CONSTRUCTING NANOBUSINESS: THE ROLE OF TECHNOLOGY FRAMING IN THE EMERGENCE OF A COMMERCIAL DOMAIN

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Entrepreneurs seeking to commercialize science-based technologies face considerable challenges including uncertain environments, policy makers and investors' ignorance, and public opposition and ethical concerns. Most research exploring the emergence of technologies assumes the existence of accepted uses or products, despite the fact that efforts to commercialize science-based technologies often begin before specific applications exist. We have little empirical evidence of how individuals and organizations influence the earliest development of technologies. To address this gap, I conduct a real-time, seven-year, qualitative study of the nanotechnology venture investing community. The study draws on extensive archival data, participant observation of a complete series of annual nanotechnology investing conferences, and case studies of the three venture capital (VC) firms specializing in nanotechnology through the period of the study. The cases are based on semi-structured and website archives.

I document the emergence of competing nanotechnology frames in the period prior to the identification of product applications. I identify three sequential activities of nanotechnology business proponents: constructing a socio-semiotic space, positioning as experts within the space, and translating scientific, opposition and futuristic discourse for a target audience. I introduce the concept of a socio-semiotic space and develop a model reflecting the three activities to explain the process through which technology proponents project a business frame to support the commercialization of science-based technologies.

This dissertation contributes to our knowledge of technology evolution by focusing on the understudied period of early emergence and the sociopolitical process of technology framing. I contribute to our knowledge of how science discoveries become the basis for fields of commercial activity. The findings of this dissertation provide knowledge that can assist business people and policy makers seeking to develop science-based technologies and the fields that emerge around them.

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CHAPTER I

INTRODUCTION

Scientist alone is true poet he gives us the moon/
He promises the stars he'll make us a new universe if it comes to that.
Allen Ginsberg (1961)

The means by which we live have outdistanced the ends for which we live.
Our scientific power has outrun our spiritual power. We have guided
missiles and misguided men.
Martin Luther King, Jr. (1963)

In the mid 1800s, in London, scientific experimenters claimed to have temporarily resurrected the dead, created life from inert matter and cured many seemingly incurable ailments, all with the wondrous powers of electricity (Morus, 1998). Reactions to these claims and the experimenters' demonstrations coincide with the contradictory views of science illustrated in the two opening quotations. To some, with the aid of electricity "man would …be able to resolve into their elements the most refractory compounds, to fuse the most intractable metals …almost to annihilate time and space" (William Robert Grove, 1842 in Morus, 1998: 3) To others, such efforts were "blasphemous meddlings with God's laws" (Morus, 1998: 140). Those seeking to develop and commercialize electricity had to overcome technical challenges, invent acceptable public roles for inventor-scientists, challenge social disdain of those seeking monetary gain from philosophy and assuage public fears regarding the application of the new knowledge (Morus, 1998).

The claims of proponents and detractors as well as the challenges faced by those seeking to profit from the new discoveries bear a striking resemblance to the discourse surrounding nanotechnology and to the challenges facing those seeking to commercialize it. Proponents claim nanotechnology will "improve on the gifts of nature…bones would become stronger…muscles…more powerful…[and] people should be able to regain most of their youthful health strength and beauty, and to enjoy an almost indefinite extension of life" (Freitas, 2000: 6). Conversely, opponents argue that nanotechnologies "can spawn whole new classes of accidents and abuses" and are "threatening to make humans an endangered species" Joy (2000). Nanotechnology and electricity are both technologies that promised to change life, challenge definitions and understanding, and breach boundaries. Today, as in the early 1800s, definitions and boundaries matter.

In the 1800s, in response to his colleague's claim to have created life from inert matter with electricity, a prominent inventor named Michael Faraday sought to define a socially acceptable role for electrical experiments in relationship to life. Faraday contrasted his experiments on the eel, which produced electricity by its own volition, with those of his colleague, arguing that his own were "upon the threshold of what we may, without presumption, believe man is permitted to know of the matter" (Faraday, 1838 in Morus, 1998: 143). In the nanotechnology domain, controversy raged around the feasibility and possible effects of self-replicating nano-scale machines. While some argued that this technology was feasible and would deliver on the most fantastic promises of nanotechnology (Drexler, 1992), others claimed the technology was not feasible (Lovy, 2004) or posed a serious threat to health and the environment (Feder, 2002).

Nanotechnology proponents recognized some positive effects of this public debate. In response to Michael Crichton's novel, *Prey* in which intelligent nanoparticles threaten to take over the earth, Mike Roco, the founding chair of the National Science and Technology Council's subcommittee on Nanoscale Science, Engineering and Technology (NSET), said, "The fact that the book speaks about nanotech, it brings in the attention of the general public to this field" (Small Times January/February, 2003). However, those seeking to commercialize nanotechnologies noted that if the science fiction implications of the technology were largely accepted as feasible, public fears might threaten regulation that could slow commercialization. "There will be a backlash against nanotechnology, largely in the media, spurred on by Crichton's new book and the movie to come. Expect to see ethical debates, like those on cloning, on what regulation should be put in place to limit the manipulation of molecules" (Josh Wolfe, 2003).

Following calls for such limits, business and government supporters formed a collation and debunked the depictions of nanotechnology supported by futurists and some scientists, which were associated with the grandest potential applications and threats. Berube (2006) quotes University of Tennessee law professor Glenn Reynolds' summary of the conflict:

> A sometimes bitter war has been waged within the nanotechnology community itself, between the scientists and visionaries on one hand and the business people on the other. The business community is afraid that advanced nanotechnology just seems too, well spooky--and worse, that discussion of potentially spooky implications will lead to public fears that might get into the way of bringing products to market.

A House version of a nanotechnology bill was revised to exclude a description of a feasibility study of molecular manufacturing and self replicating nanoscale machines, leading a trade journal reporter to argue that "by carefully selecting which theories are the ones the general public is supposed to believe, then marginalizing the rest…[business leaders are] redefining "real" nanotechnology to suit what is best for nano-business" (Lovy, 2004: 2). Eric Drexler blames former executive director of the NanoBuisniess Alliance, (NbA), Mark Modzelewki, for the exclusion of molecular manufacturing from the House bill.

As did the scientists-inventors of electricity, in addition to overcoming technical difficulties, those seeking to commercialize nanotechnology required the support and funding of government, corporations, and investors, who are influenced by media portrayals of nanotechnology and the perceptions of their constituents. As evidenced by barriers to the commercialization of nuclear power and genetically modified foods (see Jasper, 1992 and Krimsky, 1992), in democratic societies, public perception can influence economic success and failure. Importantly, public perception can affect the outcomes of technology commercialization regardless of the actual threats posed by the technology.

In the nanotechnology domain, technology proponents recognized this potential. Authors of a nanotechnology trade report argued, "NGO's with an axe to grind, journalists seeking the next big story, and consumers skeptical of what they perceive as corporations 'playing God' could set off a self-reinforcing groundswell that could make the use of nanoparticles verboten…even if no real risks were actually shown to exist"

(Nordan, 2005). Academic researchers drawing on technology management and institutional literatures validate these concerns, arguing that the successful emergence of a technology field necessitates the development of public trust (Aldrich and Fiol, 1994; Garud, Jain and Kuraswamy, 2002). However, while the economic importance of emerging science-based technologies is widely recognized and observation and theory indicate that perception can influence the success of such technologies, we know little of if and how entrepreneurs frame emerging technologies.

To address this gap, I undertake an interpretive, qualitative study set in the context of the developing nanotechnology domain. I explore how technology proponents project a technology frame into public discourse. I document the emergence in the general press of competing nanotechnology frames and develop a process model to explain how a small group of venture capitalists (VCs), attributed as builders of nanotechnology business by the nanotechnology investing community, projected a "nanobusiness" frame. I find that the VCs engaged in three sequential activities. They constructed a socio-semiotic space, positioned themselves as experts within the space, and translated scientific, opposition and futuristic discourse for their target audience, large business corporations and government. These activities generated resources and power that enabled this group to project their preferred frame into the public discourse. Greater understanding of technology framing processes contributes to our understanding of how new technologies emerge by focusing on the understudied period of technology pre-emergence. In particular, by explaining how technology proponents create the sociopolitical infrastructure necessary for emerging technologies to thrive, the findings of this study provide guidance to business people and policy makers seeking to develop and support such technologies and the domains that emerge around them.

CHAPTER II

LITERATURE REVIEW

The economic importance of emerging technologies and ventures founded to commercialize them is widely recognized (Drucker, 1985). It is therefore not surprising that how technologies emerge, evolve and are adopted has been a topic of interest to management and organization scholars for some time (e.g. Dosi, 1982; Tushman and Andersen, 1986; Utterback, 1994). After decades of research it remains of critical importance to both researchers and managers (Kaplan and Tripsas, 2008).

This dissertation is designed to explore the processes through which abstract scientific discoveries become the basis for domains of commercial activity. Despite calls for explorations of the emergence of commercial activity—in organizations, markets, industries and organizational fields—the phenomenon remains under-explored and difficult to approach (Meyer, Gaba and Colwell, 2005). Similarly, technology and innovation management research has largely neglected the question of how new technologies emerge (Munir and Philips, 2005; Kaplan and Tripsas, 2008). Most technology and innovation management research focuses, instead, on how technologies with known product applications displace existing products in an established market.

Many technologies, however, develop from scientific discoveries that occur long before the emergence of viable products. Consider, for example, the theoretical arguments that made computers possible or the scientific discoveries that formed the basis of the biotechnology industry. The understandings of proponents, opponents, users, scientists, and designers of technologies that influence the end design and the success or failure of commercialization attempts begin to form in this pre-emergent stage (Garud, 2001; Kaplan and Tripsas, 2008). Without explanations that consider the processes that shape the early emergence of technologies, our knowledge of the technology development cycle and the emergence of commercial activity based on technologies is incomplete.

The study of emergence in general and of basic-science technologies in particular poses some unique challenges. Despite frequent calls for explorations of emergence, we know little of how new industries, fields, markets, and organizations come into being (Chiles, Meyer, and Hench, 2004; Meyer, Gaba, Colwell, 2005). Early neoclassical economics depicts perfectly competitive markets in which innovative entrepreneurs act rationally to discover existing opportunities to supply unmet demands. From this perspective, commercial activity in markets is structured through the price mechanism and competition. This view is based on a conception of man as a rational optimizer, largely immune to the influence of social relations. Although this view facilitates empirical studies resulting in testable causal relationships, it has been criticized by sociologists, organization theorists and new institutional economists for failing to acknowledge the extent to which economic behavior is embedded in, and influenced by, social relations and institutions (Granovetter, 1985; Denzau and North, 1994; Fligstien, 2003). Researchers are increasingly recognizing the influence of social and political processes on technology, organizations and industries.

Because of the ambiguity and possible social implications of technologies that develop from scientific discovery, research seeking to explain how such technologies emerge and become commercial opportunities must be sensitive to social and political processes (Tushman and Rosenkopf, 1992). To successfully shepherd technologies through the transition from scientific discovery to commercial application, technology proponents require resources and support from potential stakeholders (Aldrich and Fiol, 1994). In the case of science-based technologies, proponents must ask constituents to support a vision of an often complex something, which does not, and may not for some time, exist. Furthermore, there may be no widely understood language through which to ascribe meaning to the activity (Aldrich and Fiol, 1994; Hill and Levenhagen, 1995; Fligstein, 1996, 2003). Gaining support requires collective sensmaking (Weick, 1995) and sensegiving (Gioia and Chittipeddi, 1991), involving cognitively bounded human agents, political conflict, and framing (Dowell, Swaminathan, and Wade, 2002; Hargadon and Douglas, 2001; Garud, Jain, and Kumaraswamy, 2002).

I adopt a sociopolitical perspective to explore the question: How do science discoveries become the basis for domains of commercial activity? Meyer, Gaba, and Colwell (2005) argue that researches studying fields in flux, such as an emerging technological field, should collect longitudinal data, engage in process theorizing, and adopt context sensitive designs. I conduct a longitudinal, embedded case study. I use a grounded theory analysis approach (Glaser and Strauss, 1967; Strauss and Corbin, 1990) such that my initial analyses guide additional data collection and conceptualization. Through this process, grounded in data, I move from my general research question, how do science-based technologies become the basis of commercial activity, to focus on the framing processes of entrepreneurs in emerging technology domains. Specifically, I explore the question: How do entrepreneurs project a technology frame into the general discourse?

This study contributes to our knowledge of how areas of commercial activity, such as industries, markets and organizational fields emerge by focusing on how scientific discoveries—which form the basis for many such entities—transition to business opportunities. Through this dissertation, I contribute to our knowledge of the technology life cycle by studying the heretofore largely neglected period of pre-emergence. Specifically, I explore the role of technology proponents in actively projecting a technology frame that supports the development of commercial activity.

In the remainder of this chapter, I review the literature that provides the foundation for this research. I begin by elaborating on the emergence of organizations and technologies. Next, I review work that identifies and explains the unique characteristics of science-based technologies and I discuss the implications of these characteristics for the management of technology. Then, I review sociopolitical approaches to the emergence of commercial activity—termed organizational or technology fields in this literature—and researchers' recent applications of the concept of institutional entrepreneurship to the study of emerging technologies. I focus on one social skill, framing, which is identified but not elaborated in the technology management literature. Finally, I draw on additional concepts from studies of the social construction of technology and science controversy and risk to develop and describe the conceptual framework that guides this dissertation.

The Emergence of Organizations and Technologies

The term "entrepreneurship" has a variety of meanings. It is used to mean economic risk taking, technological and organizational innovation to bring to market a new product or process, and finally, the creation of novel forms of organization and of the ideas to deploy and exploit new technologies (Constant II, 1987). However, most entrepreneurship literature has focused on the first or second definitions, exploring the attributes of individual entrepreneurs and their propensity to found new ventures (Schoonhoven and Romanelli, 2001). "This approach…does not adequately depict the creation of macrosystems and related grand entrepreneurship. Nor do these perspectives adequately capture the interaction between cultures of technology, organizational cultures, and society at large" (Constant II, 1987; 241). Schoonhoven and Romanelli (2001: 369) argue that although it is the market-creating activities of collectives of entrepreneurs that merit researcher attention, "…little attention has been paid to the question, "Where do new firms come from?" The authors illustrate their point by noting that of 130 papers on entrepreneurship in the 1999 Frontiers of Entrepreneurship Research only two papers explore the origins of new firms and conclude that as "Neither new organizations nor the new populations they spawn are the creation of single individuals…the Myth of the Lonely Only Entrepreneur can be and should be laid to rest" (Schoonhoven and Romanelli, 2001: 387).

The dominant model of technology evolution is based on a life cycle metaphor. A new technology is said to elicit competing designs that usher in an "era of ferment." The competition and uncertainty ends with convergence on a dominant design (Tushman and Anderson, 1986). This model has been tested and found robust in many industries (Kaplan and Tripsas, 2008). As with much entrepreneurship literature, underling the model is the assumption that a market exists. Research has focused on how new products influence the market. With few exceptions (e.g. Hargadon and Douglas, 2001; McGuire and Granovetter, 2003) the attention of management research has focused on product technologies for which for an application is already defined (e.g. Garud and Rappa, 1994; Tripsas, 1997; Munir and Philips, 2005). Similarly, popular attention and academic scholarship focus on standards wars and the era of ferment between technologies embedded in products with largely specific and known uses, such as the classic case of the war over formats for videorecording (Beta vs. VHS). As with studies of entrepreneurship, much less attention has been devoted to the phenomenon of emergence. We know little of the pre-emergent period, before a discontinuity occurs and products are developed.

This neglect perhaps results in part from the difficulty of studying emerging systems. Meyer, Gaba, and Colwell (2005) note that despite frequent calls for studies of organizational dynamics, researchers of management and organizations have generally avoided studying fields undergoing discontinuous change. The authors argue that the study of organizational fields in flux makes unique demands, requiring longitudinal data, process theorizing, and context-sensitive, multi-level research designs. Not surprisingly, given the demands of the phenomenon, the rare empirical examples of studies exploring emergent phenomena are generally qualitative and emphasize complex, social processes (e.g. Garud and Rappa, 1994; Hargodon and Douglas, 2001; McGuire, Phillips, and Hardy, 2001; Chiles, Meyer, and Hench, 2004; Munir and Philips, 2004).

An emerging technology is by its nature a system in flux. Furthermore, some our most significant technological innovations are born in the realm of basic science long before a known application exists and these innovations often introduce systems of applications (i.e. computers, the internet, bio-technology). The evolution of today's computers begins before Macs and PCs, with mathematical research such as that of Alan Turing published in 1937 (Wikipedia, accessed 2009). Before a technological discontinuity can occur, a basic science-based technology must traverse a difficult path from scientific discovery to a marketable product or useable process. However, despite the fact that the frames and expectations that develop as a basic science discovery transitions to a commercial technology influence future technological trajectories, we know little of how frames emerge (Hargrave and Van de Ven, 2004; Kaplan and Tripsas, 2008).

Traditionally, most organizational theories have treated technology deterministically and have ignored the role of human agency in shaping its development (Orlikowski and Barley, 2001). Although this approach has enabled researchers to better understand how technologies influence organizations and has provided the robust life-cycle model, it is less well suited to explain the social and political processes that dominate the period before a technological problem and solution find each other in the form of an application or product. Recognizing this gap, researchers have begun to call for explanations that take into account the social aspects of the phenomena that influence the evolution and adoption of technologies and recognize that emerging technologies are embedded in larger social systems (Garud and Rappa, 1994, Hargadon and Douglas, 2001; Garud, Jain, and Kumaraswamy, 2002; Munir and Phillips, 2005; Kaplan and Tripsas, 2008).

Science-based Technologies and Technology Stigmatization

Because science-based technologies often have national consequences, governments are more likely to be involved in research funding, standard setting, and regulation (Tushman and Rosenkopf, 1992). In democratic societies, the public may influence decisions regarding regulation and standards. Studies have shown that public perceptions of the risk associated with science-based technologies are ambiguous and often inaccurate and can contribute to the "stigmatization" of technologies (Gregory, Flynn, and Slovic, 2001). Technology stigmatization "represents an increasingly significant factor influencing the development and acceptance of scientific and technological innovation and, therefore, presents a serious challenge to policymakers" (Gregory, Flynn, and Slovic, 2001: 4). Technology stigmatization can lead to burdensome regulations, lack of investment and failure of product markets, thereby posing a serious threat to the success of emerging science-based technologies and the nascent industries which develop from them.

A stigma is a deeply discrediting attribute of people, places, or technologies. Stigmatization refers to the process by which an attribute is singled out and the people, places or technologies possessing the attribute are denigrated. Stigmatization results in the widespread devaluation of the possessor of the attribute and frequently includes labeling and the communication of labels. Stigmatization of technologies occurs when the perceived risk associated with a technology is socially amplified. The social amplification process usually begins with a trigger event such as an accident or report of a hazardous condition and involves three stages: 1) the risk-related attributes of the technology receive high visibility in the media, 2) the technology is perceived and marked to identify it as risky, 3) the marking and the social amplification of perceived risks alter the image of the technology such that those encountering it change their behavior (Kasperson, Jhaveri, and Kasperson, 2002).

Risk perception is a critical part of risk amplification and stigmatization. As noted, public perceptions of technology risk are often ambiguous and inaccurate. Recent studies in the field of risk analysis have highlighted the strong role played by feelings in how risk is assessed. While any manager will recognize that in the world risk and benefit tend to be positively correlated--high risk, high gain--these studies show that risk and benefit tend to be negatively correlated in people's minds (Slovic, Finucane, Peters, and MacGregor, 2002). This inverse relationship is linked to the strength of the positive or negative feelings associated an activity or technology. If people like an activity or technology, they are more likely to judge risks as low and benefit as high and likewise if they dislike and activity or technology they are more likely to judge the risks as high and the benefit as low. According to this model, feelings come prior to and direct judgments of risk and benefit (Slovic, et al., 2002). Additionally, risks that are perceived as new or potentially catastrophic, connect to a group agenda, or pose a threat to deeply held values or social institutions are particularly likely to generate the strong public concerns and high media coverage that lead to the social amplification of risk and stigmatization (Kasperson, Jhaveri, and Kasperson, 2002).

Science-based technologies often involve risks of this nature. While the successful emergence of a technology domain is dependent upon the development of public trust, the risks associated with new science-based technologies are particularly likely to generate public concern. If public concerns are amplified, the end result may be technology stigmatization, or the complete absence of public trust. The ambiguous nature of science-based technologies, combined with the potential for extreme positive and negative social and economic consequences (e.g. from new products and industries, or unforeseen catastrophes and failed investments) supports the appropriateness of a sociopolitical perspective and qualitative approach to this study.

Sociopolitical Approaches—The Emergence of Technological Fields

Technology management scholars have recently adopted the concept of institutional entrepreneurship to examine the emergence of technology fields, and in particular the generation of public trust or legitimacy. The realization of opportunities created by new technologies requires sociopolitical legitimacy (Aldrich and Fiol, 1994). Stakeholders such as the general public and government officials come to accept emerging technologies as appropriate and feasible through the process of social legitimization, whereby norms and rules—including definitions, identities, boundaries, standards, and practices—become institutionalized (Aldrich and Fiol, 1994). Researchers have increasingly recognized that interested individuals with sufficient resources can influence the legitimization of new technologies and the fields emerging around them by creating and promoting valued institutions (DiMaggio, 1991; Fligstein, 1997; Garud, Jain, and Kuraswamy, 2002). These "institutional entrepreneurs" utilize social skills to build support for institutions they value (Fligstein, 2001).

While traditional entrepreneurs create new businesses or products, institutional entrepreneurs work to create new institutions by gaining institutional and societal acceptance of new standards, practices, and definitions (Dacin, Goodstein, and Scott, 2002). Perhaps one of the most well known examples of institutional entrepreneurship is illustrated by the efforts of Thomas Edison and his allies to commercialize electric power. Electric industry founders in the U.S. mobilized resources and influence to gain acceptance of standards that supported their business model (McGuire and Granovetter, 2003). By creating and gaining acceptance for the infrastructure on which new technologies depend, institutional entrepreneurs play a key role in the emergence of technology based ventures, industries, and sectors.

Origins of the Concept of Institutional Entrepreneurship

A fundamental assumption of institutional theory is that institutions matter: organizations are influenced by an environment made up of taken-for-granted institutions and other organizations responding to the institutional environment and each other (Scott, 2001). The focus on the taken-for-granted aspect of institutions led to criticisms that institutional theory could explain only static, homogenous populations whereas observation illustrates that institutions change over time and are challenged as well as contested (Dacin, Goodstein, and Scott, 2002). Arguing that to explain institutional change and emergence researchers must consider interested actors, DiMaggio (1988) introduced the concept of institutional entrepreneurship. The topic of institutional change has since emerged as a central focus for organizational researchers (Dacin, Goodstein, and Scott, 2002). However, as discussed below, little exploration has been devoted to either the origins of institutions in new fields or institutional entrepreneurs' efforts to create institutions in support of emerging fields.

Early empirical work on institutional change reintroduced to organization scholars the role of power and interested actors emphasized in Selznick's "old institutional theory" (Selznick, 1957). In a study of the of the changing role of art museums, DiMaggio (1991) found that the art museums came to fill the role of educational rather than curatorial institutions as interested actors including the Carnegie Foundation and museum professionals constructed field-wide structures such as professional associations to legitimize the new role. The process involved conflict over definitions and metaphors as well as struggle for power as control shifted from patrons, trustees and donors to museum professions, educators and government. Similarly, in a study of the redefinition of the role of community colleges from liberal arts to vocational institutions, Brint and Karabel (1991) found that the vocationalization of community colleges was driven initially by administrators interested in securing a labor market niche and in increasing their status by moving two-year colleges from the bottom of the liberal arts academic hierarchy to the top of a newly created occupational training hierarchy. After years of effort, the support of powerful outside sponsors such a private foundations and the federal government helped to legitimize the new role. Galaskiewicz (1991) found that new organizational forms to encourage corporate community involvement emerged when a cadre of business leaders with corporate clout and long-standing community ties orchestrated changes in the control of the largest corporations in the area. Consistent with DiMaggio's (1988) definition, these studies illustrate the existence of interested actors using resources to create and legitimize institutions that they value. However, the creation of new institutions in these studies occurs as a response to existing institutions rather than in the context of an emerging field.

