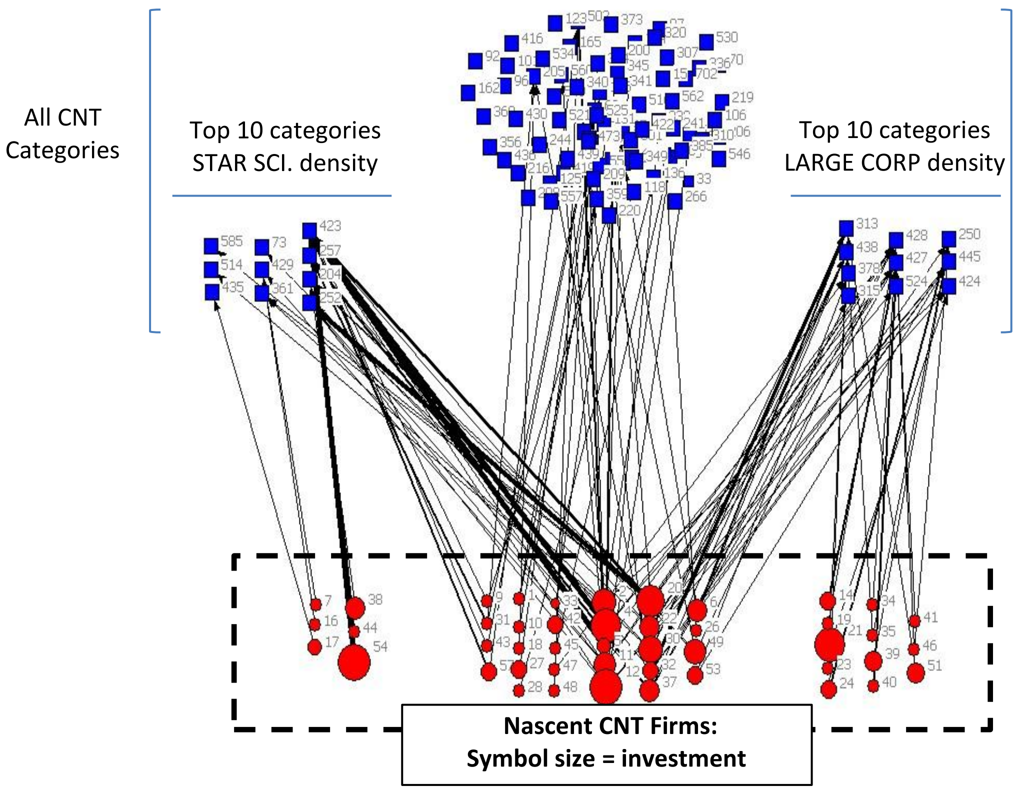

FIGURE 3-4.
Multidimensional Scaling Plots of Nanotube Category Similarities

GENERAL DISCUSSION AND CONCLUSIONS

Over the past decade, organizational theorists have become increasingly interested in the study of categories. This work germinated with efforts showing that categories stabilize markets because they reflect shared understandings about which products or firms go together, and which do not (Polos, Hannan, & Carroll, 2002; Zuckerman, 1999). Through this act of grouping, studies have shown that categories provide the cultural apparatus for understanding the identities of firms and products (Carroll & Swaminathan, 2000; Hsu & Hannan, 2005; Zuckerman et al, 2003) and also carry behavioral expectations which actors are sanctioned for violating (Hsu, 2006; Hsu et al, 2009; Rao, Monin, & Durand, 2003; and see Hannan, 2010 for a review). These effects have been shown with a wide variety of categories, ranging from movie genres (Hsu, 2006; Zuckerman et al, 2003) and eBay categories (Hsu et al, 2009), to industries (Zuckerman, 1999) and market segments (Carroll & Swaminathan, 2000).