Many studies of institutional dynamics continue to attribute the emergence of new institutions to a reaction or challenge to existing institutions. For example, Haveman and Rao (1997) analyzed multi-level changes in institutions and organizations in California's thrift sector to show that institutional entrepreneurs deployed new organizational forms that coevolved with institutions. The authors note however, "The period covered by our…analysis does not include the earliest history of thrifts in California" (1615). More recently, in a special issue devoted to institutional change, several studies support the notion that actors are not passive adherents of institutions, but rather, through their "perceptions, interpretations, and enactments of institutional logics…give meaning and life to institutions" (Dacin, Goodstein, and Scott, 2002). Technology researchers have adopted this perspective, arguing that technology standards are institutions, to explore the emergence of technology fields. However, as with studies of institutions in other contexts, most work has not focused on the early emergence of technologies from science discoveries.

Institutional Entrepreneurship and Technology Management

Researchers have recently explored the role of institutional entrepreneurs in emerging technology fields. This work addresses calls for greater attention to the role of agency in the development of technology (e.g. Orlikowski and Barley, 2001). However, these studies do not explore the early emergent period of technology evolution.

In a historical study of the emerging electric power industry McGuire and Granovetter (2003) show that electric industry founders mobilized resources and influence through social networks to construct a business model and build a system of governance that supported the diffusion of their model. They note however that the process through which this occurred requires additional study.

Garud, Jain, and Kumaraswamy (2002) studied Sun Microsystems' sponsorship of Java as a technology standard. They found that institutional entrepreneurs require political and social skills, including framing, to address challenges to collective action fostered by the constraining and enabling characteristics of technology standards. The authors argue that Sun Microsystems attempted to create a common interest among computer vendors and users by framing Java as a network standard 'solution' mobilized against the 'problem,' "Microsoft's desktop-centric view of computing." Sun's collective action frame helped them gain support for Java among systems assemblers, software firms and component manufacturers.

Munir and Phillips (2005) investigate "The Birth of the 'Kodak Moment'" to explore the role of institutional entrepreneurs in the process of technology adoption. They find that technology promoters used a variety of discursive strategies to influence the meanings that consumers attributed to roll-film cameras. Importantly they note "Technologies are not, therefore, simply disruptive, or not as much as research seems to suggest (e.g. Christensen, 1997). At least from a user's perspective, it is the degree to which some institutional entrepreneur can mange the meanings of technology …that determines how disruptive the technology will be" (Munir and Phillips, 2005; 1683).

The three studies discussed above provide a foundation for, but do not address the overall question of this research: How do basic science discoveries become the basis for domains of commercial activity? Each of these studies began after a best use for the technology had been determined. The studies' findings suggest the importance of framing processes to the emergence of new technologies and their small number provides evidence in support of Hargrave and Ven de Ven's (2004:13) assertion that although scholars of organizations and technology have begun to view battles over the meanings of technologies as central to institutional change in technological fields, they have said little about the creation and manipulation of technology frames.

Summary

The diverse studies discussed above show that interested actors and collective action play a role in the development of institutions to support new technology. However, the institutional studies depict shifts in existing organizational fields rather than the creation of institutions to support emerging fields and thus only partially address DiMaggio's call for an exploration of the dynamics and emergence of organization fields. And, while researchers of entrepreneurship and technology have begun to explore emerging technological fields, studies have not examined how scientific discoveries become disruptive technologies. Our investigations and knowledge begin after much of the story has transpired. Thus, while providing a foundation for this study, previous work cannot fully explain how science-based technologies become the basis for commercial activity.

The realization of opportunities inherent in new technologies requires public trust (Aldrich and Fiol, 1994). Researchers argue that emerging technologies must have technology, safety and business standards in order to gain public trust and legitimacy (Aldrich and Fiol, 1994; Garud, Jain, and Kumaraswamy, 2002). Such standards emerge from sociopolitical processes, which can be influenced by institutional entrepreneurs who generate collective action (Garud, Jain, and Kumaraswamy, 2002). While the importance of collective action and public trust to the emergence of new technologies is recognized, and researchers have argued that institutional entrepreneurs fill the role of generating collective action and trust (DiMaggio, 1988; Fligstein, 1997;), we know little of how this is done (Aldrich, 1999; Dowell, Swaminathan, and Wade, 2002). This dissertation addresses this gap.

Conceptual Framework

I began this dissertation with the concept of a technology frame and a set of theoretical assumptions derived from social studies of science and technology, in particular from studies of the social construction of technological systems (Bijker, Hughes, and Pinch, 1987) and science controversy and risk (Nelkin, 1992). Researchers from these disciplines seek to explain how science and technology progress and why they progress as they do. The literatures have in common a rejection of deterministic views of science and technology and adopt instead a socio-political perspective (Callon, 1987). In contrast to rational models, which focus exclusively on researchers and inventors and depict the development of science and technology as a linear march down one path toward scientific fact or technological efficiency, socio-political models depict the development of science and technology as a political process involving many social groups with diverse definitions of problems and conflicting favored solutions (e.g Bijker, Hughes, and Pinch, 1987; Garud and Rappa, 1994; Garud, Jain, and Kumaraswamy, 2002; Garud and Karnoe, 2003).

These literatures share a concern with framing, a view of boundedly rational human action, and a socially constructed environment. From this perspective, the end meaning and uses of technology are socially constructed (Bijker, Hughes, and Pinch, 1987, Garud, Jain, and Kumaraswamy, 2002). Collectively, the literature that provides the foundation for this study suggests the following concept, theoretical presuppositions, and definitions, which along with a process perspective, serve as conceptual framework for this study.

Technology Frames

Due to the fundamental character of emerging science-based technologies, what the technologies will mean and how consumers and producers will use them, is unclear. Technology frames define and bound technologies in much the same way that collective action frames define social problems, facilitating collective action and creating sociopolitical legitimacy by answering the questions, 'What problems does this technology address?' and 'With what solutions?' (Orlikowski and Gash, 1994; Bijker, 1995; Kaplan and Tripsas, 2008). Technology frames comprise "all elements that influence the interactions within the relevant social groups and lead to the attribution of the meanings to technical artifacts," including, problems facing the technology and problem solving strategies and solutions (Bijker, 1995: 123). A technology frame is institutionalized, as the solution presented in the frame comes to be seen by stakeholders as an acceptable, trustworthy solution to relevant problems. Like an institutional practice, such as marriage, an institutionalized fame comes to be taken for granted and no longer questioned. For example, as explained below, we no longer question that the dominant purpose of a bicycle is transportation, whether for pleasure or need, and two wheels of the same size are the preferred solution.

The creation of a technology frame is attributable to the actions of many actors, including not only those who discover ideas but those in institutional forums, those who develop complementary assets and those who oppose the research or technology (Bijker, 1987; Garud and Karnoe, 2003). These actors can be identified as "social groups"--formal organizations or unorganized groups of individuals that attach the same shared set of meanings to a technology (Bijker, 1987). The institutional acceptance of a technology is a process of struggle between social groups with competing technology frames (Bijker, 1987; Garud and Karnoe, 2003). The contested nature of technology frames means that the end form of the technology and meaning given to it are not known a priori. Technology frames shape technologies at the same time that technological developments and political maneuverings by supporting groups shape technology frames. The process ends in closure when a particular frame dominates and is publicly accepted, becoming an institution.

In accordance with constructionist interpretations of institutional theory, the physical attributes and understanding and use of a technology interact with each other and evolve over time. The initial interpretations of the uses and meanings, problems to be solved and suggested solutions related to a technology are flexible, and socially constructed interpretations influence the end design of the technology (Bijker, 1987, Orlikowski and Gash, 1994;). While in hindsight, the evolution of a technological development may appear to be linear, it is actually the end result of many possible paths created by many interpretations, needs, and uses, which constitute the technology frame (Garud and Karnoe, 2003).

Researchers can trace the development of a technology by analyzing the problems and solutions encompassed in the technology frames of relevant social groups. For example, Bijker (1995) shows how competing technology frames influenced the development of the bicycle such that the bicycle with two equally-sized wheels, once known as the 'safety bicycle' to differentiate it from competing designs, has become emblematic of our current understanding of the term bicycle. At one time, the dominant bicycles were high-wheeled 'Ordinaries,' used by aristocratic young men with the goal of showing off for their lady friends in parks. For this social group, the primary function of the bicycle was sport and daring. The high-wheeler's meaning as a 'virile, high-speed' bicycle supported the development of ever larger front wheels to solve the problem of continually impressing ladies. For these athletic young men, an important characteristic of the bicycle was that it could easily topple over--impressing ladies required risk. However, for the social group including women and elderly men with the goal of safe transport, the key characteristic of the high-wheeled Ordinary bicycle was its lack of safety. It was a "non-working machine." As the frame defining the bicycle from the perspective of women and elderly men became dominant in English society, the accepted meaning 'virile' attributed to the high-wheeled bicycle was superseded by the accepted meaning 'unsafe.' The high-wheel 'problem' was then corrected and the bicycle developed into a 'working machine' with a low front wheel recognizable today as a bicycle.

Human Agency

A critical principle of a sociopolitical perspective on science and technology is that the emergence of a scientific or technological path is attributable to the actions of many actors (Bijker, Hughes, and Pinch, 1987; Martin and Richards, 1995; Garud and Karnoe, 2003). Actors may include individual people, groups of people or organizations who participate in defining the developing path. This includes not only those who discover ideas but those in institutional forums, those who develop complementary assets and those who oppose the research or technological path. In accordance with constructionist interpretations of institutional theory, actors influence the development of a scientific or technological path by using strategic tactics to collectively build attributes of their technologies into emerging institutional structures (Constant II, 1980; Garud, Jain, and Kumaraswamy, 2002). Strategic tactics are actions involving social skill (Fligstein, 1997, 2001), the ability to motivate cooperation by providing common meanings and identities to justify action, made in an attempt to create stable organizational fields. The principle of collective human agency implies that the purposeful actions of individuals in a collective can influence the development of a scientific or technological path.

Social Construction

The social construction of technological systems literature maintains that alternative paths of technological development exist (Bijker, et al., 1987, Garud and Karnoe, 2003). The initial interpretations of the uses and meanings, problems to be solved and suggested solutions related to a technology are flexible. Socially constructed interpretations influence the end design of the technology (Pinch and Bijker, 1987). Thus, while in hindsight, the evolution of a technological development may appear to be linear and determined by efficiency, it is actually the end result of many possible paths created by many interpretations, needs and uses.

A similar perspective is evident in studies of science controversy and risk. Controversies provide alternative accounts of the natural world suggesting that such accounts are not given by nature but are the products of a social process of negotiation, which mediates scientific explanations (Martin and Richards, 1995). The principle of social construction suggestions that in order to understand the development of science and technology one must identify conflicting definitions and accounts.

Political Struggle

A third principle of a sociopolitical perspective on science and technology is that of political struggle. The institutional acceptance of a technology is viewed as a process of political struggle between social groups with competing technological frames (Bijker, et al., 1987, Garud and Karnoe, 2003). Social groups may be institutions, organizations or organized or unorganized groups of individuals that attach the same shared set of meanings to a technology (Pinch and Bijker, 1987). Similarly, a political approach to science risk and controversy studies views controversy as a form of politics: a process of compromise involving competing groups in a political marketplace (Nelkin, 1992). Scientific knowledge may become a tool used by competing groups to advocate their positions (Martin and Richards, 1995). This principle suggests the need to identify key groups and their definitions of the problems and solutions related to an emerging technology.

Additional Definitions

Researchers studying the development of technology have described interrelated components variously as communities, systems and fields (Constant II, 1987). For this study, I will rely on the concept of a technology field. The concept of a technology field is similar to that of an organizational field. Organizational fields are comprised of a shared set of meanings (Scott, 2001). Technology fields "represent a pattern of relationships among objects and humans related to a product-market domain" governed by an institutional environment (Garud, Jain, and Kumaraswamy, 2002: 197). This study is an investigation of the early emergence of a technology domain, before a field has formed, I will refer to an emerging field or technology domain. As the efforts of actors to project a technology frame are the focus of this study, the social, political and discursive elements of the emerging technology domain will be of greater concern than the physical or scientific elements of the technological system.

The entrepreneurship literature contains many sometimes conflicting definitions of entrepreneurship based on many dimensions. It is beyond the scope of this paper to define entrepreneurship in general. For this study, I will adopt a definition of entrepreneurship as a societal phenomenon in which actors introduce new activity that leads to change (Davidsson, 2002). I will focus on entrepreneurs involved in institutional entrepreneurship. As discussed previously, following DiMaggio (1988) I define *institutional entrepreneurship* as the action of interested agents deploying resources to create and empower institutions that they value. Institutions constrain the choices of actors and include norms, rules, culture, and laws (Ingram and Silverman, 2000).

Process Perspective

I view the projection of a technology frame as a process. This is congruent with Weick's (1979) view of structure, as applied by Barley (1986: 79) to the study of technology: structure is "patterned action, interaction, behavior, and cognition." Process researchers seek to understand how things evolve over time and why they evolve in the way they do. Process data deal with sequences of events, involve multiple levels and units of analysis, are temporally embedded and are often eclectic including in addition to events, changing relationships, thoughts, and interpretations (Langley, 1999). Process theories provide explanations in terms of the sequence of events leading to an outcome and must consider temporal ordering and probabilistic interaction (Mohr, 1982). A process perspective will direct me to collect stories and information about events.

activities and choices ordered over time. Methods appropriate for analyzing this type of data will be discussed in a following section.

Conclusion

Following previous theory and research I begin this study with the following expectation: Entrepreneurs attempt to influence the development of technological systems by actively mobilizing collective action and utilizing collective resources to avert perceived and expected threats. Their tactics involve the use of social skills and are likely to include the creation of a favorable technological frame. The concept of a technology frame, theoretical presuppositions and definitions described above along with a process perspective provide a conceptual framework from which to explore the broad research question posed in this dissertation: How do scientific discoveries become the basis for domains of commercial activity? And, the more focused question that emerged from the data, How do technology proponents project a technology frame in the general discourse?

Emerging technologies and ventures founded to commercialize them have wide-ranging economic and social impact. Although researchers have for some time explored how technologies emerge, evolve and are adopted, little attention has been devoted to early emergence, prior to the identification of applications and products, when the assumptions and definitions that drive technology trajectories are forming (Kaplan and Tripsas, 2008). Recent work by technology management scholars addressing calls for greater attention to the social and political aspects of technology evolution with suggests the importance of the role of framing in the process of technology emergence, evolution and adoption (Orlikowski and Barley, 2001; Kaplan and Tripsas, 2008). However, management scholars have said little about the creation and manipulation of technology frames (Hargrave and Van de Ven, 2004). This dissertation contributes to our knowledge of technology emergence, evolution and adoption by focusing on the understudied period of early emergence and understudied sociopolitical process of technology framing. Specifically, I contribute to our knowledge of how science discoveries become the basis for domains of commercial activity by explaining the process through which technology proponents project a technology frame into the general public discourse.

CHAPTER III

METHODS

Overview

As explained in the previous chapter, despite the economic importance of science-based technologies, our knowledge of the path they take from science lab to commercial arena is limited. Extent theories and studies that focus on the development of technologies begin after a problem has been generally agreed upon, at the point that the likely commercial uses of a scientific discovery are known (e.g. Garud, 1994; Christensen, 1997). Without an understanding of the earliest stages of the science to technology path, our knowledge of how commercial activity emerges from scientific discoveries will remain incomplete. In this chapter, I describe the methodological approach I use to I explore the general research question, How do new areas of business activity emerge to commercialize science based technologies? And, specifically, How do technology proponents project technology frames? As I explain in this chapter, consistent with my grounded theory approach, the more specific question emerged during the study from the data rather than from my review of the literature.

This chapter builds from the assumptions and definitions derived from the literature and detailed in the previous chapter. First, I describe and explain the overall approach to this study including my assumptions, the research design, empirical setting, case boundaries, and units of analyses. Next, I describe my approach to data collection and organization. Finally, I describe and explain my approach to data analysis, threats to the validity of analyses based on qualitative data, and how I have addressed these threats.

Research Methods

This dissertation is a qualitative, inductive study exploring how basic science discoveries become the basis for new areas of commercial activity. As detailed in the previous chapter, because economic explanations of industry emergence assume the existence of a product and market, they are not well suited to explain the emergence of commercial activity from science-based technologies. Emergence is a complex, novel and understudied phenomenon (Chiles, Meyer, and Hench, 2004) and requires longitudinal data, process theorizing, and context-sensitive, multi-level research designs (Meyer, Gaba and Colewell, 2005). Characteristics of science-based technologies, including their extreme ambiguity and unforeseeable social and economic consequences, suggest that sociopolitical processes, and in particular technology framing, play an important role.

While the emergence of any new industry can be expected to involve some political struggle (Fligstein, 1996, 2003), new industries based on new scientific knowledge are an extreme case. Innovation based on new knowledge has a long lead time; requires the convergence of many types of knowledge, not limited to the scientific or technological; and unlike other innovation which exploits a change that has occurred, knowledge-based innovation brings about the change (Drucker, 1985). During the early emergence of knowledge, or science-based technologies, the dimensions of merit on which the new technology will be judged are unclear because neither founders nor users are certain which characteristics will be critical (Tushman and Rosenkopf, 1992). This uncertainty fosters increased political activity: "The more complex the system, the more complex the social and technical uncertainty, the greater the intrusion of social and political processes on the nature of technological progress" (Tushman & Rosenkopf, 1992: 337). An exploration of sociopolitical processes requires an approach that takes into account participants' interpretations and use of language (Creed, Langstraat, and Scully, 2002).

The design of this dissertation is consistent with researchers' suggestions for exploring emergence and sociopolitical processes. I use an embedded, single case study design (Yin, 1984) and inductive, grounded theory approach to analyze the data (Glaser and Strauss, 1967; Strauss and Corbin, 1990). This approach allows me to explore emergence of science-based technologies and the role of social issues and political maneuvering in the emergence process.

Interpretive Assumptions and Research Strategy

As explained in the previous chapter, research on emergent phenomenon, including technology emergence is limited. Researchers that address related questions frequently use case studies (e.g. Garud and Rappa, 1994; Hargadon and Douglas, 2001; Munir and Phillips, 2006) and analysis techniques that include discourse, frame, narrative, and grounded theory analysis. These approaches have in common an emphasis on participants' interpretations.

Interpretive studies draw on several key assumptions. First, a premise of such research is that people act on the basis of their interpretations of the world. Through their actions, people enact social realties and endow them with meaning (Berger and

Luckmann, 1967; Smircich and Stubbard, 1985; Weick, 1979; Orlikowski and Gash, 1994). Second, individuals and groups draw on frames of reference, which are implicit guidelines that shape and organize peoples' interpretations and give meaning to events (Weick, 1979; Orlikowski and Gash, 1994). Frames are created through social interchange, negotiated over time, and come to represent the dominant logic of a group (Isabella, 1990). Finally, interpretations are made after an event has occurred, as people attempt to make collective sense of what has happened (Daft and Weick, 1984).

Building from the suggestions of researchers exploring emergence (e.g. Chiles, Meyer, and Hench, 2004; Meyer, Gaba, and Colwell, 2005) and the interpretive assumptions described above, I use an inductive, grounded theory approach to explore how scientific discoveries become the basis for commercial activity and, in particular, how technology proponents project a technology frame.

This dissertation is designed to explore the processes through which abstract scientific discoveries become the basis for domains of commercial activity. Consistent with an embedded case design, which I explain below, my research occurs in three phases. In the first phase, I analyze the case of the emergence of nanotechnology beginning with the first mentions of nanotechnology in the *New York Times* in 1985 through 2008. In the second phase, I focus on the period in which nanotechnology start-ups were being founded (2000-2008) and three particular venture capital (VC) firms. In the third phase, I consider the larger and embedded cases together. I collected data through participant observation, interviews, and extensive searches of archived electronic WebPages. I supplemented this data with print and electronic documents from public and proprietary sources. I analyzed the data using an inductive, grounded theory approach (Glaser and Strauss, 1967; Strauss and Corbin, 1990).

The inductive approach I take is appropriate for this study for several reasons. First, empirically, the process by which scientific discoveries become the basis for commercial activity is economically important, inherently risky and not well understood (Drucker, 1985). Second, theoretically, the organizational literature says little about the early emergence of technologies (Kaplan & Tripsas, 2008). Finally, this approach is consistent with my research goals and the methodology and assumptions used in similar studies (e.g. Hargadon and Douglas, 2001, Munir and Phillips, 2005).

Research Design

I use a embedded, single case design for this dissertation. Yin defines a case study as, "an empirical enquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used (Yin, 1984: 23). Case studies focus on understanding the dynamics of a setting and are typical of process research (Langley, 1999). Case studies are particularly appropriate for exploratory research focusing on "why" and "how" questions (Yin, 1984). Additionally, case studies offer a distinct advantage over other designs when, "A 'how' or 'why' question is being asked about a contemporary set of events, over which the investigator has little or no control" (Yin, 1984: 20). Given the questions this dissertation seeks to answer, a case study design is appropriate.

There are many types of case studies, including longitudinal, comparative, single and embedded (Yin, 1984). Aldrich and Fiol argue that in order to study the emergence of industries, "when a new industry's origin is identified, researchers must focus intensively on its early years" (1994: 665). This suggests that researchers seeking to develop a thorough understanding of how new areas of business activity emerge to commercialize science based technologies focus on a single case. In order to capture fine-grained detail, I focus on the single case of emerging nanotechnology, including three smaller cases of particular VC firms embedded within the larger case. An investigation of embedded cases can improve the validity of a study based on a single case. An embedded case design involves the study of smaller subunits within a larger case, allowing for some comparison between the embedded cases (Yin, 1984).

Empirical Setting

I introduce the empirical setting for this study here and elaborate on it in Chapter IV. The term nanotechnology was first suggested by Norio Tanguchi of the Tokyo University of Science to describe technology that strives for precision at the level of one nanometer, or a billionth of a meter. While the term did not originate until 1974, credit for inspiring nanotechnology is generally attributed to a lecture given by Richard Feyman in 1959, titled *There's Plenty of Room at the Bottom.* In this lecture, Feyman proposed the possibility of maneuvering matter atom by atom and suggested research to make computers smaller and to create mechanical surgeons that could travel to trouble spots in the body. Feyman offered two prizes to get things started: $1000 to the first person to make a working electric motor that was no bigger that one sixty-forth of an inch on any side, and another $1000 to the first person to shrink a page of text to 1/25,000 its size. The first prize was awarded in 1960 and the second in 1985 (Keiper, 2003). My analysis of the single case extends from Feynman's 1959 speech through 2008, however, few events occurred prior to the 1980s.

The embedded cases include the only three venture capital firms focusing solely on nanotechnology during the period of early emergence. These firms were identified through my initial analysis and were credited by participants as being instrumental in the creation of the nanotechnology investing space. The firms were founded in 1999 and 2000 and my study includes their activities from founding through 2008.

My selection of this setting can be characterized as a combination of "planned opportunism" (Pettigrew, 1997) and theoretical sampling (Eisenhardt, 1989; Glaser and Strauss, 1967). The development of nanotechnology has a clear beginning and encompasses many small dramas, such as groundbreaking innovations and the passage of specific legislation, which may "provide a glimpse into the social system" at a particular time (Pettigrew, 1990: 275). Between 2000 and 2008, nanotechnology was evolving from a science discovery to business opportunity. The first nanotechnology start-ups were being founded with patents but no products. Investors, policy makers and corporate leaders were trying to figure out what nanotechnology is and what were the likely implications. Proponents and opponents were organizing and taking stances, which were reported in the media. Nanotechnology was making its way into mainstream fiction. When the phenomena of study are contained within a single case, researchers should "go for extreme situations, critical incidents and social dramas…where the progress is transparently observable" (Pettigrew, 1990: 275). The emergence of the nanotechnologies involved such a public drama and, given the lack of familiarity, observability and complexity of the technology, it represents an extreme situation.

From a theoretical perspective, although the literature points to the importance of sociopolitical processes on the development of new technologies (Hargadon and Douglas, 2001; Kaplan and Tripsas, 2008), empirical studies begin after the meaning of the focal technologies are largely understood (e.g Garud and Rappa, 1994) or focus on technologies for which known products exist (e.g. Hargadon and Dougnlas 2001; Munir and Phillips, 2005). The case of the emergence of nanotechnology offers the opportunity to study a technology at the earliest stage of its emergence from its basic science roots, in real-time, and in context. During the period of the study, sensemaking and sensegiving were actively occurring and the meaning of the technology was contested, allowing for the collection of rich data in the form of stories and histories as they were being constructed. The efforts of individuals and organizations to make sense of nanotechnology and promote their perspectives are "transparently observable" (Eisenhardt, 1989, Pettigrew, 1990).