Based on their utility for understanding the dynamics of fields and markets, numerous scholars have pointed to category studies as a promising research direction for organizational sociology (see Greenwood et al, 2008; Hannan, 2010; Lounsbury & Rao, 2004; Negro, Kocak, & Hsu, 2010; Rao et al, 2003). Although I agree with this sentiment, my dissertation follows the assertion that a more robust account of category effects requires a shift away from studying individual categories and toward a deeper appreciation of category systems. Indeed, while extant studies have generated a number of important insights, there is an implicit assumption that a category's meanings are primarily related to its internal properties. While this is undoubtedly true to a certain extent, it neglects research that shows categories cannot be meaningfully understood in isolation; for example, the category ‘woman’ doesn’t mean very much without the category ‘man’ as a point of comparison (see Bowker & Star, 1999; Douglas, 1986; Zerubavel, 1997). In this context, categories may be orthogonally related (as is typically assumed in extant studies) but audiences may also view categories as being related in different ways and quantities. As such, actors may locate meaning in individual categories, but also have broader perceptions about the overall topography of relations among the categories in a classification system: this may have a number of implications. Evidence suggests that inter-category relationships may affect the potency of category boundaries, thus shaping the types of identities that field members claim, the lines of innovation that they pursue, and how these are evaluated by relevant audiences (Kovacs & Hannan, 2010; Rao et al, 2005; Ruef & Patterson, 2009). Categories may also become linked together at higher levels of analysis and convey meaning precisely because of these linkages (Bingham & Kahl, 2011; Kennedy, 2008; Kennedy, Lo, & Lounsbury, 2010).

Building on these insights, my dissertation argues that studying the evolution of inter-category relationships has the potential to cultivate insight into the role of categories in shaping cognition and action beyond just providing rigid lines of distinction. In this way, my effort is part of a move general move among organizational scholars to analyze the dynamics of category systems. To date, however, studies in this milieu have tended to follow the zeitgeist of extant categories research, focusing on the creation of completely new categories (Khaire & Wadhwani, 2010; Lounsbury & Rao, 2004; Rao et al, 2003) or the sharpening of distinctions among existing ones (Ruef & Pattison, 2009). A handful of other studies have focused on the emergence of inter-category relationships, but have concentrated on only a few categories rather than the broader topography of a full category system (see Kennedy, 2008; Kennedy et al, 2011; Rao et al, 2005). Further, many fields are comprised of actors with varied interests and identities (Glynn, Barr, & Dacin, 2000) and this is particularly evident in dynamic contexts, such as nascent fields (Fligstein, 1997, 2001; Rao, 1994), high technology industries (Powell et al, 2011), and large-scale collaborative projects (Bartel & Garud, 2009). Despite the practical and theoretical importance of understanding how meaningful patterns of inter-category relationships emerge and help to stabilize action in such contexts, we have little insight into how this occurs.

To help address this, I empirically investigated the relational structure of technology categories in the emerging field for nanotube technology. Adapting insights from complexity theory, my first paper shows how meaningful patterns of inter-category linkage can emerge from the distributed actions of diverse actors. Results suggest that the overall structure of relationships significantly affected patterns of action at the field-level – fluidly directing attention and action in particular areas – even as the structure shifted on an ongoing basis. Further exploring the implications that this had, my second paper examines how inter-category relationships affect the types of innovations pursued by individual actors. Whereas extant studies imply that actors will be dissuaded from category spanning because they are punished for doing so (Hsu, 2006; Hsu et al, 2009; Zuckerman 1999; Zuckerman et al, 2003) or that they repeatedly mix specific combinations to create a new hybrid category (Kennedy, 2008; Kennedy et al, 2010), I show that the relationships between an inventor's home category and others in the system are an important predictor of when spanning will happen and which categories will be bridged. My last study shows that a firm's position across categories can provoke very different reactions based on which categories are spanned and when. Moreover, I highlight multiple ways in which categories can be related and show how the potential interplay between them can shape important organizational outcomes.

In each paper, I discuss the implications that my findings have for future research in specific domains such as institutional emergence and change (paper 1), innovation (paper 2), and entrepreneurship (paper 3). Rather than reiterate these here, the remainder of my discussion focuses on three very broad research directions that my dissertation signals: The study of inter-category linkages; the distinction between categories in use and categories as exogenous; and empirical strategies for studying categories and category systems.

Inter-category Linkages

Although most organizational studies focus on individual categories, scholars in cultural sociology (e.g. DiMaggio, 1987; Lamont & Molnar, 2000; Mohr, 1998; Zerubavel, 1997) and cognitive psychology (e.g., Mervis & Rosch, 1981; Rosch & Lloyd, 1978) have long recognized the importance of studying the ways that categories connect to each other. Examining this literature reveals two approaches; those related to 'horizontal' category linkages and those related to 'vertical' category linkages. Examining categories at a common (horizontal) level of analysis, studies have shown that boundaries can be variably clear or fuzzy, with the result that certain categories are perceived to be more or less similar to others (think of a color spectrum: red and orange are generally conceived of as distinct categories, but they have a fuzzy boundary and are more closely related to each other than 'red' is to 'black', for example); 2) Categories can also be linked vertically in a 'stem and branch' type hierarchy where higher level categories encompass a series of lower level ones (for example, anyone who has been to a car rental agency knows that there are a variety of sub-categories of 'cars'). This approach importantly notes that categories are variably useful for guiding cognition and action: high level classes may not provide meaningful enough distinctions, while low level ones may be too fine-grained to be practically useful. 'Basic' level categories sit somewhere between these solitudes and convey the types of distinctions that are relevant to the typical actor in a field (Rosch, 1978; and see also Porac & Thomas, 1990).

Reading the organizations literature against this framework, it is clear that the dominant approach has been to study (assumedly) 'basic' level categories, to the relative neglect of their vertical and horizontal linkages (e.g., Hsu, 2006; Hsu et al, 2009; Khaire & Wadhwani, 2010; Zuckerman, 1999; Zuckerman et al, 2003). This is perfectly acceptable as an analytic strategy if one assumes that category systems are static. Other studies have started to cast some doubt on this, however, noting that the horizontal linkages among classes can shift (Rao et al, 2005; Ruef & Patterson, 2009) and new vertical linkages can be made where lower level categories cohere as a distinctively new one (Kennedy, 2008; Kennedy et al, 2010; Mohr, 1998; Mohr & Duquenne, 1997). Figure 4-1 provides a visual illustration of the ways that categories can be related, showing where extant organizational studies fit in this context.

----------Figure 4-1 about here----------

My approach makes a number of contributions to the study of inter-category linkages – both for the organizations literature and for category studies, more generally – and points to a number of potentially fruitful research directions. With regards to horizontal relationships, I show how these can be dynamically shifting over time. While this possibility has been nominally recognized (Ruef & Patterson, 2009), I surface a series of mechanisms which animate these dynamics (paper 1). This has important implications for the study of 'relatedness', both as it applies to the categories literature, as well as to cognate areas such as strategic management and innovation where related versus unrelated diversification / innovation are prominent areas of study.

With regard to the latter, my approach shows that relatedness can be dynamic and temporally specific, whereas extant studies tend to treat it as a natural and static feature of two entities (e.g., Katila, 2002; March, 1991; Miller, 2006; Miller, Fern, & Cardinal, 2007; Robins & Wiersema, 1995). As such, I signal the utility of more fine-grained measures for research in this domain, with the attendant possibility of surfacing more nuanced insight into processes of interest. This may have implications for studying issues such as the relationship between industry evolution and innovation opportunities, the temporal effectiveness of diversification strategies, and the interplay between the breadth of a firm's knowledge and its ability to act ambidextrously (Raisch et al, 2009).

In addition, my dissertation points to the utility of considering the relationship between horizontal and vertical category linkages (paper 3). While studies have examined these independently (Figure 4-1), their intersection is rarely considered – even in the broader cognitive sociology and social psychology literatures. I provide some initial evidence that this may have important research implications, and envision a broader program of research that investigates this more systematically. For example, although studies have shown that multiple categories can be combined to form new ones – either at a higher level in a category hierarchy (Mohr & Duquenne, 1997) or as a hybrid at the same level as the input categories (Kennedy, 2008; Kennedy et al, 2010) – questions remain about how and why certain categories come together in this way. My results suggest that groupings may be more likely among similar categories, but empirical investigation is required to understand what triggers this process as well as the types of reactions that different combinations elicit.

Further, questions remain as to why some groups of categories congeal as new constructs, whereas others persist in various forms of relatedness but remain distinct. Following from this, there are a number of questions related to when horizontal category relationships will spur the recalibration of a category system (Rosa et al, 1999), undermine distinctions among basic level categories (Rao et al, 2005), or give rise to new classes (Kennedy, 2008). Each of these has different implications for how categories shape cognition and action, making this an important research question.