Data Sources

The data for this study were collected between January 2002 and December 2008, from five sources: 1) participant observation and informal interviews at a series of annual nanotechnology investing conferences, 2) journalistic reports and commentary, 3) semi-structured interviews with VC and startup founders and executives, 4) Internet media including; VC and startup websites, press releases, interviews, electronic journal articles.

blogs, newsletters, and electronic conference presentations and marketing materials, and 5) trade publications and proprietary reports. The journalist reports and commentary and trade publications provided a means to triangulate and buttress my naturalistic observations and interviews (Eisenhardt, 1989) and to extend my investigation to include the earliest years of the case. The Internet data document a real time, less formal account of events and provide an additional basis for triangulation. The data sources are summarized in Table 1.

Nanotechnology Investing Conference Series

I began collecting data for this dissertation by directly observing and informally interviewing participants in nanotechnology investing at the 2003 Nanotechnology Investing Forum, a two-day industry conference organized by International Business Forum (IBF). Meyer, Gaba, and Colwell (2005: 467) call such conferences "field configuring events" – settings where people from diverse social organizations assemble temporarily with the conscious, collective intent to construct an organizational field." This affords an excellent setting to observe and interact with field founders (DiMaggio, 1991, Fligstein 1997). Attendees included representatives of trade associations, economic development agencies, private investors, and networking organizations actively engaged in institution-building projects.

The conference series began in 2002 with what organizers and participants recognize as the "the first conference in the States…to specifically focus on [nanotechnology] private equity investing." The conference continued annually with minor modifications in format through 2008. In 2009, the meeting was reduced to a two-hour workshop between other conferences at the same venue.

Table 1: Data Sources

Source	Data	Date	Quantity
Traditional media			
New York Times	Articles	1985-2006	313 docs.
Participant observation			
NanoInvesting Event	Conference agendas, names/organizations of sponsors, speakers, attendees	2002-2008	8 notebooks/ 1513 entries
	Transcribed audio recordings of presentations	2002-2008	98 single spaced pgs.
	Field notes & memos	2003-2009	120 handwritten pgs.
Semi-structured interviews			
Nanobusiness leaders	Transcribed audio recordings and field notes	2003-2008	119 single spaced pgs.
Electronic Media			
Web Archive	Websites	2000-2008	1837 single spaced pgs.
HighBeam Research	Journal articles, press releases	1997-2008	519 docs.
Google	Conference agendas, newsletters, blogs, videos	1997-2008	2386 urls
Trade & proprietary reports			
Nanotechnology Opportunity Report		2002	
Nanotechnology Opportunity Report, 2nd ed.		2003	
Nanotechnologies in 2009: Creative Destruction or Credit Crunch		2009	
A Prudent Approach to Nanotech Environmental, Health, and Safety Risks		2005	
Nanotechnology Corporate Strategies		2008	
Exits for Venture Capitalist in Nanotechnology Remain Elusive		2006	
Forbe/s Wolfe Nanotechnology Report		2002-2006	monthly
Small Times editorials		2001-2004	quarterly

I personally attended six of the eight conferences and with the help of colleges who attended the two events I missed. I compiled a complete record of the conference series. I collected notebooks, which, contained lists of attendees, sponsors, speakers and the titles and descriptions of presentations, audio recordings and field notes from each of the eight conferences. I had the audio recordings of key presentations transcribed, yielding 98 pages of single-spaced text. I took notes at and after the events and conducted numerous informal (Lofland and Lofland, 1984).

Print Journalism

After attending the 2003 Nanotechnology Investing Forum, I began collecting archival data from journalistic media sources. I initially used Lexis-Nexis Academic Universe to obtain all articles on or related to nanotechnology published in the *New York Times* from the first article in 1985 through July of 2005, which yielded a total of 226 articles. I selected the *New York Times* because it was a crucial medium for communication about nanotechnology to the general public. The *Times* has the largest circulation of US daily newspapers, is targeted to a general news audience, and is headquartered near Boston, a nanotechnology center. Additionally, at the time I began collecting data, the *New York Times* was publishing more stories about nanotechnology that competing newspapers, as shown in Table 2. As time progressed, I collected articles published in the *Times* through December 2008. This yielded a total of 313 articles.

Table 2: Prevalence of Nanotechnology Articles in Major Papers

East Coast U.S.	Circulation Rank		Number of Nanotechnology Articles Jan. 2000- Jan. 2005
	National	Regional	
New York Times	1	1	211
Boston Globe	11	5	89
Washington Post	3	2	71
West Coast U.S			
San Francisco Chronicle	16	2	74
Seattle Times	20	3	25
LA Times	2	1	0

Source: Lexis Nexis Academic and *85th Editor and Publisher International Yearbook Encyclopedia of the Newspaper Industry Part1: Dailies*, 2005.

Semi-structured Interviews

At the IBF Nanotechnology Investing Forums, I approached participants, described my project, and conducted informal face-to face interviews. I took detailed notes of these conversations. Between January 2006 and January of 2008, I conducted follow-up open-ended, semi-structured telephone interviews with 11 nanotechnology business leaders. I recorded and transcribed the interviews.

The individuals selected for follow up interviews included the founders of the three (3) focal VC firms in my study, four (4) leaders of the media, research and political organizations founded by the VC firms, and four (4) business leaders who had either received funding from or partnered with the VC firms. The interviews lasted from 45 to 90 minutes and I interviewed one founder multiple times. I asked interviewees to first tell me the story of the founding and evolution of their organizations. I then asked them to elaborate on specific domain building activities that they had engaged in, which I had identified from my previous analyses. I focused on the actions and decisions of the founders, changes in strategic direction, rationale behind the actions, decisions and changes, and the benefits and costs the founders perceived they gained from their domain building activities. In sharing their perspectives, interviewees gave detailed histories of their goals and rationales driving their actions, which helped me to understand how they made sense of their actions and impact. I recorded and transcribed these interviews yielding 119 pages of single spaced text. The interview questions are shown in Appendix A.

Internet Media

I began my data collection process by collecting articles on nanotechnology published in traditional media outlets, newspaper articles and trade reports. As my study progressed, it became apparent that much of the public information about nanotechnology, and about my focal VCs was available only on the Internet. One organization founder explained the importance of the Internet to the dissemination of information about nanotechnology as follows:

> Nanotech has been the first wave of technology to come along whilst we have been living in the Internet age and information age. When nanotech came along, you know, '98, '99, suddenly everybody was on the web or was on Wikipedia, or all these types of things. So the amount of misinformation and disinformation probably outweighed the ...[information] in scientific journals. You could imagine ten, fifteen years ago, people didn't have Internet; didn't have all these hordes of emails and newsletters and WebPages to research things with.

Organizations and individuals posted blogs and newsletters. Each of the print sources I collected had, or created during the course of my study, a corresponding electronic forum that disseminated information more frequently than the traditional print articles. Much of this information did not enter print articles. Additionally, each of the focal VCs put out press releases using electronic wire services. Although the events described in some of these press releases were picked up and reported in print outlets, many were not. But, the press releases remained available to interested readers on the Internet. Thus, the Internet media offered a vital source of data documenting real time sensemaking of nanotechnology. I collected Internet media using three different search tools, Google, Highbeam Research and the Web Archive. I searched using the name of each of the three focal VCs from the first appearance (1999) through 2008.

I conducted searches using Google with a search by date command that allowed me collect web pages posted within stated dates. These searches generated electronic newsletters, blogs, conference promotions and materials, biographies, and interviews organized by year posted. I collected 2386 urls. I used HighBeam to locate electronic versions of print articles, articles published only on the web, and press releases. This search yielded 519 electronic documents.

Finally, I searched the Internet Archive for the archived websites of each of the focal VCs. The Internet Archive is "a non-profit organization that was founded to build an Internet library, with the purpose of offering permanent access for researchers, historians, and scholars to historical collections that exist in digital format" (Internet Archive, March 30, 2009). It is searchable by url. A search results in a list of hyperlinks to WebPages for the specified url, by date, that are included in the archive. A change to the website is indicated with an asterisk. For each focal VC, I collected one complete website from each quarter in which the VC site appeared in the archive, unless no change had occurred. I converted the WebPages to PDF documents, yielding 1837 pages.

Trade Publications and Proprietary Reports

I collected trade publications and propriety reports as they became available. I collected editorials from the print version of the nanotechnology trade journal *Small Times*, the *ForbesWolfe Nanotechnology Report* in whole, and the following proprietary reports:

- *Nanotechnology Opportunity Report* (2002, Cientitifca)
- *Nanotechnology Opportunity Report*, 2nd ed., (2003, Cientitifca)
- *Nanotechnologies in 2009: Creative Destruction or Credit Crunch* (2009, Cientifica)
- *A Prudent Approach to Nanotech Environmental, Health, and Safety Risks* (2005, Lux Research)
- *Nanotechnology Corporate Strategies* (2008, Lux Research)
- *Exits for Venture Capital in Nanotechnology Remain Elusive* (2006, Lux Research)

I organized the data into four databases, depending upon the type of data and my use of it. I used computer assisted qualitative analysis software, NVivo and Atlas.ti to organize and analyze the text documents and WebPages that I coded most intensively (Lewis, 2004; Muhr, 2004). These included the *Times* articles, the transcriptions of the conference presentations and semi-structured interviews, and the PDF files generated from the VCs' archived websites. I used Scrapbook, a Mozilla Firefox add-on, to download, store, and organize Internet media in intact web pages and web sites. Scrapbook allows users to specify the number of hyperlinks on a web page to capture. I saved a copy of entire websites including at least two hyperlinks so that the links can be followed in the future, even if the webpages on the Internet are changed or deleted. Data from conference notebooks are organized and stored in an Access database. Finally, my field notes and conceptualizations and printed trade journals and proprietary reports are stored and organized in a file cabinet. The organization of the data is shown in Table 3.

This wide array of data from multiple sources and time periods provide rich, contextual detail of the emergence of commercial activity around nanotechnology. Those data revealed key events, individuals and organizations, and their actions and motivations. Informants' causal attributions revealed their interpretations of the relationships between events and the actions of key players. These interpretations formed the basis the actions that influenced the social structure of the emerging space and meaning of nanobusines.

Table 3: Data Organization

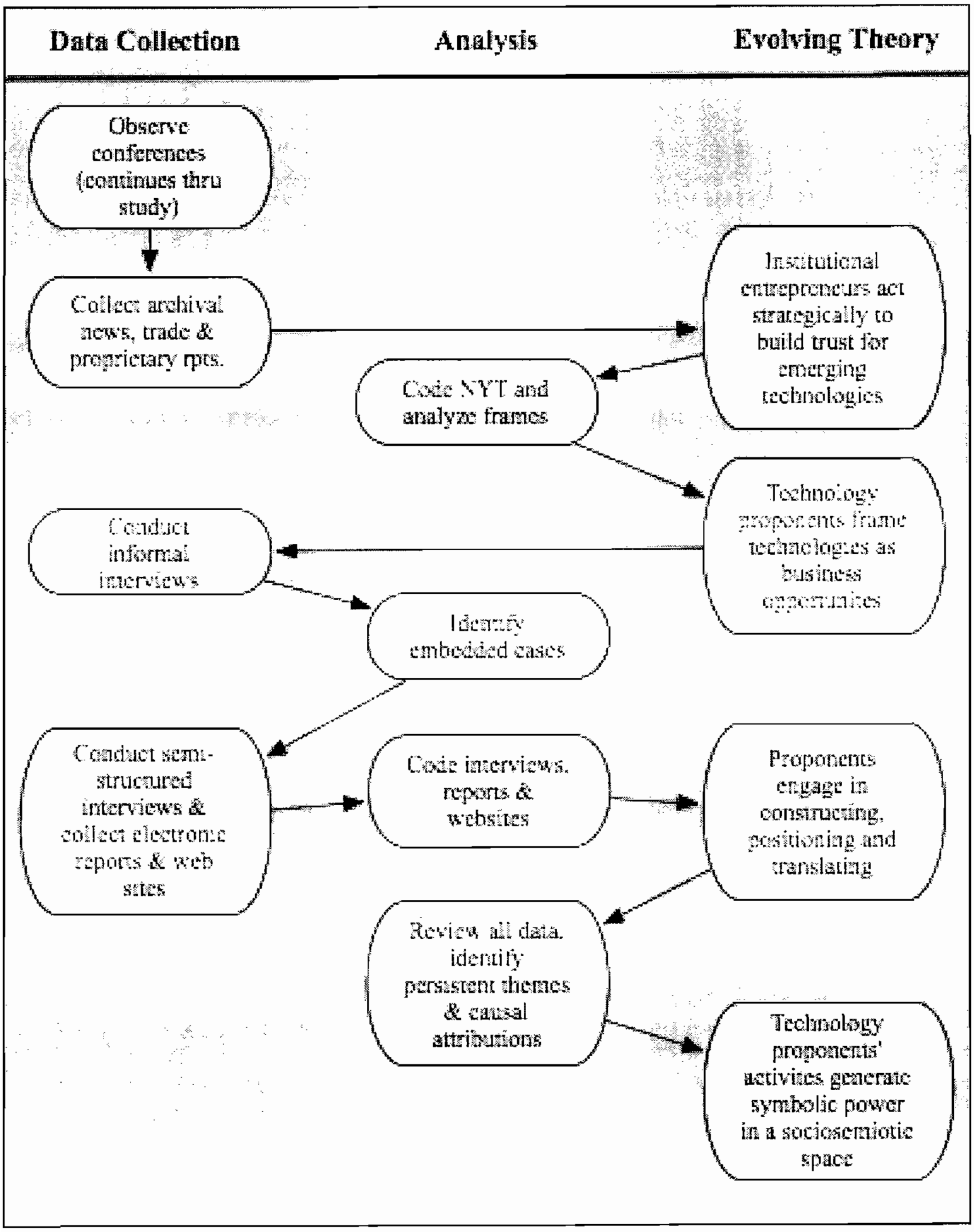
Database/Data	Data Form
NVivo & Atlas Ti	
New York Times articles	text files
Semi-structured interviews	transcribed audio files
Web archive web sites	PDFs
Key IBF presentations	transcribed audio files
Firefox Scrapbook	
Electronic journal articles	html documents
Press releases	
Conference agendas	
Blogs	
Newsletters	
Interviews	
Access Database	
NanoInvesting Event notebooks	org & individual names, presentation titles
File Cabinet	
Field notes and memos	handwritten & typed mix
Printed reports	

Data Analysis

I followed a grounded theory approach formalized by Glaser and Strauss (1967) and recently elaborated by Corbin (Corbin and Strauss, 2008) to analyze the data. This approach involves comparing and contrasting the data with the researcher's evolving theory throughout the data collection and analysis process. The researcher's evolving theory directs her attention to important dimensions that have been identified through the initial research and the data simultaneously focuses attention on how well the evolving theory explains the most recently collected data (Isabella, 1990). The iterative movement between theory and data results in re-conceptualization, which should account for the nuances in the data. This re-conceptualization is often based on a creative leap (Isabella, 1990).

In accordance with my grounded theory approach, my study progressed through a process of iterative cycles of data collection, data analysis, conceptualization and literature review. Each iteration was influenced by, and built upon, previous iterations such that my question, focal groups and conceptual models were refined as the study progressed. I constantly compared my evolving theory with new data, and allowed the theory to suggest additional data collection. After attending conferences, I wrote memos and drew diagrams to reflect my understanding. I discussed my ideas with academic colleagues and attendees at subsequent conferences, where I used my diagrams as an entry to informal interviews (Meyer, 1991). A simplified depiction of my process and the evolution of my theory in shown in Figure 1.

Figure 1: Data Collection and Analysis Process



Initial Impressions—Participant Observation

The process of evolving theory in this dissertation began with my field observations at a conference I attended as a research assistant. After the conference, I conducted broad review of the literature. I then returned to the conference the next year, I took notes of the facts, details, and frequently reported information and concerns of individuals at the conferences. This frequently repeated information augmented my evolving theory and provided the basis for general research question, research approach and initial categories (Van Maanen, 1983; Isabella, 1990).

Individuals with whom I spoke at the IBF Nanotechnology Investing Forum claimed to be making strategic decisions and taking action to influence the development of nanotechnology business. I also observed many heated discussions about how the nanotechnology "space" (a word used by the participants) should be characterized. Participants debated whether nanotechnology was an industry, a science project, an enabling technology, or an investment space. They also discussed the likely impact of public perceptions of these characterizations, public concerns about nanotechnology health and safety risks, and the possibility that "nanohype" would lead to a backlash and reduction in public support. These observations and the literature suggested my initial theory, that individuals acting strategically can influence the emergence of commercial activity and that technology frames are a key aspect of the process. This theory and the literature suggested the initial categories: key events, social groups, problems and solutions. As I collected data, I compared it with my theory and sought to identify themes. I discussed my impressions with academic colleagues and conference participants and my ideas evolved to account for the data.

After formulating my general research question, the data collection and analysis occurred in three phases. In the first phase, I collected and analyzed data on the encompassing case, at the level of the emerging nanotechnology domain. The units of analyses include organizations involved in building the space and their characterizations or frames for nanotechnology. In the second phase, I focused on the embedded cases, the VC firms. The units of analyses include the histories, actions and rationales of the individual founders and the strategies and actions of the VC firms. In the third phase, I considered the larger and embedded cases together. I sought to identify thematic concepts that could provide a theoretical explanation for the patterns that I observed in the data. The units of analyses included persistent themes and participants' perceptions of outcomes and causal attributions.

Phase 1—Exploratory Research

In phase 1 of this study, I collected newspaper articles, trade and proprietary reports and attended the 2003 IBF Nanotechnology Investing Forum. I used these data to construct timeline of events (Langly, 1999; Chiles, Meyer, and Hench, 2004). I identified key events in news reports and organized them in a timeline to depict the history and development of nanotechnology. In keeping with the interpretive assumptions that guide this study, I identified as "key events," events that were mentioned in multiple sources, events that continued to be mentioned over time and events that were specifically described as milestones in reports. For example, a brief description of the discovery of the Buckyball—a spherical molecular cage assembled from carbon atoms—is included in most early articles.

Next, I conducted a qualitative analysis of the content of the *New York Times* articles. I used NVivo qualitative analysis software to systematically code the articles. I began by coding at the level of the article as a whole. I created an attribute table within NVivo showing the title and date of each article, the section of the newspaper in which it appeared (for example, business-financial, metropolitan, science), the word used for nanotechnology (e.g. Buckyballs, "nanotechnology," nano-technology), and the general topic. I recorded the title, date, sections, and word used for nanotechnology as they were listed in the articles. I generated the codes for themes through a process of emergent coding. I identified 35 initial themes, which I grouped into the final 8 coding categories shown in Table 4.

I used this table to identify temporal phases in the timeline, separated by breakpoints (Langly, 1999; Chiles, Meyer, and Hench, 2004). These breakpoints were based on the annual number of articles on nanotechnology in the *New York Times* and the main topic of each article. I identified four temporal phases, separated by breakpoints based on jumps in the number of articles and shifts in the topics: research and discovery, introduction of nanotechnology, applications and implications and nanousiness. The findings from this analysis with examples of the data are described in Chapter V.

Then, I conducted a qualitative analysis of the content of text within the articles. Again, using NVivo and a process of emergent coding, I began by identifying social groups, problems and solutions mentioned in the text (Bijker, 1987; 1995; Pinch and

Bijker, 1987; Maguire, 2004). I identified a total of 1127 individual segments of text, selected as "free nodes," meaning that I selected the text and saved it using the first part of the segment as the name for the segment.

Table 4: Initial Categories and Codes

Initial Category	Final Code
Feasibility controversy	Protests/Concerns
Investment fraud	
Over hype	
Environmental health and safety	
Prey	Science Fiction
Books I read	
Meeting	Science/Scientists
Profile	
Image of science	
Nobel prize	
Development of nano	
Buckyballs	Term for nanotechnology
Nanotechnology	
"nanotechnology"	
Nanotubes, nano-composite, etc.	
Nanosystems	
Nanophase	
Nano-technology	
Research Report	Breakthrough or finding
Product or application	
Research near application	
Intel	Business and Finance
HP	
IBM	
Sandia	
	Government spending
Song or fiction	Peripheral
Wedding or obituary	

Thus, each segment initially had its own name. I then grouped these segments into categories allowing the categories to emerge and evolve as I went through the data. I coded the text segments into 123 categories and then, working between my emerging codes and the text, I grouped the text into the final codes. Table 5 shows examples of the initial categories and final codes for Phase 1 (Isabella, 1990).

Table 5: Phase 1 Categories and Codes

Initial Category	Initial Codes	Final Codes
Problem		Public perception
	Evil uses	Threat to health and safety
	Health risks	
	Social Implications	
	Unknown risk	Barrier to R&D
	Inadequate control	
		Barrier to Bus Dev
Social Group	Experts	Experts
	Start-up	Start-up
	Government Rep	Government
	Government Scientist	
	Foresight	Futurist
	IMM	
	Trade publication	Trade and Industry
	Trade group	
	Industry	
Solution	Increase regulation	Regulation
	Limit R&D	
	More research	Increase Research
	Research risks	
	Dev bus infrastructure	Develop infrastructure
	Reduce research cost	
	Educate public	Manage Perception
	No Problem	

I then used NVivo's analysis tools to identify links between the social groups and problems and solutions. I conducted a proximity search to identify problems and solutions discussed in the same paragraph as social groups. I reviewed each of these paragraphs and then created visual maps diagramming the connections. Graphic representations of data are useful for the analysis of process data because they allow the simultaneous representation of multiple dimensions (Meyer, 1991; Langley, 1999). An example of a diagram that assisted my analysis is shown in Appendix B.

I created visual maps for each of the temporal periods and used these maps to get a sense of how nanotechnology was portrayed over time and who was associated with each portrayal. Working iteratively between my timeline, diagrams, tables, coded segments of text and evolving conceptualizations, I traced emergence and evolution of nanotechnology technology frames across the temporal phases that I identified in my earlier analysis. The decomposition of data into adjacent phases separated by breakpoints facilitates the analysis of processes in a sequential fashion by allowing one to examine how actions and context change and influence each other across phases (Langley, 1999). The findings of this analysis are described in Chapter V.

Phase 1 of my analysis allowed me to gain overall understanding of the case and the subunits within in it. I sought to understand what was happening, who was involved, and what they were doing. This analysis provided a grounded basis for the identification of the embedded units within the larger case.

Phase 2—Technology Framing by Nanotechnology VCs

Phase two of my analysis focuses on the embedded cases, the focal VCs and the media, research and political organizations they founded. I sought to identify the VCs' actions and understand the rationales behind them. The units of analyses included the actions, "strategic tactics," and stated rationales of the participants.

I began my analysis of the embedded cases by constructing a timeline of key events and actions for each VC based on participant observation and the VCs' current web sites. I read my notes and printed the web sites and highlighted key events and actions to construct a visual timeline. Again, I selected as key those events that were mentioned frequently or given described as key or a milestone on the websites. This provided me with an overall understanding of the three cases. This analysis guided my construction of a protocol for semi-structured interviews. I continued to fill in details in the timeline and narrative as I moved to systematic coding of the interviews, VC web sites and conference presentations.

Next, I turned to my semi-structured interview and web archive data. To develop a rich sense of the strategies and tactics of the VCs and how they unfolded over time, I systematically reviewed the interviews, conference presentations and web archive pages. I began with the notion of "strategic tactic," from the literature (Fligstein, 1997) as part of my guiding framework (Miles and Huberman, 1994). Using "open coding," in Atlas.ti—selecting quotations with out assigning a particular code—I marked text describing actions and decisions as quotations (Muhr, 2004; Sheon, 2007). Then, I used Atlas.ti's network view function to view the selected quotations and sort them into similar "piles" (Sheon, 2007). The network view allows a researcher to view the selected text on an "index card." The researcher can move the index cards on the screen and draw links between them to construct a network diagram. By selecting a particular card, the researcher can view the selected text in the larger document from which it was pulled. This mode of analysis allows the researcher to view the piles in a list to determine if any segments do not fit and move them to different piles. These piles became the categories of activities and themes that form the basis of a descriptive model, which I will present and elaborate on in Chapter VI. The categories and themes are shown in Table 6.

Table 6: Phase 2 Categories of Themes and Activities

Preliminary categories	First order categories	Examples	Second order categories
Nature of Nanotech	Unknown field	In the micro technology world…most people didn't know anything about it.	Niche-space
	Definition war	You get people talking about what's nanotechnology, microtechnology its like a holy war.	
	Industry vs. tech	It is a common industry. Its just an enabling technology.	
Rationale	Be at the center	It is public and actual perception of us being at the epicenter of everything going on in nanotechnology.	Positioning
Actions	Launched and founded entities	When NanoTech was founded… we were looking to focus… one of the ideas that we had was there needed to be a leading media outlet.	Constructing
	Help people understand	It was more of an educational message…So this is what nanotechnology is and this is where its getting applied.	Translating
Benefits	Credibility	They could walk into a room of investors or meet with startups and have instant credibility.	Symbolic Resources
	Exposure	[The] exposure that came attracts a lot of entrepreneurs and people to you.	
	Opened doors	Well the benefit…was it opened a lot of doors for them.	
	Raising money	And from a raising money standpoint focusing on nanotechnology proves to be a fairly big advantage.	Substantive Resources
	Deal flow	They attracted all the deal flow.	
	Information/ knowledge	[One of] the benefits of what we did is we still know more about small tech than probably anybody around.	

I crosschecked my understanding against reports in the electronic media, highlighting and annotating text using Scrapbook tools. Scrapbook is an add-on program for the Mozilla Firefox search engine. It allows for the download and storage of individual web pages as well as complete websites. Scrapbook also allows one to search, highlight and annotate text. Scrapbook does not have sophisticated tools for searching and retrieving coded text. I chose to store and review the electronic articles in Scrapbook because the program allowed me to deal directly with the WebPages without converting them to PDFs or text documents. This retained the actual presentation of the information and allowed for much more efficient reviewing of the documents as I could use the original hyper-links saved in Scrapbook. Because I did not code these documents as intensively as the interviews and conference presentations, I determined that the benefits of viewing the original presentation and traveling efficiently through the sites outweighed the better search and retrieval functions of qualitative analysis software.

Through Phase 2 of my analysis, I sought to identify the actions of the focal VCs and the rationales behind them. I identified three activities based on my categorization. These activities form the basis for the descriptive model I discuss in Chapter VI.

Phase 3—A Process Model of Technology Frame Projection

Phase three of my analysis focuses on the data and cases as a whole. I sought to understand the participants' perceptions of the outcomes of their actions and to develop a theoretical explanation of the data. The units of analyses included the outcomes and causal linkages as perceived by the participants.

I reviewed all of my notes, memos and draft conceptual models. I identified persistent themes in my understanding. I wrote memos on these themes and checked my understanding with academic colleagues. I returned to the Atlas.ti database and reviewed my pile sort. I marked additional text describing participants' motivations, explanations and perceptions of causal influences. I then worked back and forth between the data, my memos, my descriptive model, and the literature to explain the data (Eisenhardt, 1989; Glaser & Strauss, 1967). The resulting model and examples of the supporting text segments are displayed and discussed in Chapter VI.

As described above, my grounded theory approach involved constant comparing and contrasting of the data with my evolving theory throughout the data collection and analysis process. This iterative movement between theory and data resulted in the findings I describe in Chapters V and VI of this dissertation. Single cases and a grounded theory approach often provide rich descriptions, useful for future comparisons, and context-sensitive theoretical explanations (Dyer and Wilkens, 1991). However, as discussed below, this approach has limitations.

Limitations and Threats to Validity

A principal limitation of this research design is its reliance on a single case. Organizational researchers have debated the value of single versus multiple case studies for theory building, and have made strong arguments in favor of each (Dyer & Wilkins, 1991; Eisenhardt, 1989). However, single case research has long been considered an acceptable research approach in the social sciences and is accepted as particularly valuable for gaining in-depth understanding of unique and/or little understood phenomena (Yin, 1984; Dyer and Wilkins, 1991). An analysis of a single case cannot confirm or disconfirm causal relationships and the findings are not generalizable to a larger population. Rather, single-case studies provide fertile ground for extending and building theory (Yin, 1984). Thus, cases should be selected so as to generalize to theoretical propositions rather than populations (Yin, 1984). Thus, the emergence of nanotechnology is not a representation of similar cases, but rather an extreme case likely to illuminate our theories of how technologies emerge.

Validity in qualitative research corresponds to the question "How can an inquirer persuade his or her audiences that the research findings…are worth paying attention to?" (Lincoln and Guba, 1985: 290). To provide a check on the reliability of this study, I rely on triangulation. I triangulate data obtained from my observations, interviews, Internet sources and journalistic media. I include in my report the data that were corroborated across sources. Additionally I triangulate across time periods by comparing accounts from early web pages with later accounts given in the interviews I conducted, in conference presentations and in interviews in the journalistic press. Throughout my analysis, I rely on the constant comparative method. This method provides validity checks as new data are integrated into the emerging categories. When new data conflicted with my conceptualizations or offered additional insights, I modified my developing theory to incorporate them. I repeat this process until I achieve theoretical saturation (Glaser and Strauss, 1967).

This chapter builds from the assumptions and definitions derived from the literature and detailed in the previous chapter. The setting of this study is well suited for a study of the emergence of a science-based technology. My grounded theory approach is consistent with the setting, question and similar research. While a single case design has some inherent limitations, the wide array of data collected and analyzed for this study serves to mitigate the limitations to the extent possible.

CHAPTER IV

EMPIRICAL CONTEXT

Overview

In the previous chapter, I described the research design for this dissertation. This dissertation is a qualitative study, with an embedded, single case design, set in the context of the emerging nanotechnology domain. As I explained in the previous chapter, the nanotechnology domain is a setting well suited for this study. The literature suggests that framing in general is a driving component of political debates such as those surrounding the emergence of nanotechnology and technology framing, in particular, is likely to be most evident when a new technology emerges (Bijker and Pinch, 1987; Orlikowski and Gash, 1994; Fulk, 1993). In this chapter, I describe the empirical context of this dissertation including the larger setting of the nanotechnology domain and the three organizations that are the focus of the embedded cases.

I begin by restating a definition of nanotechnology. Next, I describe the development of nanotechnology over time and present a timeline of key events. I constructed the timeline from trade publications and proprietary reports. I collected additional data and checked this timeline against reports in the general press and in my interviews. In keeping with the constructivist assumption that knowledge of a situation accumulates as agents' interact with and make sense of a context (Weick, 1979), I identified as "key" those events that were mentioned in multiple sources, events that continued to be mentioned over time, and events that were described as milestones in accounts. For example, a brief description of the discovery of the Buckyball, a spherical molecular cage assembled from carbon atoms, is included in many early articles and I thus, selected this discovery as a key event. Additional examples of frequently mentioned events include the discovery of a method for mass-producing Buckyballs, the invention of the scanning tunneling microscope—which can image and manipulate the height of individual atoms—and the passage of the $422 million National Nanotechnology Initiative.

I conclude this chapter by describing the role of venture capital in the emerging nanotechnology domain and the three VC organizations that became focal cases of this study. I selected the three organizations that are the focus of the embedded cases because they were identified as playing a key role in the development of the nanotechnology business community in their own WebPages and my interviews with them, in general press reports, and by other members of the community. I generated descriptions of the focal organizations by collecting stories about them from my interviews and in their WebPages. I checked these stories with other members of the community and against accounts in the general press.

The Nanotechnology Domain

The setting for this study is the emerging nanotechnology domain. Nanotechnology is the study (sometimes referred to separately as nanoscience) and output of the control of matter on an atomic and molecular scale, at dimensions of between 1 and 100 nanometers. A nanometer is one billionth of a meter, which is about the width of three or four atoms. By comparison, a sheet of paper is about 100,000 nanometers thick (NNI, 2009), a human hair is about 25, 000 nanometers wide (Center for Responsible Nanotechnology, 2009). A man's beard grows a nanometer in the time it takes to lift a razor to his face (Kahn, 2006).

Size matters because matter behaves differently at the nanoscale. Unusual chemical, biological, and physical properties that differ from the properties of single atoms may emerge. For example, calcium carbonate molecules arranged in a sawtooth pattern form chalk, whereas the same material stacked like bricks forms the shiny shell of abalones (Kahn, 2006).

These properties and the ability to manipulate the construction of matter suggest dramatic and wide-ranging applications. Nanotechnology promises economic and societal impacts likely to exceed those of comparable discoveries such as plastics and biotechnology. For instance, "Merely sprinkling carbon nanotubes into epoxy strengthens the glue by more than 30 percent" and scientists are actively researching medical applications to detect and eliminate cancerous cells (Kahn, 2006). The National Science Foundation estimated in 2000 that the market for nanotechnology products will be over one trillion dollars by 2015 and that the industry will employ over 250 million workers (NSF, 2001). While the commercial development of nanotechnologies and their diffusion into many sectors seems certain at the present time, the path to this point has involved contentious positioning and discussion among government, investment, commercial, and opposition communities.

Chronology of Events

A timeline showing key events in the early development of nanotechnology is shown in Figure 2 and discussed in this chapter.

The term nanotechnology was first suggested by Norio Tanguchi of the Tokyo University of Science to describe technology that strives for precision at the level of one nanometer, or a billionth of a meter. While the term did not originate until 1974, credit for inspiring nanotechnology is generally attributed to a lecture given by Richard Feyman in 1959, titled "*There's Plenty of Room at the Bottom.*" In this lecture, Feyman proposed the possibility of maneuvering matter atom by atom and suggested research to make computers smaller and to create mechanical surgeons that could travel to trouble spots in the body. Feyman offered two prizes to get things started: $1000 to the first person to make a working electric motor that was no bigger that one sixty-forth of an inch on any side, and another $1000 to the first person to shrink a page of text to 1/25,000 its size. The first prize was awarded in 1960 and the second in 1985 (Keiper, 2003).

Feyman's ideas have blossomed into the growing nanotechnology domain. Growth in nanotechnology was spurred by research discoveries such as the discovery of Buckyballs in 1985 and the ability to mass produce them in 1990; supporting inventions such as the scanning tunneling microscope, which can detect and manipulate the height of

Figure 2: Timeline of Events

1959

1959-Feyman introduces nanotechnology

1981-Scanning tunneling microscope invented

1985-Bucky Balls discovered

1986-Atomic force microscope invented

1986-Drexler publishes Engines of Creation and founds Foresight Institute

1990-Bucky Balls mass produced

1991-Carbon nanotubes discoverd

1996-Smalley & Curl win Nobel Prize

2001-NNI passed

2001-NbA founded

2002-Prey published

2002-*Small Times* founded

2002-ETC calls for moratorium

2003-Greenpeace publishes report on risks of nanotechnology

2003-21st Century Nanotechnology Reserch and Development Act passed w/o molecular manufacturing

2004-Berkeley protest

2006-total private investment reaches $9.6 billion

2009-proposed NNI budget for FY 2010 is $1.64 billion

2009

Total market for nanotech products estimated to be $1 trillion by 2015 individual atoms; public funding, such as the passage in 2001, of the $422 million National Nanotechnology Initiative and, in 2003, of the $3.63 billion 21st Century Nanotechnology Research and Development Act; and private venture capital investment, which rose from one investment of $3.3 million in 1998 to estimated investments of $650 million in 2006 (Lux Research, 2006).

Growth in the nanotechnology field resulted in increased visibility and public opposition. Organized opposition emerged in 2002 with a call for a moratorium on the commercial production of nanomaterials by the ETC group, a self-proclaimed technology watchdog. In 2004, there were three protests. Berkeley residents concerned about the potential release of nanoparticles from the Lawrence Berkely National Laboratory, Topless Humans Organized for Natural Genetics (THONG), and The Heavenly Righteous Opposed to Nanotech Greed (THRONG) gained attention for their protests against nanotechnology. Supporters of nanotechnology recognized that public concerns posed a threat to the emerging technology. Mark Modzelewski, executive director of the Nanobusiness Alliance (NbA) announced the creation of a group devoted to dealing with safety concerns and expressed hopes that the new group could dispel some of the fears prompted by the media attention.

As competition to define nanotechnology increased, proponents of a "mainstream" definition framed nanotechnology as an extension of ongoing miniaturization, which would result in improvements to existing products. This conception was at odds with the vision introduced by Eric Drexler (the first scientist to receive a PhD in nanotechnology and author of the first comprehensive texts about nanotechnology), which includes "molecular manufacturing" and self-replicating machines that might be able to manufacture anything manufactured by traditional processes at drastically reduced cost and improved performance. The so-called mainstream and more radical views were contrasted in press accounts:

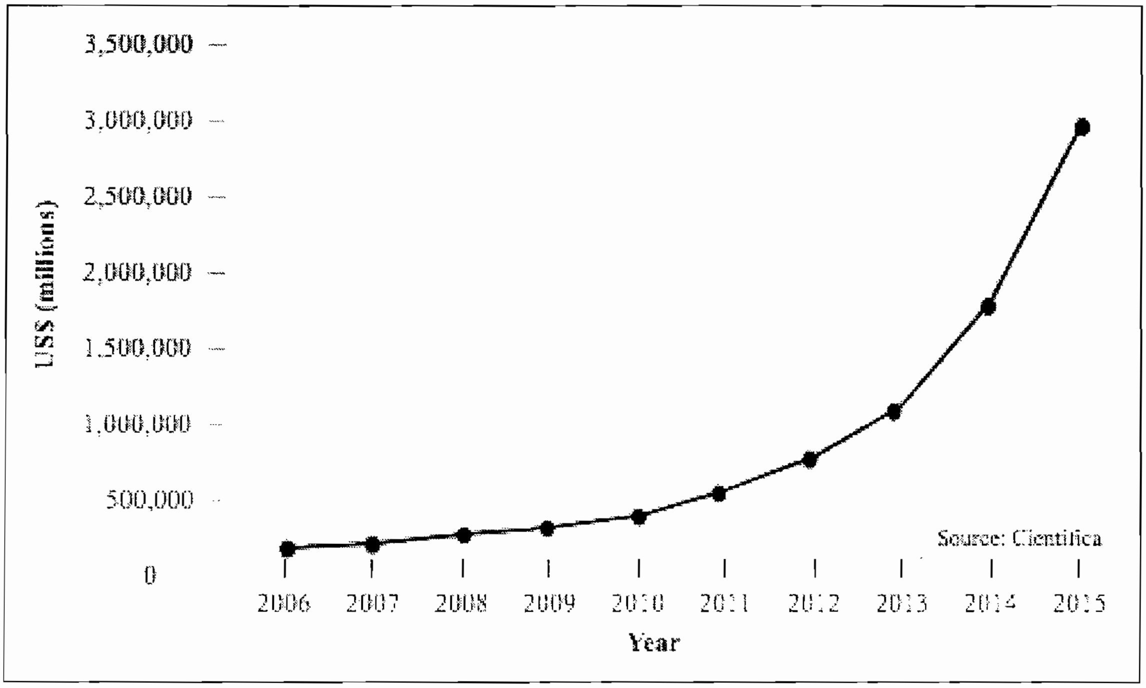
> "Mainstream nanotechnology will soon be used by cosmetics companies to help their current products…last longer and work better. But if Drexler's version of nanotechnology were to come to fruition…nanomachines could precisely adjust your hair and skin color to your liking; wrinkles could be smoothed and excess fat removed" (Keiper, 2003).

Proponents of the mainstream definition won a victory when they argued successfully that a feasibility study of the more radical molecular manufacturing and self-replicating machines, which were featured in Michael Crichton's *Prey,* be removed from the House version of the Nanotech Act of 2003 (Lovey, 2004).

Nanobusiness has become a recognized area of commercial activity. In 2007, Cientifica, a European research and consulting firm specializing in nanotechnology, confirmed that the NFS's estimate of a one trillion dollar market by 2015 is likely accurate and may even underestimate the size of the future market for nanotechnology products (see Figure 3). Government and public investment in nanotechnologies continues to grow.

The proposed National Nanotechnology Initiative budget for the fiscal year 2010 is $1.64 billion and will bring the cumulative investment to nearly $12 billion (NNI, 2009). Recognizing the public concerns that emerged in 2002, in 2005 NNI began investing in research on environmental health and safety and in education and research on ethical, legal and societal implications. Investments in research in these areas now total over $350 million and $220 million, respectively.

Figure 3: Growth in Global Nanotechnology Market



These investments support a desire of nanobusiness and government interests to prevent public fears from slowing commercial development. Reflecting this interest, a NNI brochure describes the risks of nanotechnology and the benefits of research into such risks:

> Knowledge...can guide researchers and engineers in creating handling and disposal guidelines...[and] can help them to avoid using certain materials in products or to modify the materials to make them safe. Researchers have found, for instance, that special coatings can make potentially hazardous nanoscale materials safe for use.
>
> Risk, according to experts, involves two factors--hazard and exposure. If there is no exposure, even a hazardous material does not pose a risk...The National Institute of Occupational Health and Safety has recommended that employers take appropriate precautionary measures for handling new

> materials—including engineering controls, administrative controls, and personal protective equipment--to avoid worker exposure to nanoscale materials (NNI, Big Things From a Tiny World, 2009).

These efforts, along with the emergence of businesses and products, seem to have shifted public discussion away from regulation specific to nanotechnology towards risk management.

Likewise, private investment in nanotechnology is growing. Private investment in nanotechnology is dominated by large global corporations, which had invested more than $6.6 billion on nanotechnology R&D as of 2006 (Lux Research, 2006). Venture capital has also contributed to growth in the nanotechnology field, investing $650 million in 2006. bringing the cumulative total of VC investment to $3 billion.

Research and investment in nanotechnology have resulted in actual businesses and products. By 2006, 18 VC-backed nanotech startups achieved successful exits through acquisition or IPO (Lux Research, 2006). Products using nanoscale materials and processes that are now available include: anti-bacterial wound dressings using nanoscale silver; a nanoscale dry powder can neutralize gas and liquid toxins in chemical spills; batteries for tools to deliver more power, more quickly, with less heat; sunscreens containing transparent nanoscale titanium dioxide or zinc oxide; and eyeglasses, windows, and car mirrors with scratch and glare-resistant coatings (NNI, 2009).

The Role of Venture Capital

It is widely accepted that collective action is necessary to capitalize on opportunities inherent in new technologies (Aldrich & Fiol, 1994, Rao, Morrill, and, Zald, 2000; Dowell, Swaminathan, and Wade, 2002). Founders of a technology domain must act collectively to reduce uncertainty, develop an institutional environment and generate social acceptance (Shane and Venkataraman, 2003). In the case of nanotechnology, VC firms were the first to undertake collective activities to support the commercialization of nanotechnology.

Venture capital (VC) is a specialized source of financing generally focused on young, growth-oriented companies (Hellmann, 2000). VCs are professional fund managers who invest on behalf of other investors. They raise funds from wealthy individuals, insurance companies, pension funds and other investors who seek to invest in entrepreneurial start-ups, but lack the necessary expertise (Gaba and Meyer, 2008). After raising funds, VCs invest in companies that they select, nurture and sell. VCs consider a potential prospect's business plan, intellectual property, and management team and often become actively engaged in building the companies they select for investment. Venture returns are realized when a VC backed start-up is acquired by an established corporation or through an initial stock offering (IPO). An IPO is the preferred outcome as it achieves the highest valuation for the start-up and provides liquidity to the investors (Gompers and Lerner, 2001).

A large VC firm may have several funds at different stages. The funds are managed as separate entities and can be equated to business units within a corporation. Each fund has a stated lifetime, typically 10 years, and is liquidated after that period so that investors can receive returns. The limited partners who invest into the fund typically contribute 99% of the capital and the VCs contribute about 1%. VC firms charge a management fee of approximately 2% to 3 % annually. If capital gains are realized, they are typically divided 80% to the limited partners and 20% to the VC firm.

VCs invest predominately in technology-focused industries such as computers, semiconductors and biotechnology (Hellmann, 2000). Because investments are typically early stage, they are often very risky. VCs try to minimize their risks by spreading investing among a portfolio of companies, co-investing with other funds, managing many funds simultaneously and collecting market intelligence (North American Venture Capital Association, 2003).

Start-up firms require different levels of funding depending upon their stage of development. Contrary to popular perception, venture capital plays only a limited role in funding the earliest stages. The range of funding provided by VC firms includes (Runhka and Young, 1987):

- Seed capital—investment in a company with a concept but no commercial production, activities may include research and product development.
- Early stage or start-up capital—investment in companies that have developed a specified product, activities may include initial marketing, manufacturing and sales efforts.
- First round capital—investment in companies with products in development or commercially available, the total size of this first round is usually not less than $5 million.
- Second round capital—investment made in a company that is producing inventories and has growing accounts receivable, the funds are used for working capital for expansion.
- Third round—investment provided for major growth expansion of a company with increasing sales volume which is breaking even or close to it, activities include marketing and development of improved or additional products
- Later stage capital--investment in an established start-up that is producing and shipping product and increasing its sales volume.

Although VCs do invest in each of the above stages, much VC investment is made at the first round, rather than the seed or start-up stage. The majority of VC investment does not fund research and innovation but goes to "follow-on funding for projects originally developed through the far greater expenditures of governments and corporations" (Zider, 1998: 132).

This general trend is evident in nanotechnology, where government and large corporations have provided the majority of research and seed funding. However, it was VC firms that made the first efforts to create a business infrastructure to support the commercialization of nanotechnology. VC firms founded and served on the board of the first nanotechnology trade association. They established, sponsored, and distributed newsletters and trade journals, spoke frequently at conferences and government hearings, and undertook significant efforts to educate government and business leaders. Berube (2006: 243) refers to VCs as the pioneers of nanotechnology and concludes his description of the nanotechnology industry, "The quest for economic dominance in nanotechnology is being led by the pioneers."

Participant Observation Site

My data collection began at a conference sponsored by International Business Forums (IBF). International Business Forums is a private firm that produces upscale financial and business conferences on venture capital, private equity investing, corporate finance, mergers and acquisitions, corporate strategic investing, and related topics. IBF promises to provide its attendees with leading-edge information and new business contacts to achieve business objectives. In 2002, IBF introduced what is recognized as the first nanotechnology investing conference in the United States.

IBF launched the Nanotech Investing Forum in 2002, in the wake of the dotcom investing collapse. Venture investment in nanotechnology was increasing rapidly, triggering the formation of a new community comprised of technology entrepreneurs, academic researchers, federal scientists and administrators, venture capital funds, professional associations, university technology transfer professionals, and others. One informant likened the 2002 conference to California's 1849 Gold Rush: "You've got prospectors staking claims, rapacious mine owners, suppliers of services and equipment (think Levi-Strauss), and a throng of camp followers." Traditional VCs were exploring the nanotech space, brand new nanotech venture funds were being raised, and nano-focused industry associations were forming and vying for dominance. The questions "What is nanotech?" and "What is not nanotech?" spurred often-heated informal conversation and were included topics on conference's formal program. This debate lasted for several years and then subsided, as attention shifted to showcasing actual applications of technologies. Although the nanotech conference flourished after the bust of the dotcom bubble, it was restructured and downsized to a 2-hour workshop held between other investment-focused conferences in 2009.

Focal Cases

In this study, I focus on the efforts of three VC firms that claim to be, and were recognized as being, particularly active in attempting to create a commercial domain for nanotechnology. Each of these VCs was active at the IBF conference as sponsors, speakers or session chairs. Each was recognized by other participants as playing a key role in the development of nanotechnology investing. Key characteristics of these three firms are their focus on nanotechnology, their engagement in very early investing activity, their relative small size and lack of status, and their intent to use their focus on nanotechnology to ameliorate their relatively weak position in the VC marketplace.

The three VC firms that are the focal cases of this study were the only national VC firms specializing in nanotechnology in 2000. They were each were identified by field participants as actively engaging in public efforts to promote nanobusiness. The firms were sponsors, speakers, or chairs of the first nanotechnology investing conference held in 2002. Two of the firms were identified and described as focal nanotechnology entrepreneurs by David Berube in his 2002 book about nanotechnology. Additionally, individually or in partnership, the three were responsible for founding of the first nanotechnology trade association, the first nanotechnology trade magazine, the first nanotechnology report for corporations, the largest nanotechnology investing newsletter, and undertaking some of the first VC investments in nanotechnology.