In addition, it would be interesting to explore the potential for horizontal relationships to affect where the 'basic' level of distinction sits in a given classification system. While I suggest that determining the basic-ness of a category should be a matter of empirical investigation (paper 3), the potential for this to shift with the dynamics of a category system is an intriguing and heretofore unaddressed possibility. Finally, a more radical interpretation of my findings is that some category systems may operate without a basic level. Rather, meaning may emerge among groups of overlapping categories that cannot be cleanly reduced to a higher order aggregate. To the extent that further studies return similar findings, this would be a novel and significant contribution to our understand categories and category effects.

Categories in use versus Categories as Exogenous

Another implication of my approach is that it focuses on the ways that categories are used by actors – and the implications that this has – rather than assuming that categories are exogenous and reflect collectively shared understandings. Indeed, the category effects which I observed were fundamentally shaped through the activities of actors who linked classes together and pursued various category configurations in their patenting. And, while my data can't speak to the level of individual cognition, it appears that the patterns which arose through the 'categories in use' were much more influential than the official USPTO categories (papers 1, 2, and 3). As such, my approach suggests that it may be productive to make an ontological shift toward a 'tool-kit' approach in categories research and treat categories as cultural elements that are subject to creative and agentic uses (Sewell, 1992; Swidler, 1986). While the agentic use of categories is likely to be most evident in dynamic and emergent fields, the fact that category spanning is observed in so many studies suggests that category meanings are not shared as uniformly as most studies seem to imply (see especially Hsu & Hannan, 2005), even in settled contexts. While some studies hint at this more directly than others (e.g. Kennedy et al, 2010; Khaire & Wadhwani, 2010; Lounsbury & Rao, 2004; Rao et al, 2005), focusing on it discretely evokes a number of potentially interesting research questions.

Indeed, studies in psychology have demonstrated that understandings about categories and their relationships are intertwined with an actor's expertise (Johnson & Mervis, 1997). So, for example, it would not be surprising for individuals and firms who are deeply embedded as category users to have systematically different, and more nuanced, understandings about how categories are related vis-à-vis the audiences who use these categories to evaluate them. This is an interesting postulate for a few reasons. At the very least, it points to the importance of studying the interplay between the active use of categories and official evaluation schemes. Beyond this, though, it reverses the imagery of embedded agency (Greenwood et al, 2008) and suggests that the most deeply embedded actors may also have the types of nuanced knowledge that enable creative action. Further, to the extent that this is true, studying categories in use may offer insight into the evolution of a category system. Indeed, Zuckerman's (1999: 1410) canonical study hinted at the importance of this question, noting that "the very issue of whether a new era or 'paradigm' has been reached is a perennial issue [for analysts who assess firms that straddle industry boundaries]".

Empirical Strategies for Studying Categories

In many ways, the preceding discussion reflects the distinction that Jepperson and Swidler (1994) make between 'collective' versus 'shared' levels of analysis in cultural studies. In this context, the former refers to "dominant public culture or collective rules", while the latter "reflects culture in a more individual or aggregate sense" (1994: 365); this points to an important measurement issue for category studies. Most studies in the organizations literature focus on 'collective' categories, and take genres, industry categories, and product classes as given (but see Porac & Thomas, 1990 for an exception). Although these categories can tell us interesting things about the official meanings associated with a class, these may or may not align with 'shared' understandings about a category system. Building on insights from studies in cultural sociology (Mohr, 1998; Mohr & Duquenne, 1997; White, 1965), my approach of modeling the aggregate linkages that actors make between categories is one potentially useful strategy that may help future studies access these shared understandings more directly. Still, there is much work to be done bringing these levels of analysis together and exploring the implications associated with different levels of concordance between them. Further research is also required to help illuminate the conditions under which collective and shared understandings are more or less likely to align. Given the groundswell of interest in understanding audience perceptions of categories (see Negro, Kocak, & Hsu, 2010), such studies would be a natural and potentially valuable extension. Going beyond this, future research might also investigate the understandings that actors have as they engage with a category system. While I hint at this (papers 1 and 2), a deeper appreciation of this more micro level of analysis has the potential significantly enrich our understanding of the mechanisms which shape individual action in ways that animate the dynamics of category systems across levels of analysis.

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TABLES AND FIGURES

FIGURE 4-1.
Visual Overview of Category Linkages with Illustrative Studies