In general, the investments made early in the life-cycle of a start-up are more risky than later stage investments due to the unproven nature of the business idea and the time required to bring a product or service to market. As explained above, many investors, including VCs, avoid investing in start-ups that are still refining their business plans. Funding at the earliest stages is typically provided by family and friends, government programs, business competitions, and angel investors. In contrast, the three focal VCs of this study claim to be unique because they become involved at the very early stages of start-up development as indicated on one firm's 2002 website:

> [We] believe the most innovative venture opportunities will emerge from centers of intensive research, particularly top engineering and computer science programs. With relationships at over 25 leading research-driven universities since inception, [we] are the forerunner to this new model of technology creation and development. [Our] university network includes top faculty, researchers and PhDs at the nation's top Computer Science and Engineering schools and research labs…[our firm] has positioned itself as the premier early-stage financier of nanotechnology ventures.

Two of the three firms devoted considerable time to making connections with university scientists, while the other hired science PhD's in order to identify and assess very early ventures.

An additional characteristic of each of the three firms is their relative small size and status and their intention to use nanotechnology to differentiate themselves. This intention is evident in the excerpt from the website above and also in the explanation of one firm's decision to focus on nanotechnology during an interview with the author "it [our focus] afforded us a brand differentiating strategy."

Two of the focal VCs were recent start-ups themselves, the third had recently refocused on nanotechnology. Each had only one or two funds of approximately $100 million. In 2000, two had made less than a dozen investments in nanotechnology and one had yet to make any. In contrast, compare this with one of the larger firms involved in nanotechnology investing, Draper Fisher Jurvetson (DFJ). DFJ is active, but does not specialize in, nanotechnology. The firm has a 24-year history, manages over $6 billion, and has made more than 600 investments in technology companies.

Star Venture Capital

Several young entrepreneurs founded Star Venture Capital[1] in 2000, about a year after they earned undergraduate degrees. As explained by one of the founders:

> We've gone in 6 years from literally nothing like sleeping on the floor in New York City as we started the company to hiring 45 employees and have an 80 million dollar venture fund under management and I'm 30 years old and my partners are 28 and 29. So its been a ton of work for us. We've gone through some very challenging times over the years but I think we finally feel that we've graduated from high school and we're entering college and we have to prove that we can actually put some money to work and make money off of nanotechnology.

As is typical of many new ventures, the start-up VC firm was funded with under $100,000, from credit card debt and family contributions. The founders had no experience as venture capitalists and no status within the filed. One peer explained his initial perception the firm in an interview with the author:

> I remember making fun of them. I was looking at it [their report] and the first thing I did was I flipped to the people who had written it. I went to my partners and I was like look at these, these investment bankers. Their not technologists, their not VCs their not experienced with anything even closely related to anything. What morons right? And I wanted to say that because I have been so impressed with what they've done. Considering that they did start off as that. A peer group that was very skeptical of them…

Star Venture Capital's founders positioned their firm as the sole VC focusing on commercializing federally funded academic research. On their webpage in 2002, the founders described their firm as follows:

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[1] To protect the confidentiality of the participants in this study, the names of the firms are pseudonyms and direct quotations have been revised if necessary to protect the identity of the firms.

> Star believes the most innovative venture opportunities will emerge from centers of intensive research, particularly top engineering and computer science programs. With relationships at over 25 leading research-driven universities since inception, Star is the forerunner to this new model of technology creation and development. Star's university network includes top faculty, researchers and PhDs at the nation's top Computer Science and Engineering schools and research labs. Star has targeted industries gaining traction due to an influx of capital and resources from academic and government research funding. DARPA funding was instrumental in creating the Internet industry. NIH funding helped build the Biotechnology industry. Star believes the same trend exists with the government's $1 billion R&D expenditures to the Nanotechnology industry in the past two years. Star has positioned itself as the premier early-stage financier of nanotechnology ventures.

The young entrepreneurs attracted the support and attention of an experienced private investor who provided strategic guidance and bankrolled their first fund. They used this fund to make investments of up to $2 million each in six startups. Their 2005 website listed many "firsts:"

> Star Capital is credited with introducing the first investment framework for nanotechnology adopted by other venture capital funds and top-tier Wall Street investment banks. Some other Star "firsts":
>
> - First to discover and publish on nanotechnology investing
> - First to introduce nanotechnology to Wall Street (Merrill Lynch, Credit Suisse, First Boston)
> - First to found political industry association on nanotechnology
> - First to launch nanotech investment publication [with prominent national publisher]
> - First to be invited by the President to the White House's Oval Office to represent nanotech investors

By 2009, the founders had successfully raised their second $100 million fund and made investments in over 20 companies.

NanoTech Investing

Experienced VCs, including an entrepreneur who made a personal fortune as the president of a computer industry startup, founded NanoTech Investing in October of 2000 after raising and investing a separate fund that was not focused on nanotechnology. As explained by one of the founders in an interview with the author:

> I think that the original concept was there's a new industry and there was an opportunity to be the glue for the industry. To be the party in the middle that was able to take, was able to create the bridge between research and finished products. And it could be through intellectual property, it could be the gathering of intellectual property it could be through the creation of standards, it could be through the creation of manufacturing techniques there were a lot of ways to bring value in that chain that you know in between research and finished product. And basically as a company we could choose where in that chain we wanted to play and we could fill in that role.

The VC firm began with a $100 million fund backed by a group of high profile investors. NanoTech planned to invest in start-up and early-stage companies working with microelectromechanical systems technology. The firm's stated intention was to become "an industry accelerator in the microsystems industry, combining traditional venture capital and commercial incubator capabilities with industry-building resources such as fabrication facilities and new trade publications." As explained to the author in an interview, "The primary function of Nanotech was to identify technology, in many cases coming out of universities, license it, support it long enough to be commercialize and either sell off or own the investment and make a return on their money." In 2001, NanoTech's webpage emphasized the firm's industry building role:

> NanoTech is more than just a company - we're igniting the future of small tech and microsystems. This enabling technology will change how we

> communicate, how we interact with the environment, and how we treat and prevent illnesses. We'll be the leader in bringing commercial small tech solutions to the global marketplace.
>
> Others may do similar things, but what makes NanoTech stand out is the one thing we do that others don't. NanoTech develops industry-building resources such as trade publications, web sites and trade shows. We're investing in an entire industry, not just one company.

NanoTech attempted and failed to generate enough investment for a new fund and as of 2009, had completed its investing activities. The firm's web page summarizes NanoTech's contribution to nanotechnology, emphasizing NanoTech's role in building a commercial domain for nanotechnology:

> Through its investment in Small Tech companies, NanoTech has become a leader in bringing Small Technology products to the global marketplace. NanoTech was formed in October 2000, when it raised almost $100 million in private funding. NanoTech had since established itself as the leader in commercializing Small Tech products. NanoTech served as the bridge between the universities/research laboratories involved in cutting edge basic research and the customers searching for product solutions that Small Tech can provide. In that role, NanoTech created five Small Tech start-up companies (many involving technology licensed from universities) and had invested in a number of early stage companies focusing on Small Tech's role in next generation products for the areas of Communications, Energy, Environmental Safety/Security, and Medical Diagnostics and Treatment.

T&T Group Investments

T&T Group was formed as an investment company in 1984 and made its first investment in nanotechnology in 1994. The founder explained the firms' transition to an emphasis on nanotech in an interview with the author as follows:

> In 1994, a firm called Venture Partners brought us a deal to look at that they had spun out of [a national lab]. And so we looked at it and quite frankly we had not really paid any attention to nanotechnology prior to this. We got intrigued we made the investment and at the end of the day

> we became the second largest shareholder…In the course of doing the due diligence on that I began to realize that nanotechnology was going to be an enormous scientific technological and commercial phenomenon in time. Ao, I looking at other nanotech deals whenever I could find one, but I couldn't really find any that weren't to science projects for a long time. And so, we didn't make another such investment, one that one might identify as a nanotechnology investment, until 2001. …In 2001, I felt or believed that I saw what I needed to see and since then we've never invested in anything else.

The firm described this decision on its website as follows:

> Although we are not restricting our small-tech investing to nanotechnology per se, we are inspired by the National Nanotechnology Initiative's plan, which envisions nanotechnology as "a revolution in the making! leading to the next industrial revolution," promising "to be a dominant force in our society in coming decades." We concluded earlier this year that if we wanted to specialize in small technology, we either had to take the risk of being too early or too late. We decided to take the risk of being too early. We decided that for us, as the President's Committee of Advisors on Science and Technology has stated, "now is the time to act."

Like the other two firms, T&T founders saw nanotech as an opportunity to position, and gain power for, their relatively small firm, as explained by the founder in an interview, "This focus gave us an identity. We have been able to emerge as a leader and as a result have a much more robust deal flow than a firm of our size could normally expect to enjoy."

In contrast to the other two VC firms T&T Group does not claim to be building the nanotechnology domain for their own benefits, but sees their efforts as a duty to stakeholders. The founder explained his perception of his firms' activities as follows:

> Well, I would say in a small way we think that part of our duty to our portfolio companies is to make sure that there is a healthy infrastructure out there for them… We feel that every industry or in this case every area needs trade publications. And so we think that part of our job is to lend some support…And we will speak on occasion at research universities that

> ask us to do that…support conferences about nanotechnology by giving some time to them. And these are to our minds normal good citizenship things that one does.

Despite this firms' more modest claim in regard to domain building activity, peers recognize the firms as a leader. The company's founder is recognized as "'one of the true investment sages of the nanotechnology business' known for 'opening up nanotech VC to the masses'" (Berube, 2002). The firm currently has over thirty nanotechnology companies in its portfolio and on its website claims to be, "one of the most active nanotechnology investors in the world."

The development of nanotechnology has a clear beginning and encompasses many small dramas, such as groundbreaking innovations and the passage of specific legislation, which may "provide a glimpse into the social system" at a particular time (Pettigrew, 1990: 275). The VC firms that are the embedded cases claim to have, and are credited as having, played a key role in the overall drama. The literature suggests that framing in general is a driving component of political debates, such as that surrounding the emergence of nanotechnology (Tushman and Rosenkopf, 1992; Fligstein, 2003). And, technology framing in particular is likely to be most evident when a new technology emerges (Bijker and Pinch, 1987; Orlikowski and Gash, 1994; Fulk, 1993). Thus, the emerging nanotechnology domain is a setting well suited to this study.

CHAPTER V

EXPLORATORY RESEARCH

Overview

In the preceding chapter, I described the setting for this study and the focal cases within it. In this chapter, I explore the emergence and evolution of a technology frame. The purpose of this chapter is twofold. I present and provide support for my argument that a nanobusiness frame emerges in the general press and that business leaders are widely attributed to play a leading role in projecting this frame. As explained in Chapter III, a grounded theory approach requires that data collection and analysis occur throughout the research process. Early analyses guide the collection of additional data, which are used to generate refined conceptualizations through a process of constant comparison of data and emerging theory. The findings presented in this chapter provide the grounded basis for the findings and conceptual models I present in Chapter VI.

In this chapter, I document the chronology of the development of nanotechnology over time and create a timeline of key events using trade publications and proprietary reports. Next, I analyze the portrayal of nanotechnology in the general press from the first mention in the *New York Times* to the present (1985-2009). I check the key events I identified from proprietary reports against the portrayals in the general press. I identify temporal periods that are separated by breakpoints. The breakpoints are based on the annual number of articles on nanotechnology in the *New York Times* and the main topic of each article. Then, using a process of emergent coding, I identify the elements of technology frames (Bijker, 1985) social groups, problems, and solutions. I map social groups, problems and solutions across the breakpoints and describe changes in the technology frame portrayed in the general press, represented by the *New York Times*. I find that business proponents are attributed with creating and projecting a nanobusiness frame. In keeping with a grounded theory approach, this analysis provides the basis for initial conceptualizations and the refinement of the sub-unit case boundaries and subsequent data collection and analyses.

Introduction

> And, you know, I've always said that I believe that we're gonna end up winnin' this battle for the hearts and minds of the public.
>
> *Nanotechnology Business Leader. Interviewed by author, 2006.*

I begin this analysis with the general question, How do scientific discoveries become the basis for commercial activity? My initial fieldwork and literature review suggest the importance of technology framing in this process. I begin by exploring 1) What happened, when? And, 2) Which social groups were associated with particular perspectives and initiatives? Based on the data, I divide the development of nanotechnology into four temporal periods. I find that a nanobusiness frame emerged in the third temporal period of my study. This period is characterized by competition between several technology frames. While it is too early in this ongoing process to make a definitive conclusion, the nanobusniess frame appears to have gained legitimacy and dominance over competing frames, as expressed in the above quote by a business leader in an interview with the author. The projection of this frame was attributed in press accounts to the actions of individuals and organizations representing business interests.

Temporal Periods in the Portrayal of Nanotechnology

This analysis builds upon the timeline I develop from trade and proprietary reports, shown in Chapter IV. My analysis shows that the development of nanotechnology as covered in the general media can be divided into four temporal periods. Articles about nanotechnology first appeared in the *New York Times* in 1985. A jump in the number of articles in 1991, 2000, and 2003 demarcates the periods. The number of articles per year and the average over each period are shown in Figure 4.

One article was published in 1990 and eight in 1991. The initial articles and the jump demarcate the borders of Period 1—1985 through 1990. The average number of articles per year during this period was 0.83. The next jump occurred between 1999 and 2000. Eight articles were published in 1999, jumping to 35 in 2000. This jump demarcates the border of Period 2—1991 through 1999—with an average of 7 articles per year. Between 2002 and 2003 the number of articles jumped from forty-nine to sixty-seven. This jump demarcates the border of Period 3—2000 through 2002—with an average of 38.7 articles per year. The number of articles peaked at 67 in 2003. This peak demarcates the border of Period 4. Period 4 is characterized by a tapering of the number of articles per year, with a noticeable drop from fifty-eight in 2007 to thirty six in 2008.

The breakpoints dividing the periods coincide with significant events identified as such in both the trade and general press; the discovery in 1985 of Buckyballs and in 1990 the ability to mass produce them, the passage of the National Nanotechnology Initiative in 2000, and the emergence of the first organized opposition to nanotechnology in 2002. In 1985, the *Times* reported the discovery of Buckyballs:

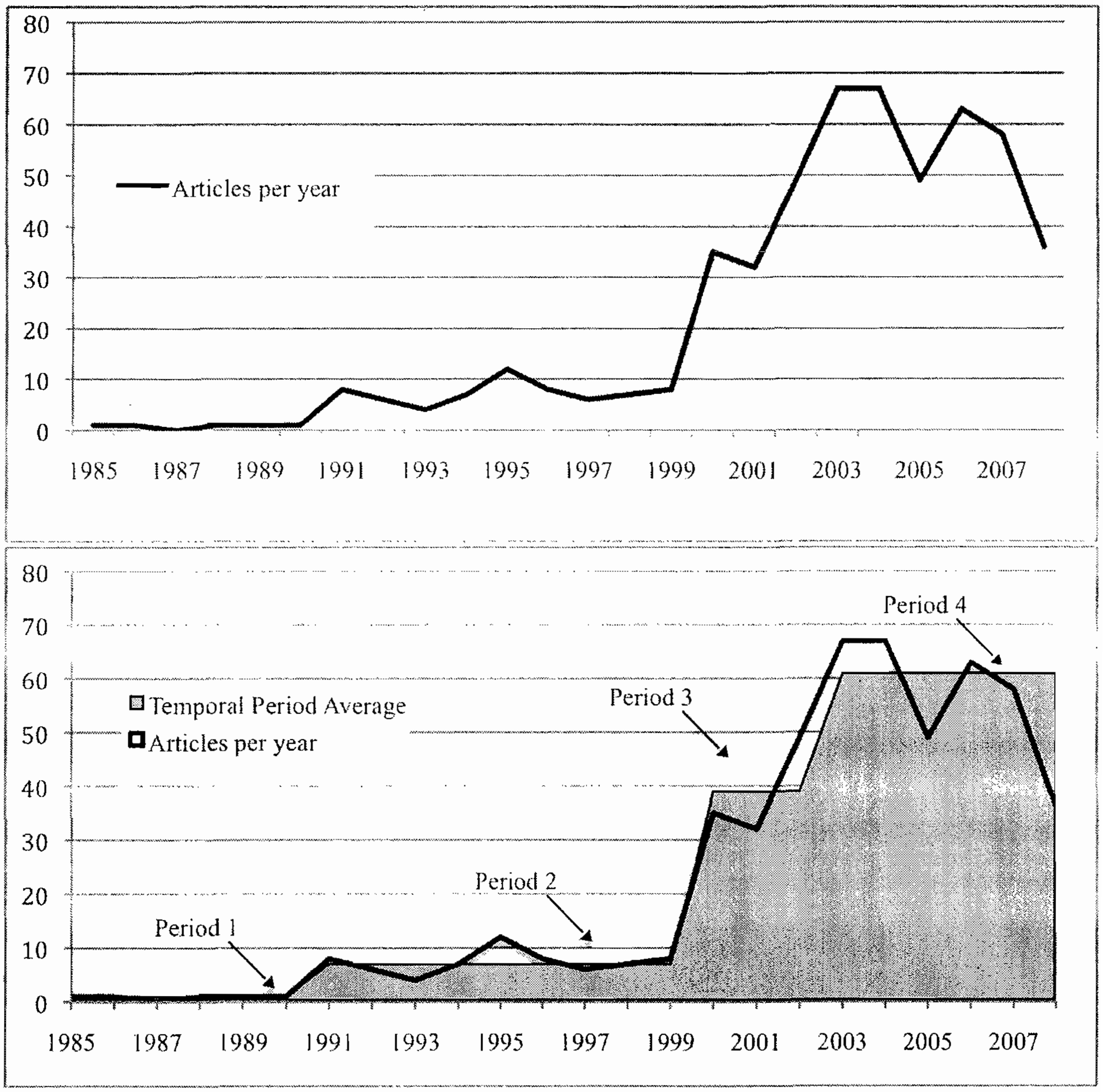
> Carbon atoms can be linked together in practically limitless combinations, and some chemists devote themselves to creating carbon molecules with highly unusual shapes. The latest of them, shaped like a soccer ball, has been named for the late Buckminster Fuller, developer of architectural designs based on the geodesic dome; it is called buckminsterfullerene.
>
> The creation of buckminsterfullerene (also called truncated dodecahedrane) was a joint project of researchers at Rice University in Texas and the University of Sussex, England…The synthesis of dodecahedrane, which involved an extremely complex series of chemical steps, took 19 years. (*New York Times*, December 3, 1985)
>
> This discovery of Buckyballs was followed in 1990, by the discovery of how to mass-produce them, bringing forth the potential for industrial applications as explained in articles at the time, " Buckyballs…unique properties suggest a bounty of commercial uses, including new lubricants, drugs, fuel, batteries and high-strength materials" (*New York Times*, April 23, 1991). However, the *Times* noted,
>
> "Buckyballs remained esoteric laboratory curiosities until last year, when physicists…discovered a way to make them in large quantities… In recent months, scientists all over the world have obtained large samples of the material to conduct their own experiments, and an international research explosion has ensued." (*New York Times*, April 23, 1991)

Similarly, a 1996 article announcing the award of the Nobel Prize for the 1985 discovery attributes the birth of the nanoscience to these events noting,

> "The carbon-60 Buckyball…was kind of a Rosetta Stone that opened a universe of possibilities, based on how nature likes to bond carbon atoms together…The potential uses are tremendous" (quoting award winner Dr. Richard Smalley). But, "In 1985, the first fullerenes were little more than laboratory curiosities, because only tiny amounts could be produced…[until] two other scientists cited in the Nobel announcement but not honored with prizes…found a way to make Buckyballs by the

pound. Since then, fullerene chemistry has burgeoned." (Browne, October 10, 1996)

Figure 4: Number of Articles by Temporal Period



In 2000, the passage of the National Nanotechnology Initiative increased nanotechology research spending to $497 million in 2001, and doubled federal spending over the subsequent 5 years. As early as 2002, the *Times* attributes the development of nanotechnology to the act:

> "The National Science Foundation's National Nanotechnology Initiative has spent more than $600 million in the last year… [and] The first fruits of these efforts are emerging in products like pants woven from nanofibers that resist stains, tennis balls that keep their bounce and more efficient light-emitting diodes." (Markoff, January, 21, 2000)

In 2002, the ETC Group, an organization dedicated to monitoring technology development, publicly advocated for a moratorium on the commercial development of nanotechnology. The *Times* reported on this in an article titled "Nanotechnology has arrived; a serious opposition is forming:"

> From its earliest days, nanotechnology has had its fear-mongers, warning of novel and terrifying risks, …Until recently, though, the debate was restricted to the relatively small community of nanotechnology researchers and experts. The risks they discussed often seemed cartoony or vague compared with the dazzling breakthroughs they projected in fields like medicine, supercomputing, energy and environmental cleanup…For the first time, nanotechnology is encountering the kind of real-world headwinds that have impeded biotechnology. The ETC Group's call for a moratorium continues to be mentioned in later reports on risks. For example, a 2007 report of DuPont's voluntary release of guidelines for evaluating the safety and environmental risks of nanotechnology products concludes by quoting the ETC's research director and noting that the ETC group " has called for a moratorium on the commercialization of nanotechnology." (Feder, August 19, 2002)

My analysis indicates that the portrayal of nanotechnology in the *New York Times* can be divided into temporal periods, which demarcate increases in the visibility of, and public interest in, nanotechnology. The timing of the breakpoints is evidenced by increases in the number of articles and the occurrence of events that reports in later years attribute with significance. In accordance with a grounded approach, my subsequent analyses build upon this finding. In the following sections, I describe findings from my analysis of the emergence of competing social groups and nanotechnology frames across the temporal periods.

Nanotechnology Frames: Discovery, Salvation, Annihilation or Business

Four technology frames are evident in the general press accounts of the development of nanotechnology. Nanotechnology is framed as discovery, salvation, annihilation and business opportunity. Table 7 summarizes the defining characteristics of the frames including, the characterization of nanotechnology, the focal time perspective, and the problems the technology will solve and the solutions it will offer. I explain each frame below.

Nanotechnology as Discovery

The term nanotechnology is not widely used in the *Times* reports until 1991. Prior to that, reports refer to "Buckyballs," which are sometimes described as "nanotechnology" in quotes, in reference to Eric Drexler's 1986 book, *Engines of Creation*. Discoveries that make up what we come to know as nanotechnology, are described factually. Nanotechnology is portrayed as an avenue of scientific inquiry, which solves the problem of our need for knowledge with cutting edge scientific research. This frame is exemplified in the first report about nanotechnology (called Buckyballs) in the *Times*, in 1985, titled, "Molecule is Shaped Like a Soccer Ball." The report gives a factual, present oriented, description of the activities of scientists:

> "Carbon atoms can be linked together in practically limitless combinations, and some chemists devote themselves to creating carbon molecules with highly unusual shapes." Then continues with a factual description of the discovery. "The latest of them, shaped like a soccer ball, has been named for the late Buckminster Fuller…Buckminsterfullerene is

> apparently a stable compound, and the Rice researchers surmise that it may be a common form of carbon in interstellar space, especially in the vicinity of exploded stars (novas) with high carbon content." (*New York Times,* December 3, 1985)

The topic is discovery and the report doesn't mention of possible applications.

Nanoscience as Salvation

In the salvation frame, nanotechnology is depicted as applied science. The technology is described in terms of scientific discoveries, but the emphasis shifts to distant applications and positive implications that will arise from them. Broad applications of nanoscience are presented as solutions to almost all great human challenges, from environmental degradation and resource scarcity as suggested above, to cancer and even death.

This frame is exemplified in the article, "They've seen the future and intend to live it" (Schechter, July 16, 2002). The report describes a meeting of the Foresight Institute, "an organization founded on the belief that nanotechnology will transform almost every facet of human existence by giving people mastery of matter." The article explains:

> "Smaller computers built from atomic-scaled carbon tubes, ultrastrong cables that could be used to build an elevator into space, better drug-delivery systems and much more," are on the horizon. And, "Nanofactories will churn out everything from rocking chairs to rocket ships, superior to any ever made, at "the cost of potatoes and wood"...Nanocomputers will interface directly with the brain, vastly increasing human intelligence. And nanobots will cruise through bloodstreams, banishing disease and debility" (Schechter, July 16, 2002).

The focal topic of the article is a profile of nanoscience with a focus on the positive implications of future applications.

Table 7: Timing and Characteristics of Frames

	Discovery	Salvation	Annihilation	Business
Time of Emergence	Period 1	Period 2	Period 3	Period 3
Nature of nano	Pure science	Applied science	Applied science	Technology
Focal time perspective	Present and distant future	Distant future	Distant and near future	Present and near future
Problem solved	Quest for knowledge	Great human challenges (i.e. cancer, death)	Creates problems	Quest for economic achievement leadership
Solution	Scientific discovery	Broad applications (i.e. space travel)	—n/a—	New businesses, products and processes
Exemplar article title	Molecule is shaped like a soccer ball	They've seen the future and intend to live it	Nanotechnology has arrived; A serious opposition is forming	Nanotechnology near the point when it's time to go public
Exemplary statements from article	Buckminsterfullerene is apparently a stable compound…[and] may be a common form of carbon in interstellar space	nanotechnology…[will] reverse disease and aging	nanotechnology could create a divided and inequitable world where the rich live forever	by 2015 nanotechnology will play a crucial role in $1 trillion worth of products
Focal topics	Research reports	Profiles of science and scientists	Descriptions of health, safety and security threats	Descriptions of start-up firms and products and contribution to economic development

Nanoscience as Annihilation

Reports adopting the annihilation frame share with the savior frame a portrayal of nanotechnology in terms of applications of future scientific discoveries. However, whereas the salvation frame emphasizes positive implications that allow humankind to conquer all obstacles, the annihilation frame emphasizes negative implications, up to the annihilation of humanity. From the perspective of the salvation frame, applied nanoscience solves problems; from the perspective of the annihilation frame it causes them.

This frame is exemplified in the article, "Nanotechnology has arrived; A serious opposition is forming" (Feder, August 19, 2002). The article begins by referencing the so-called "Gray Goo" debate noting, "The great Gray Goo debate is beginning to matter." The debate is about whether it is possible or likely that self-replicating microscopic robots could fill the world and wipe out humanity. While this is the extreme example of a threat, the article presents less encompassing, yet still devastating possibilities:

> "The characteristics that make carbon nanotubes and similar nanoscale particles attractive candidates for carrying drugs into the brain could also allow such particles to transport toxins...nanotubes, because of their needle-like shape, could become "the next asbestos...[and] nanoparticles absorbed by bacteria might enter the food chain" (Feder, August 19, 2002).

Although the article focuses on distant applications of nanoscience, the focal topic of the article is threats to heath and safety that may result from such applications.

Nanotechnology as Business Opportunity

In reports adopting the business frame, what we now know as nanotechnology is portrayed as a technology. That is, a tool that enhances production or end products. The time perspective shifts to the present and near future. Nanotechnology will solve individual, organizational and national quests for economic achievement through the creation of new businesses, products and processes. This frame is exemplified in the article, "Nanotechnology near the point when it's time to go public" (Flanigan, December, 20, 2007).

The article goes beyond potential applications to emphasize actual, in-use products noting, "There are 200 commercial products in cosmetics, apparel and sporting goods in which nanotechnology plays a role…[such as] clothing with a coating of nanoparticles - from the Nano-Tex Corporation of Oakland, Calif. - that repels stains." Discussions of the future are likewise in terms of products in the near term, as opposed to the descriptions of distant future, general applications that are found in articles exemplifying the salvation and annihilation frames, for example "Increasing numbers of nanotech products are in the offing…by 2015 nanotechnology will play a crucial role in $1 trillion worth of products, 'which would require two million workers.'" The focus is on nanotechnology enabled start-up businesses, founders and products, such as Unidym, Inc. described as follows:

> [Unidym, Inc.] works with clusters of carbon nanoparticles that possess extraordinary…Our carbon nanotube technology makes the light-emitting chipsets less brittle and able to emit more light…Our screens can take a pounding (Flanigan, December, 20, 2007).

Social Groups' Use of Nanotechnology Frames

The nanotechnology frames emerged in the sequence discovery, savior, annihilation, and business. Social groups generate and evoke frames to shape perceptions and direct discourse (Benford and Snow, 2000; Dowell, Swaminathan, and Wade, 2002). My analysis of the emergence of frames documents the use of the four frames by five social groups: scientists, futurists, nano-foes, business and government. These groups are shown with examples from the data in Table 8. I describe the emergence of the frames and social groups below.

During Period 1 scientists were the only social group represented in accounts and they evoked the discovery frame. During period 2, futurists and governments appear in the reports. Both groups evoke the savior frame. During Period 3, nano-foes and the business social group appear in the reports and conflict begins. Although, the business and government social groups originally at times evoke the savior frame, both groups emphasize the nanobusiness frame by Period 4. At the present time, although they remain committed to their positions, nano-foes and scientists have begun to evoke modified frames that incorporate elements of the nanobusienss frame. This, along with funding and regulatory decisions suggests that the nanobusiness frame has gained legitimacy at the expense of the savior and threat frames. The time period each social group and frame appeared in the data is shown in Table 9.

Table 8: Social Groups and Examples

Group	Includes	Example	Description (from text)
Scientists	University and non-affiliated, not for profit research groups	Richard Smalley	…said Richard E. Smalley, the Rice University chemist who shared the Nobel Prize in 1996 for the invention of buckyballs, a similar carbon-based molecule …according to specialists like Dr. Peter R. Cavanagh, chairman of the department of biomedical engineering at the Cleveland Clinic Foundation, one of the nation's largest hospital and health research centers
Futurists	Futurist individuals and organizations	Eric Drexler, Foresight, IMM	Dr. Drexler popularized his ideas by presenting a vision of the future of material plenty and physical well-being made possible by armies of invisible machines. All were members of the Foresight Institute, an organization founded on the belief that nanotechnology will transform almost every facet of human existence by giving people mastery over matter.
Nano-foes	Individuals, environmental groups, other NGOs	Bill Joy, ETC, Green Peace	Bill Joy warns that the human species may be on the verge of collective suicide. "The 21st-century technologies -- genetics, nanotechnology and robotics -- are so powerful that they can spawn whole new classes of accidents and abuses," he writes. The ETC group, a Canadian watchdog organization for socially responsible technology, released "The Big Down," a report on nanotechnology
Business	Start-ups, VCs trade groups, corporations, industry experts	DFJ, NBA Merrill Lynch, IBM	…the NanoBusiness Alliance, a trade group for businesses at work on nanotechnology Industry experts say nanotechnology applications have the potential to make almost anything smaller, sturdier, stronger and more powerful.
Government	Govt. reps., departments, and scientists	DARPA, EPA, Pres. George Bush	…the Defense Advanced Research Projects Agency has had the daunting assignment of making sure that no … has access to tomorrow's technology faster than does the Defense Department. Darpa, as the agency is known…

Table 9: Frames and Social Groups by Period

	Period 1	Period 2	Period 3	Period 4
Primary frame(s)	Discovery	Discovery Salvation	Salvation Annihilation Business	Business Risk (revised annihilation)
Evoked by	Scientists	Scientists (both) Futurists (both) Government (both)	Scientists (salvation/annihilation) Futurists (salvation) Foes (annihilation) Business (salvation/business)	Scientists (business/risk) Business (business) Government (business/risk) Foes
Theme(s) of discussions	Factual reports of discovery moving to descriptions of distant future examples of 'hypothetical' applications with positive outcomes	Descriptions and explanations of nanoscience, profiles of scientists with grandiose 'likely possible' applications with positive outcomes,	Descriptions of negative outcomes of applications vs. negative outcomes of failure to lead development 'Grandiose' vs. 'mundane' applications	Profiles of founders and start-ups, descriptions of products Heath and safety risks

Periods 1 and 2: From Discovery to Salvation

During periods 1 and 2, nanotechnology is introduced. Two social groups and the discovery and savior frames appear during these periods. However, neither the groups nor frames are in conflict.

Scientists are the only social group represented in Period 1. When quoted, they evoke the discovery frame and primarily give reports of their scientific discoveries, with few potential applications. When applications are mentioned in reports, they are presented as hypothetical and are usually not attributed to an individual. For example, the *New York Times* (Brown, 1991) reports on findings to be published in *The Journal of Applied Physics,* referring directly to the scientists as follows:

> Dr. Arthur L. Ruoff and his colleagues at Cornell's department of materials science and engineering reported their calculations...Diamond, they said, should become very much stronger as the pressures to which it is subjected approach double the pressure at the center of the earth. Above this pressure -- between eight and ten megabars, or eight and ten million times the pressure of the atmosphere at sea level -- diamond would be transformed into a metal and lose its strength, however. Before the new study, Dr. Ruoff said, it was believed that diamonds could not survive stresses produced by pressures greater than about 3.2 megabars, somewhat less than the pressure of 3.61 megabars that prevails at the center of the earth.

However, individual scientists are not mentioned in connection with possible applications, for instance, "High-pressure experiments are also expected to benefit practical technology...Many important applications are foreseen..." And, when the account mentions specific scientists and applications, the scientists stress the difficulties of practically achieving what is theoretically possible: "Dr. Ruoff and other investigators using diamond anvils note that even if it is theoretically possible to achieve pressures of eight megabars or more, each increase in pressure makes an anvil more difficult to assemble."

During Period 2 government representatives and futurists appear in the reports. Although government representatives give less grandiose examples of how nanotechnology will change the future, both groups evoke versions of the savior frame. A report describing the upcoming announcement of the 2000 National Nanotechnology Initiative notes that President Clinton will set out "grand challenges" which include:

> Shrinking the entire contents of the Library of Congress into a device the size of a sugar cube; assembling new materials from the "bottom up" -- from atoms and molecules; developing ultralight materials that are 10 times as strong as steel; creating a new class of computer chip millions of times as fast as today's Pentium 3; doubling the efficiency of solar cells; using gene and drug-delivery technologies to detect and target cancerous cells, and developing new technologies to remove the smallest contaminants from water and air (Markoff, January, 2000).

Bill Clinton is not attributed with stating the implications of achieving these grand challenges. However, efficient solar cells could eventually lead to the end of polluting process as suggested by futurist Eric Drexler "Strip mines, clear-cutting, refineries, paper mills and oil wells are some of the crude 20th century technologies that will be replaced". And, cures for cancer might eventually support futurist Ray Kurzweil predictions that we will be able to "reverse disease and aging." The groups and frames and not in conflict during these periods.

Periods 3 and 4: From Nanoscience to Nanobusiness

Period 3 is characterized by conflict and coalition building that by period 4 appears to have resulted in the legitimization of the nanobusiness frame. During Period 3, nano-foes and businesspeople appear in the articles. These groups begin to evoke the annihilation and business frames respectively. Initially, government, business and futurists appear united in opposition to nano-foes. However, the business group's framing comes to openly conflict with that of the futurists. The business group distances nanobusiness from nanoscience as portrayed by both the futurists and nano-foes. By Period 4, the salvation and annihilation frames have been eclipsed by a broader business frame that incorporates familiar risks which can be identified and managed through scientific research. Government and business evoke this frame. Futurists become less visible in press accounts and both scientists and nano-foes adopt the business groups' language and framing of "manageable risks" over the nano-foes' previous suggestion of "uncontrollable threat."

Government and business interests form a coalition and seek to distance nanotechnology from the extreme characterizations of both futurists and nano-foes. Mark Modzelewski, one of the founders of the NanoBusiness Allience (NbA), announces the formation of a taskforce of business leaders, scientists and government:

Mr. Modzelewski said that many members of the [trade and business] group had decided, in light of growing speculations about potential dangers posed by nanotechnology, that they wanted a forum for sharing research and developing better public explanations of the issues…One job of the task force is to keep fears of such a [gray goo] nightmare, which the industry views as science fiction, from playing much of a role in the debate over nanotechnology (Feder, 2003a).

The coalition downplays the uniqueness of nanotechnology arguing that the particles are not very different from materials that occur naturally: "People who worry excessively underestimate the number of natural materials that size that have surrounded us for years…It requires the usual good care but I don't see any new or unique threat" (Greg Blonder quoted in Feder, 2003b). This framing conflicts with the salvation and annihilation frames in which the extreme uniqueness of nanotechnology is the basis of exceptional feats or catastrophe.

The business and government coalition comes to directly conflict with the futurists, arguing that nanotechnology poses no real problem because concerns are based on applications of the technology that are infeasible.The coalition frames nanotechnology as an extension of ongoing miniaturization, which will result in improvements to existing products. This conception is at odds with the vision introduced by futurist, Eric Drexler (1992), which includes "molecular manufacturing" and self-replicating machines. While, "Mainstream nanotechnology will soon be used by cosmetics companies to help their current products…last longer and work better…if Drexler's version of nanotechnology were to come to fruition…nanomachines could precisely adjust your hair and skin color to your liking; wrinkles could be smoothed and excess fat removed" (Keiper, 2003). The coalition distances 'real' nanotechnology from Drexler's vision, which they portray as science fiction. For example, Angela M. Belcher a university scientist and nanotechnology company founder, is careful to point out that her discovery involving self-assembly is quite different from self-replication, "These materials don't replicate themselves," she says. She describes them instead as self-healing, "You design a circuit, and if there's a break, it can heal itself" (Anne Belcher quoted in Eisenberg, 2004). In a well-publicized debate Nobel Prize winner Richard Smalley admonished Dr. Eric Drexler:

> You and people around you have scared our children...I hope others in the chemical community will join with me in turning on the light and showing our children that while our future in the real world will be challenging and there are real risks, there will be no such monster as the self-replicating mechanical nanobot of your dreams (quoted in Chang, 2003).

Proponents of the mainstream definition won a victory when they lobbied successfully for cutting funds to study the more radical molecular manufacturing from the House version of the Nanotech Act of 2003. This event led a trade journal reporter to argue that "by carefully selecting which theories are the ones the general public is supposed to believe, then marginalizing the rest...[business leaders are] redefining 'real' nanotechnology to suit what is best for nano-business" (Lovey, 2004: 2).

Individuals and organizations in the business social group began to emphasize familiar problems and solutions and to portray the less familiar as infeasible possibilities, which belong in the real of science fiction. The coalition including the business and government groups portrayed nanotechnology as an extension of existing technology and something that has been used without a name or understanding for some time. Thus, nanotechnology requires only additional research to identify risks similar to those caused by naturally occurring materials, rather than a moratorium to prevent disaster.

From this perspective, nanotechnology will address our quest for economic achievement by giving us faster computers, pants that don't stain and windshields that have to be cleaned only once a year. This version of nanotechnology is much less likely to be feared than nanotechnology that will change our understanding of life and create health and safety threatening, self-replicating robots. From the business technology frame, the problems facing nanotechnology are similar to those of many familiar technologies, we just need more research to identify and mitigate risks related to the small size of the particles.

While it is too early to know for certain the ultimate framing and outcome of nanotechnology—a tragic disaster or miraculous discovery could drastically change perceptions and outcomes—this analysis suggests a trend towards the dominance of the nanobusiness frame. By Period 4, nano-foes had joined business leaders in calling for research into the risks of nanotechnology, rather than a moratorium development. While this certainly does not indicate that this social group now supports nanotechnology, it is an indication that the framing of nanotechnology as a business opportunity has achieved dominance over the framing of nanotechnology as "Grey Goo."

Conclusion

Considerable attention and public financial support is devoted to the commercialization of basic science research (Karnoe and Garud, 2003). This is not surprising given the apparent financial impact of new ventures based on these technologies (Chandler, 1990). Recent history has shown that public opinion may play an influential role in determining the success of emerging science-based technologies. However, we know little of if and how individuals and organizations shape public perceptions of emerging technologies.

Public evaluations of science-based technologies are often inaccurate. Laypeople rely on qualitative characteristics to make risk assessments. Science-based technologies, which are often unfamiliar and ill-defined are perceived as posing a greater threat (Slovic, Fischoff, and Lichtenstein, 1980). In general, risks that are new, involuntary and potentially catastrophic tend to elicit very strong concerns (Kasperson, Jhaveri and Kasperson, 2001). The characteristics inherent in emerging science-based technologies subject them to potential stigmatization, which can limit or curtail research, development and commercialization threatening entire technology domains and the many ventures in them.

Public trust, or sociopolitical legitimacy, can be viewed as an antidote of technology stigma. Stakeholders such as the general public and government officials come to trust in and accept emerging science-based technologies as appropriate and right as the norms and rules governing their production, distribution and consumption become institutionalized (Aldrich & Fiol, 1994, Garud, Jain, and Kuraswamy, 2002; Van de Ven and Garud, 1994). Before norms and rules become institutionalized, a problem and solution, must be theorized (Suchman, 1995). Technology frames define the problems that technologies will solve and the solutions with which they will solve them.

Researchers increasingly argue that interested individuals can influence the emergence of organizational fields and markets. Individuals or organizations acting as institutional entrepreneurs utilize social skills such as the creation of collective action frames to build support for emerging fields (Fligstein, 1997, 2001). Collective action frames articulate problems, identify causes and propose solutions, facilitating collective action. I draw on a related concept, the technology frame, to examine the role played by individuals in influencing public perception of emerging science-based technologies. Like collective action frames, technology frames generate sociopolitical legitimacy by defining and bounding novel undertakings. Technology frames provide meaning by identifying and articulating problems and solutions related to technologies.

This analysis of the developing nanotechnology domain illustrates a strategy on the part of nanotechnology proponents to generate sociopolitical legitimacy by creating a trust-worthy technology frame. A collective of actors in the emerging nanotechnology domain recognized public fears as a threat and coalesced on a nanobusiness frame. The comments of these proponents suggest that the creation of a technology frame is an intentional strategy and that the proponents are actively attempting to frame nanotechnology in a non-threatening manner.

The business-government coalition emphasizes familiar problems and solutions and portrays the less familiar potential applications of nanotechnology as infeasible possibilities, which belong in the realm of science fiction. The frame supported by the coalition of nanotechnology proponents defines nanotechnology as an extension of existing technology and something that has been used without a name or understanding for some time. According to this frame, nanotechnology requires only additional research to identify risks similar to those caused by naturally occurring materials. It will give us faster computers, pants that don't stain and windshields that have to be cleaned only once a year. This version of nanotechnology is much less likely to be feared than nanotechnology that will change our understanding of life and create health and safety threatening, self-replicating robots. Given proponents' technology frame, the problems facing nanotechnology are similar to those of many familiar technologies, we just need more research to identify and mitigate risks related to the small size of the particles.

While it is too early to know the outcome of the efforts of nanotechnology's proponents, this analysis suggests a trend towards public acceptance of the coalition's frame and increasing trust of nanotechnology. Nano-foes have joined the coalition's identification of risk as a problem and have identified solutions other than a moratorium on research. Nano-foes have acknowledged regulation and research into risk as potential solutions. While this certainly does not indicate that this social group now supports nanotechnology, it is the first indication of any agreement between foes and proponents.

Institutional entrepreneurs in the emerging nanotechnology domain recognize public fears as a threat and are actively seeking to generate and disseminate a nanobusiness frame. This analysis shows that a nanobusiness frame has emerged and appears to be gaining legitimacy in the national press. The projection of this frame was attributed in press accounts to the actions of individuals and organizations representing business interests. Because I am interested in understanding how science based technologies can become the basis for new areas of commercial activity, I focused subsequent data collection and analyses on understanding the period during which the nanobusiness frame emerged and the role of the business social group in its emergence.

CHAPTER VI

ANALYSIS AND FINDINGS

Overview

In the preceding chapter, I outlined the chronology of the development of the nanotechnology field and displayed a timeline of key events based on trade publications and proprietary reports. I described my analysis of the portrayal of nanotechnology in the general press from the first mention in the *New York Times* (1985) through 2008, and presented my findings. This analysis provides the basis for the analysis of the embedded cases I report in this chapter.

In this chapter, I build upon the previous analysis, using it as a starting point to guide data collection and conceptualization (as described in Chapter III). In the previous analysis, I identified temporal periods in the development of nanotechnology. I found that the predominant nanotechnology frame changed over time. Initially nanotechnology was portrayed as scientific discovery. There was very little discussion of applications. As the field matured, nanotechnology was portrayed as a portent of salvation or annihilation. Both of these frames draw on extreme, distant future applications. These frames ushered in a period of conflict. The nanobusiness frame emerged next. At first, this frame did not conflict with the salvation frame. However, as public concern increased, nanobusiness leaders distanced nanobusiness from the extreme versions of nanoscience portrayed by both the salvation and annihilation frames. The nanobusiness frame portrays nanotechnology as an extension of existing technologies. My analysis shows that participants in the emerging nanotechnology domain attributed the projection of the nanobusiness frame to a small group of business proponents. Given this finding, I continued my study by collecting data specific to this small group.

The three VC firms in this study are focused on very early stage deals, even compared to their VC counterparts. They were the only VCs operating at a national level that chose to focus exclusively on nanotechnology at the time of this study. They sought to encourage research funding and build support for the commercialization of nanotechnology. Using a grounded theory approach, I identify the actions, goals, and motivations of these key players and the outcomes they perceive to be the results of their actions. Next, I identify themes and patterns in the data and working iteratively between the data, my conceptualizations, and the literature, I develop a process model to explain how this group projected a frame into the general discourse.

I introduce the concept of a socio-semiotic space, likened to a meaning and interaction construction zone. I find that business proponents engage in three sequential activities in their attempt to create an infrastructure to support commercial activity around nanotechnology: constructing a socio-semiotic space, positioning themselves as experts within the space, and translating scientific, futuristic, and opposition discourse for their desired constituents. I discuss how symbolic power, accumulated through these activities, can allow small group can project a technology frame.

Introduction

> Now the problem....is that PCs are easy to count. You know somewhere in [this company] there is a number on what we spend on PCs every year and I am sure that you could find somebody that has it. Its easy to look at how many are sitting on your desk, and how many are in each home, and how many are built. How do you do that with nanotechnology? First of all the science is really hard. You know even seeing the stuff to manipulate it, much less figuring out how they all work together is a lot more advanced than most research. And besides that, what is nanotechnology? The government came up with a definition, [a trade publication] came up with a definition...and then we would all kind of find our own definition. It has to do something different and it can't just be soot. But definitions were hard to come by so how do you really know? *–Nanotechnology Business Leader, interviewed by Kathryn Aten*

> Right now the brand is entrepreneurs and innovators and nano companies. It's not about what they're making. It's about who they are; transforming this fundamental science into something 'cause there's not much of a physical embodiment as yet of what nanotechnology is. So the brand of nano is more about entrepreneurs, innovators, pioneers...It's the promise of the future. And the brand will be translated into what? It's critical when it makes that translation, that transference, right, from who to what. We have a very positive brand on this who. It's the myth of America. It's about entrepreneurs, risk takers, pioneers that shape a better world and future for all of us. *–Nanotechnology Business Leader, interviewed by Kathryn Aten*

Creative invention and the entrepreneurial action necessary to transform scientific discoveries into commercializable technologies are recognized as extremely important to firm and national competitiveness (Drucker, 1985). The emergence of areas of commercial activity—termed organizational fields, industries or markets—has been explored from a variety of perspectives including economic (Klepper and Graddy, 1990) and sociological (Fligstein, 1996, 2003; Aldrich and Fiol, 1994; Levenhagen, Porac, and Thomas, 1993). The classic economic view assumes that markets exist *ex ante*, waiting for entrepreneurs to recognize them. However, when entrepreneurship and innovation are based on new knowledge a market may not exist (Drucker, 1985), undermining the validity of an explanation based on classic economic theory. Levenhagen, Porac, and Thomas (1993) argue that materially-oriented analyses of market creation can be complemented by socio-cognitive and political analyses to provide a more complete understanding. These perspectives suggest that technology proponents play an active role in the creation of commercial activity: neither characteristics of the technology nor *ex ante* market demands can fully explain the emergence of commercial domains.

In emerging technology domains it is likely that neither founders nor potential stakeholders are clear as to the nature of the technology and business opportunity. Researchers argue that technologies require a defined institutional space (Dosi, 1982; Van de Ven and Garud, 1994), or technology field (Garud, Jain, and Kumaraswamy, 2002). A technology field is comprised of a pattern of relationships among objects and humans related to a product and market (Callon, 1987; Garud and Karnoe; Garud, Jain, and Kumaraswamy, 2002). Activities within technology fields are constrained and enabled by technology frames, sets of collective cognitions spelling out the meaning of technologies and patterns of interaction among actors (Bijker, Hughes, and Pinch, 1987, Orlikowski and Gash, 1994). Technology frames emerge in technology fields through a negotiated process between social groups (Bijker, Hughes, and Pinch, 1987; Garud, Jain, and Kumaraswamy, 2002). This conceptualization of technology frames is similar to that of organizational fields, which also comprise a shared set of meanings (Scott, 2001).

Entrepreneurs in emerging technology domains must gain legitimacy in order to persuade potential stakeholders to supply resources and support necessary to transform fundamental scientific discoveries into areas of commercial activity (Aldrich and Fiol, 1994). Legitimacy has been described as stakeholder consensus on competitive definitions and categories (Levenhagen, Porac, and Thomas, 1993), the degree to which stakeholders take new ventures for granted and accept them (Aldrich and Fiol, 1994), and government formalization of the rules of an industry into laws and policies (Fligstein, 2003). These definitions imply that legitimacy is intimately associated, and perhaps synonymous, with a collective agreement on the meaning of a technology that is congruent with business activity and can then be incorporated into business and industry models. As illustrated by the quotations that opened this chapter, in the highly uncertain environments of emerging technology domains, entrepreneurs must forge not only organizations and a supporting infrastructure, but also the meaning of the technology.

Researchers have grappled with but, as yet failed to offer complete explanations of how technology domains emerge. Much research on the emergence of domains begins with an assumption that market need exists and entrepreneurs recognize and take advantage of them (Constant II, 1987; Schoonhaven and Romanelli, 2001). With few exceptions (e.g. Hargadon & Douglas, 2001; Mcguire and Granovetter, 2003), the attention of technology management research has focused on product technologies for which for an application is defined (e.g. Garud and Rappa, 1994; Tripsas, 1997; Munir and Philips, 2005). However, some our most significant technological innovations are born in the realm of basic science long before a known application exists. Before a technological discontinuity can occur, a basic science-based technology must traverse a difficult path from scientific discovery to become an idea for a marketable product or useable process. It is during this pre-emergence period that the meanings and interactions that will influence technological trajectories and technology domains are formed (Kaplan and Tripsas, 2008).

I examine the pre-emergent period of technology development, when business proponents are beginning to organize around nanotechnology investing, in order to better explicate the activities and processes of the emergence of technology domains. I introduce the concept of a socio-semiotic space, a meaning and interaction construction zone, which may or may not become an institutionalized field. I find that business proponents engage in three sequential activities in their attempt to create an infrastructure to support the development of commercial activity around nanotechnology: constructing a socio-semiotic space, positioning themselves as experts within the space, and translating scientific, futuristic and opposition discourse for their desired constituents. I discuss how symbolic power, accumulated through these activities, can allow a small group of technology proponents to project a technology frame.

My analysis indicates that the assumption underling most research on emerging technologies—that characteristics of technologies and market demand largely drive the emergence of commercial activity and determine the path of technological trajectories—may be inaccurate. Although these drivers have great influence once a product and market are identified, the meaning, uses, and value of basic science-based technologies are constructed and negotiated long before products and markets are clear. These influence the development of research streams, perceived uses, proto-type products, investment and regulation; before products and markets exist. Because most research explores the emergence of technology after the construction and negotiation of meaning has occurred, the best use of a technology appears evident, inherent in the characteristics of the technology and market demand. Greater understanding of the processes of the pre-emergent period, and in particular of technology framing through which the meaning of emerging technologies is created and negotiated, will contribute to our understanding of how new technologies emerge.

A better explanation of how technology proponents create the sociopolitical infrastructure necessary for emerging technologies to thrive will provide guidance to business people and policy makers seeking to develop and support such technologies and the domains that emerge around them. Additionally, the findings of this study lend support to arguments that managers seeking to implement new technologies in their organizations should consider the meaning attributed to those technologies.

Summary of Methods

As explained in detail in Chapter III, I collected participant observation, archival and interview data. In analyzing the embedded cases, I sought to identify the VCs' actions and to understand the rationales behind them. The units of analyses included the actions, "strategic tactics," (Fligstein, 1997) and stated rationales of the participants.

I began this analysis by constructing a timeline of key events and actions for each VC based on participant observation and the VCs' current websites. I reviewed my notes and printed the websites, and highlighted key events and actions to construct a visual timeline. I selected as key, events that were mentioned frequently or described as a milestone on the websites. This analysis guided my construction of a protocol for semi-structured interviews, which I conducted after this initial analysis. I continued to fill in details in the timeline and narrative as I moved to systematic coding of the interviews, VC firm websites and conference presentations.

To develop a rich sense of the strategies and tactics of the VCs and how they unfolded over time, I systematically reviewed the interviews, conference presentations and web archive pages. As explained in Chapter III, using "open coding," in Atlas.ti, I marked text describing actions and decisions as quotations (Muhr, 2004; Sheon, 2007). Then, I used Atlas.ti's network view function to view the selected quotations and sort them into similar "piles" (Sheon, 2007). I used the network view tools to review, sort and rearrange the piles until all of the quotation segments were categorized. I crosschecked my understanding against reports in the electronic media, highlighting and annotating text, using tools in Scrapbook, an add-on program for the Mozilla Firefox search engine. These piles became the categories of activities that are the basis of the conceptual model I describe in this chapter.

Finally, I returned to the whole of the data to explain the relationship between the outcomes I documented though the analysis of nanotechnology frames in the larger setting and the activities of the three focal VCs identified in my analysis of the embedded cases. I reviewed all of my notes, memos and draft conceptual models and highlighted persistent themes. I wrote memos and checked my understanding with academic colleagues. I returned to the Atlas.ti database and marked additional text describing participants' motivations, explanations and perceptions of causal influences. I then worked back and forth between the data, my evolving theory and the literature to develop a model to explain how technology proponents project a technology frame.

Case Description

Nanotechnology is the study and output of the control of matter on an atomic and molecular scale, at dimensions of between 1 and 100 nanometers. A nanometer is one billionth of a meter, which is about the width of three or four atoms. The National Science Foundation estimated in 2000 that the market for nanotechnology products will be over one trillion dollars by 2015 and that the industry will employ over 250 million workers (NSF, 2001). While the commercial development of nanotechnologies and their diffusion into many sectors seems certain at the present time, the path to this point has involved contentious positioning and discussion among government, investment, commercial, and opposition communities.

After initial period of low-profile development relegated to science labs, scientific discoveries, the first applications, and increasing investment by government and public investors ushered in visibility, excitement about, and public opposition to nanotechnology. Business interest, formal opposition and public awareness had begun to take off when the data collection for this study began at the IBF's first Nanotechnology Investing Forum.

The Construction of Nanobusiness

> Thanks very much to all of you for coming. It's amazing how this event took on a life of its own: somewhat like bottom-up self-assembly. One year ago, this could never have happened – bringing the investor

> community to the nanotech technology end of things. Six months ago…you couldn't have done this. But two months from now, as you see, there is a whole stream of nanotech conferences. So we believe that the timing of this event makes it a watershed event for the industry and it's very exciting. Some exciting developments that are happening today for the first time: the Nanotech Opportunity Report, published by CMT Scientifica is hitting the air for the first time. We've also got CNRC, the Council for Nanotechnology Research and Commercialization, which proposes to be an interface between the university and government labs and the venture communities…[is] calling for papers…Later on today, three winners of our business plan competition will be presenting five-minute speed pitches at the beginning of the cocktail hour…I would like to acknowledge the person that really brought this together and made it the legitimate watershed event that it is, I would like to introduce Meyya Meyyapan, our chairman [applause]. *–IBF's 2002 Nanotechnology Investing Forum*

This introduction began what participants acknowledged as the first conference focused on nanotechnology investing in the United States. Such conferences have been characterized as field configuring events, settings where people from diverse social organizations assemble temporarily with the conscious intent to construct a new domain (Meyer, Gaba and Colwell, 2005). Such events often give rise to critical turning points in the emergence of domains of commercial activity (Lampel and Meyer, 2008). At these events, people develop industry standards, announce new products, construct social networks, recognize accomplishments, transact business, and, importantly, interpret and construct meaning for and of emerging domains (Lampel and Meyer, 2008).

The attendees at IBF's Nanotechnology Investing Forum were exuberant, and thrilled to be involved in the birth of what many referred to at that time as the nanotechnology industry. The excitement is indicated in the comments of one of the keynote speakers:

> My name is Steve Jurvetson. Thanks. I am actually amazed at the attendees here, and I think it's a real testament to interest in nanotechnology that so many people and so many areas of the world frankly have come to this conference. I think it's the inaugural conference of this topic and for IBF and its just a testament to the excitement. *–IBF's 2002 Nanotechnology Investing Forum*

Participants included VCs, aspiring start-up founders, the media, futurist nanotechnology supporters, academics and government representatives including the chairman of the forum, Meyya Meyyapan, Director of NASA's Center for Nanotechnology.

They came together to learn about nanotechnology business opportunities, make connections, get funding and, in the words of Jurvetson and IBF's founder, to "start a community." IBF's CEOr explained the genesis of the conference as follows:

> A few years ago we realized that there was an emerging community of corporate investors that were interested in doing strategic investing. So we pioneered the Corporate Investing Conference…Now, it came on the radar screen that our investors were looking at the nanotech area and we were interested in developing a forum to actually assist that community to gather and facilitate information and bring them in contact with the private equity investor community. And hence, this conference…There are some key groups which we identified during this process in the nanotech area…They are NanoBusiness Alliance, CMP, Foresight Institute, CNRC which is a new initiative you'll hear more about, NanoSIG, Small Times Publications and of course there are key venture funds that we have speaking, universities, government and research labs and key companies already demonstrating some success in this area. *–IBF's 2002 Nanotechnology Investing Forum*

These key groups mentioned above included the only three VCs specializing in nanotechnology at the time, Star Venture Capital, NanoTech Investing, and T & T Group. Between them, these three VCs were responsible for the founding of the first nanotechnology trade association, the first nanotechnology trade magazine, the first nanotechnology report for corporations, the largest nanotechnology investing newsletter, and for undertaking some of the first VC investments in nanotechnology.

Three young entrepreneurs with no experience in venture capital founded Star Venture Capital, in 2000, as a VC firm specializing in nanotechnology. One of the founders explains the genesis of the firm as follows:

> [The idea for the] company started in late 1999 when the three of us got together and had an idea to start a venture capital firm focused on an area that was largely ignored by a lot of institutional venture investors. That was in the materials science space, which later combined with mesoscale physics and got the popular buzzword of nanotechnology. Recognizing that we would be a new firm in the venture capital space, we looked historically over the past thirty years at what big, general-purpose technology trends emerged, like the personal computer or biotech or the Internet. And then we said "What is going to be the next prevailing technology trend out there and how can we identify that? And then, not only identify it, "How can we become experts in that space?" So being a new firm, we looked historically at firms like Sevin Rosin or Kleiner Perkins back in the 70s who really launched their franchises around the personal computer. Interestingly enough, if you look at something like Sevin Rosin the founder, Ben Rosin, had a technology newsletter that got him access to certain companies…So in late '99 and 2000 when we came together we spent a good nine months going around to universities throughout the US and asking them a couple of key questions: "What trends have you seen in terms of government funding for a lot of academic research and on top of that in what areas are you seeing explosive patent growth? What areas are really looking promising in the year to come and 5 to 10 years out?" And increasingly, the common data point that we got is that nanoscale science and technology, or advanced materials science, or even this kind of convergence of biology, electrical engineering, and physics were coming together under this popular umbrella term nanotech. So, what we decided to do, is to take a page out of the previously successful venture firms' histories and we started something that we find pretty unique for any venture firm to have. We created three strategic entities in media, in research and in politics. *–Star Venture Capital Founder, interviewed by Kathryn Aten*

Theses entities included a nanotechnology trade alliance founded in 2000, a nationally distributed newsletter initiated in 2002, and a nanotechnology research report issued in 2001 and 2003, which was spun off as a separate research and consulting firm specializing in nanotechnology in 2004.

Other VCs in attendance at the conference had noticed and acted upon these developments in a similar manner. In 2001, T & T Group made a public announcement that it would confine future investments to nanotechnology in order to take advantage of the opportunity to specialize in this new trend. And in 2000, a group of experienced venture capitalists founded NanoTech Investing with the intent of being the " the glue for the industry." NanoTech's founder came from the computer industry had reached conclusions similar to those of Star Venture's founders, and developed a media-based approach.

> [NanoTech's founder] noticed that computer magazines, PC magazines, in his opinion, played a great role in the growth of the industry. They were a way businesses and everyday consumers could learn about the technology, learn about the hardware, see how other people were applying this technology. [They could help consumers] keep up to speed on the tremendous growth and capability, and these publications got a lot of the credit for the rapid growth of the PC industry and of PC use overall. — *NanoTech leader, interviewed by Kathryn Aten*

NanoTech thus launched a media organization in 2001 with the goal of creating a website, trade magazine and conference series to educate business and consumers in order to spur the commercialization of nanotechnology.

The introduction to the premiere issue of the journal in September of 2001, titled "It starts small and simple…and then changes the world," illustrates the excitement of those involved in emerging nanotechnology:

> Consider the lowly nozzle. Until the late 1970s, ink jet printer heads were made with nozzles that had been bored with tiny drill bits. The smaller the hole, the sharper the reproduction. It worked, but not well. Along came engineers with a lithographic process that used tiny amounts of cheap raw material to "grow" nozzles an atom at a time, each with a precise microscopic hole. This simple process, one of the first commercial applications of microtechnology, allowed a few workers in a small clean room to crank out a large volume of identical, flawless nozzles. Printing quality went way up. Prices came down…One simple small tech application, originally developed to help print the family holiday letter, has spawned significant advancements in consumer products, automotive, telecommunications, health care and other fields.
>
> Now multiply that impact by the thousands of small tech devices that exist today. And again by the untold number that will exist tomorrow. You begin to see why…some believe we're at the beginning of the most dramatic technological revolution in history. Our premiere issue…is devoted to introducing microsystems and nanotechnology to a wider audience…This package will be a wake-up call for many in industry as their companies face all of the benefits, and disruptions, that accompany evolution in the marketplace…Your world is changing in fantastic ways. Rely on us to bring you information you'll need to be a part of small technology's future.— *Nanotechnology publication, October/September, 2001)*

By the time of the first IBF conference in 2002, the Nanotechnology Initiative, the first large U.S. Government funding for nanotechnology, had just passed, and nanotechnology was beginning to gain wider attention in the general media. NanoTech's media outlet proclaimed in a headline of July/August of 2002, "This year gave birth to an industry."

Shortly after the first conference, opposition to nanotechnology surfaced. Reporters from the media outlets the VCs founded covered opposition events in their news reports and editors responded to the events in editorials and opinion pages. Reports covered calls for the nanotechnology community to respond collectively to the threat posed by negative public perception. Editorials included narratives and metaphors that would eventually be carried into the general press and would help to frame nanotechnology as a business opportunity and national imperative. Nanotechnology was compared to technologies that had come before, and presented as having similar risks. For instance, following the September, 11 terrorist attacks, an editorial titled "Fear of misuse doesn't negate technology's benefits to society," ran in NanoTech's affiliated media outlet:

> When the first German V2 rocket slammed into London in 1944, its chief designer Wernher Von Braun remarked to colleagues: "The rocket worked perfectly except for landing on the wrong planet." The planet Von Braun had in mind years earlier as a student was Mars. He wanted to build rockets that would soar into space, and take mankind's hopes and aspirations with them. As TV commentator Eric Severeid noted upon Von Braun's death in 1977, "There is always a dream to begin with, and the dream is always benign." Von Braun didn't see his rockets becoming a weapon of mass destruction in Hitler's grasp at world domination any more than the scientists working in small tech see their systems playing into the hands of a dictator or a terrorist...His technology was morally inert. It was the people and governments that employed his rockets that made them instruments of good and evil. The Wright Brothers merely wanted to get lift and distance at Kitty Hawk in 1903. Could they have envisioned the use of airplanes for dropping bombs, or for commandeering them as missiles that could be plowed into office buildings? Automobiles convey people to schools, jobs and doctor offices, but they're also sometimes the delivery vehicle for time bombs. Even such basic technology as fertilizer can be used for evil purposes, as we saw in Oklahoma City in 1995. History suggests that small tech will not be immune to abuse either.
>
> What's an innovator to do? Proceed, of course, and with extra speed...Technological advantage is critical. *–Nanotechnology publication, November/December 2001*

The VCs and leaders of the political organization they founded stressed the national imperative to be a leader in the technology in meetings with business and congressional leaders to encourage support for the emerging technology. These efforts were described by one of the founders as follows:

> "[We] would go down to Capital Hill to meet with people on the House Science committee [and] spearhead these public policy tours where they would invite some key corporations or VCs or people in the industry to go down and testify in front of Congress on why more money should go into nanotech." *–Star Venture founder, interviewed by Kathryn Aten*

The participants in the emerging domain attribute the passage of additional funding for nanotechnology in 2003 to their efforts.

The Absence of a Field

Nanotechnology proponents succeeded in gaining the recognition and support of their desired constituency, thwarting calls for a research and development moratorium, and projecting a nanotechnology business frame as documented in Chapter V. However despite this success, by 2008 the conference was reduced to a two-hour workshop, the trade journal was had been relegated from print to electronic format, the newsletter and research and consulting organization had been renamed to focus on emerging technologies, and participants seemed to have reached consensus that there would be no nanotechnology industry. While academic research might suggest that this case is an example of the failure of an effort by institutional entrepreneurs to create an organizational field, most participants do not see it that way.

The discrepancy seems to result from differing assumptions regarding the best or necessary outcome. Technology and innovation management research exploring the emergence of technologies focuses on the emergence of organizational and technology fields. The research builds from underlying assumptions that characteristics inherent in technologies and market demand drive the emergence of organizational fields, technologies require institutionalized fields, and that institutional entrepreneurs seek to create organizational fields. The data in this study show a far greater degree of flexibility and ambiguity around these assumptions than much of the literature suggests.

The technology proponents that are the focus of this study explained that their decision to focus on nanotechnology was based in part on the ambiguity surrounding its meaning. The fact that it might not become a recognized industry was seen as an advantage. For example, one VC explained in an interview that he chose to focus on nanotechnology because "it would be a common denominator which would be the underling science and technology but there would be a lot of diversification in the portfolio from an economic point of view in terms of the actually products that would be produced." Another said he chose to focus on nanotechnology because "nanotechnology was and is general, because it is something that affects all different industries." And another noted, "We started with nanotech because it is very precisely broad…It has a porous definition, right?" The explanations of the VC's in this study mirror the findings of a recent study, which shows that entrepreneurs' adoption of the label "nanotechnology" for their start-up businesses has less to do with the nature of the business than with founders' perceptions of the utility of the label (Granqvist, Grodal and Woolley, 2009).

From the perspective of the VCs in this study, their efforts were a success. They resulted in the government and corporate investment that nanotechnology needed in order to become a commercially viable technology. Whether the businesses that supply materials and create products with nanotechnology become a separate industry category is not an important measure of success to most participants. For example, one participant explained that in his opinion a nanotechnology trade organization is no longer needed because it served its purpose: nanotechnology got the visibility, acceptance, and investment it needed. This participant's perspective supports Hoffman's argument that fields form around issues, not markets or technology (Hoffman, 1999). While there was an issue, there was an organization. Once the issue was solved, the organization is no longer needed.

An ongoing theme in this case history is participants' struggle to settle on terminology for describing the nanotechnology domain. While many participants originally referred to the nanotechnology "industry", others used the terms; "space," "domain," "investing space," "area," "arena," and "enabling technology." In every interview I conducted, interviewees volunteered their stance on what the nanotechnology domain would be. For example the founder of T & T Group began our conversation by stating, "First, I would say that I don't think there is such a thing as a nanotechnology industry. Its just an enabling technology at the nanoscale."

By the end of the time period covered by this study, it became clear that from the perspective of the participants, nanotechnology would not become an industry. They continued to refer to nanotechnology as a "space," "area," and "domain." In the final year of the conference, one speaker summarized the conclusion of the debate over the nature of the domain saying, "At the first conference back in 2002-2003, I stood up and said there is not, and there will never be, a nanotechnology industry, and I think we're seeing that." However, the same speaker argued, "When you see large companies, corporations, putting money into nanotechnologies, it's not just a scientific curiosity…there's something there."

This debate, and the struggle of participants to find a word to accurately convey their observations of the outcome of their efforts highlights a gap in the academic literature. Our existing concepts do not account for what comes before an organizational or technology domain, nor do they account for how and why the construction of temporary social organizations which do not result in a institutionalized field, nevertheless generate resources and can be considered successful by their founders. These temporary social organizations can be thought of as similar to scaffolding, which is built and used during construction and dismantled when a required level is achieved (perhaps to be reused in a reconfigured form in a future project).

Through my analysis of this case, I identify three activities, constructing, positioning, and translating that allow technology proponents to project a technology frame. I explain how these activities resulted in a domain of commercial activity. This domain is unlikely to become an institutionalized organizational or technology field. It nevertheless provided resources and served the ends of those who created it. I introduce the concept of a socio-semiotic space to reflect the entity technology proponents constructed and I develop a model to explain how a small group of nanotechnology proponents used the socio-semiotic space they constructed to generate resources and project a technology frame in support of nanobusiness.

Projecting a Technology Frame

The data from this research revealed three sequential activities: Constructing, Positioning, and Translating. These activities create resources and generate symbolic power allowing technology proponents to define the emerging domain. Table 10, explained in the discussion below, shows the three activities with illustrations from the data.

Constructing

The first activity the VCs engaged in is constructing. Constructing is creating a physical and cognitive infrastructure for an emerging technology. It includes founding domain specific start-ups, supporting organizations, and media outlets. These entities provide a physical and cognitive space in which technology proponents can negotiate the meaning of an emerging technology and begin to interact with those they hope will become constituents. In their words, the VCs in this study were "entrepreneurs" and "industry builders." They did not see themselves as solely investors. They sought to construct a supporting infrastructure for nanotechnology. For example, as one founder explained:

> Our decision to focus on [nanotechnology] led us to say if this is a future industry, what are the things that the industry needs to grow? We decided … we would be a company that would be focused on the advancement of [the] technology." —*Nanobusiness founder, interviewed by Kathryn Aten*

The firm's website stated more simply, we will work as an "industry accelerator."

Table 10: Activities and Examples from Data

Activity/ Tactics	Quotes from Interviews	Examples of activities from WebPages and press releases
Constructing Founded organizations, journals, newsletters, associations, nanotech stock index	We created three strategic entities in media, in research and in politics to help us get better deal flow, which is pretty much the name of the game in the venture world. But also to help us increase the value that we would add to investments once we make them. [It] was actually incorporated as an LLC in March 2001 and they had a reasonable staff and launched with the web site in May, 2001.	By building strong alliances with leading Small Tech research institutions, end users, entrepreneurs and investors, [we are] establishing a solid foundation for the industry as a whole to flourish. [We] also recognizes the need to support global information transfer among the various entities who play a part in the growth of Small Tech. To that end, we've created [a media company]. This subsidiary company is publishing a magazine, which has a circulation of more than 22,000. It also features a Web site providing daily news about the business of MEMS, microsystems and nanotechnology. [We are] an Industry Accelerator(TM) dedicated to developing the Small Tech industry. The company is building a portfolio of great companies by investing in start-ups and early stage companies; providing business and technical resources to support these companies; and developing industry- building resources.
Positioning Wrote reports, blogs, press releases, histories and biographies	They carved out their niche as the domain experts in that particular sector and because they were known as the experts in that area they attracted all the deal flow and were able to make early stage venture capital bets that proved to be very successful. [The benefit] really is twofold. It is public and actual perception of us being at the epicenter of everything going on in nanotechnology.	[We are] a venture capital firm focused on making early-stage investments in nanotechnology and related growth sectors emerging from leading academic centers of excellence. [Our] managing partners, investors, advisors and extended network are leveraged to provide unparalleled access, expertise and market intelligence to its portfolio companies. The firm's principals are recognized internationally as thought-leaders in the field of nanotechnology. Since it was founded, NanoTech has established a leadership position in the emerging field of Small Tech. It is the leader in bringing Small Tech products to the global marketplace.
Translating Told hi(stories) of nano-technology	Our original goal was to help business leaders with non- technical backgrounds understand the technology. The purpose of the publication was… education to the market place…so this is what nanotechnology is.	Nanotechnology, the manipulation and control of matter at the molecular level, has widely been recognized as critical for the future of economic and regional competitiveness, job creation, and technological superiority. [The Report] demonstrates how nanotechnology affects every existing industry, from Chemicals, Textiles/Apparel, Computing and Storage, to Transportation, Energy, Power, Healthcare and Homeland Security.

Toward this end, the VCs constructed their own firms, nanotechnology start-ups and supporting organizations. The VCs founded the first nanotechnology trade journal, the most widely read newsletter, the nanotechnology trade association, a research organization devoted to providing intelligence on nanotechnology to large corporations and a nanotechnology stock index. They also sponsored the first nanotechnology investing conference with the intent of bringing together and building a community of people interested in commercializing the technology.

The entities the VCs founded were substantive and symbolic resources. Entrepreneurs require resources to create organizations and commercialize technologies. Resources include factors such as financial capital, human capital, intellectual property and equipment. Resources can have both substantive and symbolic dimensions. The substantive dimension derives from the material aspects of an object and the tangible functions that it performs. So, for example, a VC's office is a substantive resource, serving the intrinsic function of a place of work. The office can also have a symbolic dimension. For example, acquiring a corner office symbolically signals greater permanence and legitimacy than working from home. Substantive resources can provide the opportunity to generate symbolic resources, which enable founders to define the emerging technology domain for others.

Nahapiet and Ghoshal (1998) argue that "resources providing shared representations, interpretations, and systems of meaning" generate cognitive capital. I term these resources symbolic resources, in that their value is derived from symbolic meanings. A symbol represents something else and conveys a socially constructed meaning that is different from the meaning conveyed by its material aspects or apparent function (Zott and Huy, 2007; Morgan, Frost and, Pondy, 1983). A prestigious office location can symbolically suggest status and prosperity (Zott and Huy, 2007; Oldham and Rotchford, 1983).

The physical spaces the VCs constructed provided a place to meet with potential partners and desired constituents, while the media outlets provided a means to construct a domain-specific discourse and to disseminate the VCs' interpretation of events to a target audience. When the VCs in this study acquired their first office, opened a new office, or moved to more prestigious address, they issued press releases to accentuate and disseminate the symbolic value of their new resource. And when VCs wrote reports, spoke at conferences and met with Senate and Congressional leaders, they reported these events through their WebPages and media outlets, conveying the symbolic message that their expertise was recognized and valued (Zott and Huy, 2007).

Symbolically, these resources represented the beginnings of a cognitive category. Together, the physical spaces, discourse spaces, and the cognitive category constituted a space in which activities and technology could take on a unique meaning within the context of the emerging domain. Within this space, nanotechnology proponents could act and speak as though their imagined future were a reality. For example, within the nanotechnology specific, domain the technology and activities associated with it could be given meanings that were not accepted outside of the space: Nanotechnology could mean a business opportunity; investing in companies seeking to commercialize products using nano-scale materials could be termed nanotechnology investing. Within the nanotechnology space, nanotechnology business proponents could experiment with practices, identities, labels, and frames and determine which had the greatest potential for building their domain.

By constructing entities, attending and sponsoring field configuring events such as the first nanotechnology investing conference, and disseminating domain specific discourse, the VCs initiated interactions at two levels, the structural and cognitive. Lampel and Meyer (2008: 1027) explain that organizational fields emerge when at some point "the density and intensity of participants' interactions reach critical thresholds at the structural and cognitive levels." The field acquires macro structural features that reinforce its permanence and members begin to become cognitively aware of the field and their own identity as field members. Structural and cognitive elements reinforce each other as participants construct cognitive representations of the "agglomeration" as an evolving entity alongside their representations of their positions within "this entity" (Lampel and Meyer, 2008:1027). I use the term socio-semiotic space to refer to Lampel and Meyer's (2008) "agglomeration" and the nanotechnology business proponents' "space," "niche," "domain," and "community," which exists, generates resources and influences outcomes even if it does not become an organizational field. I discuss this concept further later in this chapter.

The nanobusiness socio-semiotic space, which the VCs constructed was characterized by two key elements. The space was limited to nanotechnology and therefore, was unpopulated. There were very few business people, and no institutional investors, focused on nanotechnology business opportunities at the time, as one of the VC founders recalled:

> Nobody or hardly anybody in the venture world is focused on nanotech." [We] had idea to start our venture capital firm focused on an area that was largely ignored by a lot of institutional venture investors in the materials science space, which later combined with mesoscale physics, and got the popular buzzword of nanotechnology. —*Nanobusiness leader, interviewed by Kathryn Aten*

Another explained in an interview, "When [we] started, if you talked to the people who were the experts or analysts—and there were only a handful of them at the time—most people didn't know anything about it." These characteristics allowed the VCs to define the situation in the nanotechnology business space they created.

The substantive resources they created in the form of organizations and documentation provided a physical space for meeting and talking about nanotechnology and a media outlet for a limited, business-focused discourse. Symbolically, the entities conveyed the existence of a nanobusiness niche and lent a sense of permanence. The nanobusiness socio-semiotic space encompassed the experimental cognitive and structural interactions that come before an institutionalized organizational field and the space became a symbolic resource the VCs later used to position themselves as experts and project their nanobusiness technology frame.

Positioning

The second activity the VCs engaged in is positioning. Positioning is the process of building a reputation for domain-specific expertise. It involves the use of the substantive and symbolic resources generated through the construction of the socio-semiotic space to position oneself as a central figure and expert within the space. Constructing is the creation of the space by founding entities, whereas positioning is the use of those entities; such as for example, constructing a building involves the activities to create it and using a the building may involve living, working or holding events in it. The VCs populated the media outlets and conferences they created with internally generated discourse. Through positioning, they created resources such as a nanobusiness label, reports, blogs, press releases, organization histories and founder biographies.

After constructing the nanobusiness socio-semiotic space, the VC firms used the resources this activity generated to position themselves as experts within the space. As one VC describing his firm's strategy explained in an interview, "[Our strategy] really is two-fold. It is public perception and actual fact of us being at the epicenter of everything going on in nanotechnology." They positioned themselves as experts by populating the socio-semiotic space they had created with texts and then claiming authorship and expertise in subsequent texts.

The VCs distributed texts through the websites of the organizations they founded and invested in, the media outlets they created, and the conferences they sponsored. They wrote reports, made conference presentations and made extensive use of the Internet to disseminate blogs and newsletters. One VC described the launch of his firm's newsletter and its symbolic value as follows:

> It became the fastest growing newsletter in [our media partner's] history. It grew from 0 to maybe 5000 subscribers in under two weeks. And then it just ramped up from there to…distribution of maybe 90,000 people when you combine the free Friday e-mail newsletter that my business partner types up. The report was what originally paid our salaries but it was

> probably more important as credibility in the space...You know it opens the door to CEOs of companies like Pfizer. You can talk to them...not like a no-name from a new firm. —*Nanobusiness leader, interviewed by Kathryn Aten*

By referring to themselves as experts in biographies they included in conference programs, on their WebPages and in press releases they labeled themselves as nano VCs and nanotechnology experts. A label serves to associate something with an explicit meaning (denotation) and implicit meaning (connotation) (Pierce, 1931). Thus, the label nanotechnology associates a product or business with an explicit category of technologies based on the manipulation of matter at the nanoscale and also with implicit meanings such as "futuristic," "trendy," or "threatening," depending upon the interpreter. In the case of the nanotechnology VCs, the nano VC label denoted a limited category, in which they could claim to be the experts. The label connoted the implicit meaning of cutting edge and emerging technology, as explained by one founder in an interview, "[Our] name signifies people who are extremely connected with the industry but also does represent to a certain extent the brand of emerging technology or kind of the cutting edge." The VCs used the reports they had written and their appearances on news programs as examples of their expertise in this limited, cutting edge domain as in this biography:

> He has been an invited guest speaker, lecturer, and panelist on nanotechnology for CNBC, CNN, Harvard, Yale, Wharton, Columbia, Cornell, Merrill Lynch, Credit Suisse First Boston, Capitol Hill, government labs, and officials in France, Canada, UK, Spain, Singapore, and Germany. Widely recognized as one of the preeminent minds in nanotechnology and finance, [he] has been invited by the White House and Canadian Government to advise government organizations on funding strategies. —*Nano VC WebPage*

Key to the value of the VCs gained through positioning is the uniqueness of the information the VCs provided and their ability to link themselves with the information in order to capture symbolic value. One founder explained the importance of this linkage as follows:

> We've focused on supplying unique, very hard to get content from a research information dissemination standpoint but also we've been fairly savvy with the media and the press…We've tried to make sure that if there is any press either on CNN or NPR or going across the Wall Street circle that we make sure that [our] name is in it. —*Nanotechnology business leader, interviewed by Kathryn Aten*

Positioning created durable resources in the form of written texts and the nano VC and nanobusiness expert label. The value of these resources was enhanced by the rapid and inexpensive proliferation of the texts on the Internet. As one participant explained, nanotechnology was the first technology to emerge in the Internet age. Thus, reports, press releases, electronic newsletters, and even conference programs and biographies are easily accessible, and remain so. These resources have gained greater visibility and permanence than they would have if they existed only in hard copy form. For example, a search on "NanoTech Investing" using the Google search engine at the present time results in 31 urls from 2001, 320 from 2005, and 388 from 2007. Documents, such as conference programs, which prior to the Internet would have had a very limited dissemination and life, now remain easily accessible and generate lasting reputational capital and symbolic value.

Translating

The third activity the VCs engaged in is translating. Translating is restating ideas expressed in one language or symbolic system into another while preserving the original meaning. The VCs used resources they accumulated through their previous activities to translate nanoscience into business opportunities. The VCs translated nanoscience into nanobusiness by identifying and educating their desired constituent group by telling narratives. They created resources by selecting evocative metaphors and memorable exemplars, which diffused into externally generated texts such as Congressional records and mainstreampress accounts. The value of these resources grew as the stories, metaphors and exemplars were repeated by constituents and in the popular press.

Translation involves negotiation between parties and results in reshaping meaning (Zilber, 2006). This occurs for example when two parties trying to understand one another go back and forth, "You mean…" "No more like…" "Oh, I see…" The VCs defined their desired constituency as business and government leaders. They sought to educate this constituency about the possible business applications and economic impact of nanotechnology. As one VC explained in an interview, "Our original goal was to help business leaders with non-technical backgrounds understand the technology." They used their resources to define nanoscience as nanobusiness as described by one VC founder as follows:

> We spent the better part of two years…meeting with Senators and Congressman and trying to educate them on what is nanotechnology, why is this good for job growth, and is this good for US technology leadership and US competitiveness, and what are some tangible examples of how this

> could benefit a wide variety of industries. *–VC firm founder, interviewed by Kathryn Aten*

Their efforts were specifically targeted to translate nanoscience into nanobusiness by emphasizing the commercial and economic implications of potential applications their constituent group.

As explained in Chapter V, the VCs described business applications and products, and de-emphasized or even debunked the more grandiose potential of nanotechnology. They told stories of nanotechnology using appealing, emotive language as in this early report:

> With an onslaught of funding from almost every government science agency, major contributions from titans of technology…you can bet nanotechnology is not just a fad…Commercial developments in nanotechnology have and will continue to surface…ushering in a new frontier. *–Nanotechnology report*

Nanotechnologies were presented in metaphorical terms, compared to other technologies that are familiar and non-threatening. Metaphors, language that directly connects seemingly unrelated referents, are "simplified articulations" (p. 1062) and the first philosophical and psychological step in the development of mental models (Black, 1962; Morgan, 1980). Metaphors "lay down a foundation for language and terminology specific to…[a] given venture, organization, or industry" and "…are valuable in simplifying complex issues such that those not deeply knowledgeable about specific contextual issues may share in their understanding" (Hill and Levenhagen, 1995). As metaphors are accepted and used, the metaphorical concepts become understood as facts.

The metaphor becomes accepted as domain specific language used to articulate formal models and understandings.

The VCs were careful to position nanotechnology in terms of the next step in the history of technological development:

> There are materials with nanoscale dimensions that have been around for hundreds of years or more…If you wanna put a pretty word on it, you would say carbon black has been synthesized in the incomplete combustion of natural gas for twenty-plus years. If you wanted to be gauche about it, you would say soot has been made by burning stuff for much longer than that and these materials have nano-sized properties but nobody was optimizing for particle size…in the late 1800s…nano-sized structures [have been] employed for a long time. The purposeful engineering of them, is what's interesting. *–Nanotechnology business leader, interviewed by Kathryn Aten*

Other observers have noted that entrepreneurs can reduce resistance to innovations by positioning them within existing institutional frameworks (Hargadon and Douglas, 2001).

The resources generated from constructing and positioning provided the VCs with credibility and access to their desired constituents. The VCs were eventually able to project their definition into the more general media, as explained by a founder in an interview:

> We've been able to not only to steer some of the direction of TV programming but also to load them up with…[our research], which will get to content for a lot of their presentations. *–VC firm founder, interviewed by Kathryn Aten*

By presenting nanotechnology as the natural extension of past technologies and commercial opportunities, the VCs reduced resistance to nanotechnology. The narratives, metaphors, and exemplars they used, like the texts they created, became resources repeated in press accounts and by constituents and once again their value was amplified because they wre readily available on the Internet.

The examples above illustrate two key aspects of the value created through translating. First, the stories the VCs told were appealing, sufficiently so that they were repeated in press accounts. A story related by the VCs about "nanotechnology" in medieval stained glass was frequently repeated and appears in multiple urls in a Google search. Second, by positioning nanotechnology as an extension of the ongoing trend of miniaturization, the VCs were able to minimize resistance.

The VCs engaged in three sequential activities—constructing, positioning, and translating. These activities were sequential in the sense that the later required the resources of the former: positioning in the socio-semiotic space could not precede its construction. For example, in early reports in a trade journal, one of the VCs was consistently described as "fledgling." Whereas, in later years, the firm is described in that same journal as "premier" and "leading." The first activities did not, however, cease when new activities were introduced. Each of the activities provided the VCs with resources. These resources enabled a small group to project a nanobusiness frame, first to their limited desired constituency and then into the general discourse.

Socio-semiotic Space and the Projection of a Technology Frame

In addition to the three activities that VCs engaged in, the data revealed the VCs' perception of causal links between their activities and the generation of symbolic power. The VCs attributed positive outcomes to their activities, which they explained in response to my questions about the benefits and costs their domain building activities. Working from these perceived causal links, my theory and the literature, I explain the role of a socio-semiotic space in the projection of technology frames. The outcomes and examples of the VCs' causal attributions are shown in Table 11 and discussed below.

Table 11: Participant Outcomes and Attributions

Outcome	Positioned as experts	Influenced corporate investment and strategies	Passage of legislation to provide federal funding for nanotechnology
Causal Attribution	And it was that original report that really put [us] on the map back in 2001 as the kind of go to shop for…research and intelligence on nanotechnology.	They work with major corporations...[and] helped shape the strategy of how these companies are embracing it…It helps senior management craft strategies and allocate resources for embracing nanotechnology.	They put in all that work. If they hadn't worked to get the bill passed, if they hadn't run the conferences…if they hadn't created all of this information for the industry they would have nothing.

Perceived Outcomes and Causes

The participants in this study actively attempted to create a new business domain. The descriptions the founders of the focal firms in this study were supported by their peers, for example one business leader explained, "They put so much time and energy and effort into influencing government thinkers, influencing VCs setting up conferences, providing good speakers…They did a lot of that ground work." The VCs in this study perceived that their activities resulted in positive outcomes for their firms. As one founder explained in an interview, "By positioning ourselves at the center of things…we've absolutely attracted deal flow." A business leader commenting on this firm echoed this statement, "Any company started in nanotechnology is likely to fall into one of …[their organizations] at some point very early on. So from a deal flow standpoint, they'll see most of the deal flow out there."

The VCs believed that their activities resulted in the recognition of nanotechnology business as an entity by government and established business interests. First, they see the passage of the NNI and other funding as evidence of that a domain exists. As one business leader explained in an interview:

> It exists. I mean there are stories about nanotechnology…There is an NNI…And this was the beginning, the nucleation of the brand space for the public because suddenly the tax payer went, wow, a lot of my money is going to this thing called nanotech. It better be good. What is it? And I think that as the industry is developed, we've started, the media picked up on it and now people talk about nanotechnology, as a platform technology that is going to enable these things. So there are good, positive connotations to that brand that came simply due to the fact that the government is willing to invest in it, the universities believe it, and the researchers are willing to follow it, and there are companies now formed around it. *–Nanotechnology Business Leader, interviewed by Kathryn Aten*

Second, the participants in this case specifically attribute the passage of government funding to their efforts. For example, one business leader acknowledged the importance of NNI and attributed its passage, in part, to his organization's efforts in creating a community:

> I think the NNI initiative and the bill being passed…said very loudly this is a priority and we need to really focus on this as a core competence of our research and development. [We] played a very critical role… I believe we have created a community of folks who use us to understand how the technologies are being applied in different sectors and being able to think through the different potential applications and how it might fit with their business or where their business might fit into the larger product community…[We] definitely had an influence at least among some key players early on and then the ball got rolling…we played a role in that [getting it started]. *–Nanotechnology Business Leader, interviewed by Kathryn Aten*

Similarly, a VC explained his firm's role in gaining the support of government leaders:

> So that was [our organization] and what ultimately that led to was the bill that was promoted by Senator Wyden, of course, and Senator Hillary Clinton...So Bush signed that bill into law in 2003 and allocated about $1 billion dollars per year in government funding for nanotechnology and that was really a critical inflection point for this overall sector, if you want to call it that, in that here was a permanent Congressional mandate to have government funding go into nanotechnology. That's also helped set a lot of the data points for nanotechnology, surpassing the overall level of funding for the human genome project. Its also been one of the largest government science initiative since the space race...So, I guess that summary of how we helped create a sector, or create an industry depending on who you are talking to, is a hybrid of not only having advanced knowledge...but also in creating this kind of unique model... – *Nanotechnology VC Firm Fonder, interviewed by Kathryn Aten*

Finally, participants also credited themselves with influencing large corporations:

> [Our] work with major corporations like GE, EMAT, BAXTOR, and so forth and involvement with some of the largest corporations in the world and some of the largest financial institutions and governments for that matter has really, I think, helped shape the strategy of how these companies are embracing it.

Although participants initially spoke of creating a nanotechnology industry, it became clear that this was unlikely. However, as in the quotations above, the participants take credit for the creation of something. I term this entity a socio-semiotic space.

Socio-semiotic Space. How domains of commercial activity emerge from technological innovation has been a central and problematic question in technology and innovation management research (Aldrich and Fiol, 1994; Hargadon and Douglas, 2001; Garud and Rappa, 1994; Muir and Philips, 2004; Kaplan and Tripsas, 2008). Recent work has adopted the concept of organizational fields. However, organizational fields are by definition institutionalized. An organizational field is "a cluster of organizations and occupations whose boundaries, identities, and interactions are defined and stabilized by shared institutional logics (Greenwood and Suddaby, 2006: 28). Institutional logics "are taken-for-granted, resilient social prescriptions…specifying the boundaries of a field, its rules of membership, and the role identities and appropriate organizational forms of its constituent communities" (Greenwood and Suddaby, 2006: 28). Recent research exploring emergence draws on the notion of organizational fields (e.g. McGuire, Phillips, and Hardy, 2001; Chiles, Meyer, and Hench, 2004). However, if entity is not or does not become an institutionalized filed, academics, like the participants in the nanotechnology space, are left without words to describe the phenomena.

I use the term socio-semiotic space to refer to the entity that nanotechnology business proponents constructed and in which they created and experimented with meanings and patterns of interaction that constituted their nanobusiness frame. In a socio-semiotic space, participants experiment with boundaries, identities and interactions that may (or may not) come to be stabilized in an organizational field. Boundaries and rules of membership are argued, identities of individuals and firms are put forth and revised, new organizational forms emerge but may not stand the test of time. However, the meanings and interactions that develop in the socio-semiotic space will influence the development of the technology (whether within in a specific organizational field or dispersed through many) as well as the specific organizational field if one does develop. Additionally, the meanings and patterns of interactions are resources available to participants for future use in other situations.

I draw the term socio-semiotic from the study of social semiotics, a branch of semiotics (the study of signs), which focuses meaning making as a social practice

(Thibault, 1991). Semiotics is "a formal mode of analysis used to identify the rules that govern how signs convey meaning in a particular social system" (Fiol, 1989: 278). Researchers adopting a semiotic perspective have used the term semiotic space to describe dimensions of meaning around a particular sign (Tavory and Swidler, 2009). So, for example, the meaning represented by an individual's dress can vary along the dimension of formal to informal. Social semiotics is a reaction to what some researchers felt was a neglect of the role of social influences and individuals in creating and changing the meanings attributed to signs. Social semiotics includes the study of how people design and interpret meanings, the study of how semiotic systems are shaped by social interests and ideologies, and how they are adapted as society changes (Hodge and Kress, 1988). To social semiotic researchers, signs are resources that people use and adapt as opposed to fixed codes. I use the term "socio-semiotic" based on this perspective with the term "space" derived from my data to convey the space in which social interactions, negotiations and meaning making activities occur.

I conceptualize a socio-semiotic space with the metaphor of a construction zone. Like a construction zone, there is organization. Individuals act on goals. Patterns of action and social structures develop and are constituted and reconstituted through the actions of participants. However, the organization is rapidly changing based on the needs of the project. It is emergent. Individuals must respond to the environment they are building and each other as the project proceeds. Resources are created in the space. In a construction zone, people use and create substantive resources, such as buildings, as well as symbolic resources. The construction effort can come to represent something more than the edifices left behind as indicated by, for example, the plaques dedicated to the people who have played key roles in large projects. Dams, for example, may represent progress and ingenuity, or hubris depending on one's perspectives.

Like a construction zone, a socio-semiotic space is temporary. However, it may become the basis for a more permanent entity, such as an organizational or technology field as in the case of biotechnology. Or, as appears possible with nanotechnology, the space may never become a recognized organizational field. In either case, the meanings and interactions negotiated during the pre-emergent will influence the developing technology and may provide resources for the founders of the space.

As in a construction zone, elements that are constructed will influence the final organization after the entity ceases to be easily recognized as a construction zone. As the roads and buildings laid down during the construction process direct traffic patterns in the final site, the meanings and interactions constructed in a socio-semiotic space will influence an organizational or technology field that emerges from it. The meanings and interactions may become institutionalized in the form of industry and market categories, industry recipes, organizational identities, and legitimate organizational forms and practices.

Alternatively, as in a construction project that is halted midstream, some resources (i.e. paths and roads) may remain available for use. In the case of nanotechnology, these are substantive in the form of organizations, reports, and journals and symbolic in the form of the nanotechnology business frame, the nanotechnology business label, and the practices associated with nanotechnology investing. While it appears that there will be no enduring nanotechnology field, nanotechnology is thriving. The texts, narratives, exemplars, metaphors, and labels created within the nanotechnology socio-semiotic space remain available and continue to influence discourse. The nanotechnology business frame remains dominant.

As in a construction project where individual contractors, and certainly the architect, may profit or make a reputation even if the project fails, the founders of a socio-semiotic space may accumulate resources that are transferable to new settings. At least one of the VCs and one of the supporting firms in this study explained their intention use the resources they developed through their activities to create a nanotechnology space in future emerging domains. One founder joked, "Maybe in a couple of years from now you'll be talking to me about the new emerging technology trend that we've identified." Another leader explained in greater detail:

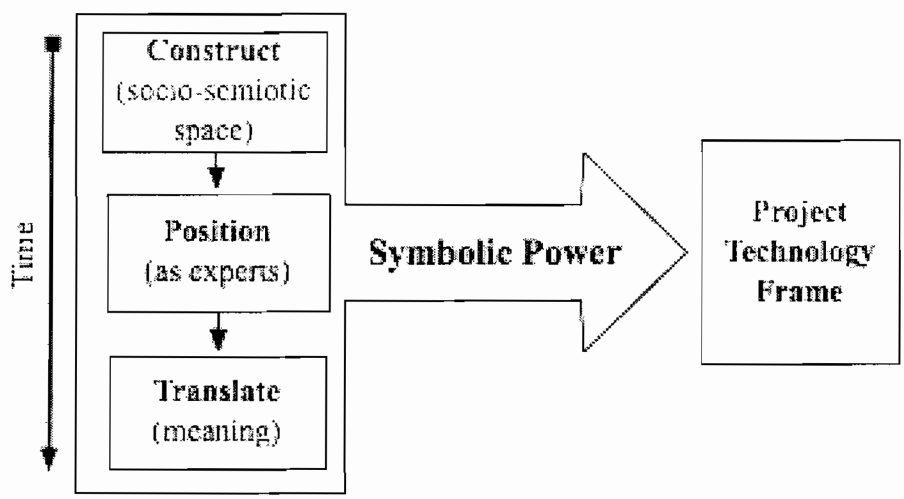
> We started with nanotech because it is very precisely broad, crossing with lots of different sectors. It has a porous definition, right? And it's something where we thought we could go in and build up a client base…A lot of people are interested in a lot of science, and energy, and environment, and then we can start to carve out industry practices, sector practices for this that are not about nanotechnology. They are about a broader field of science-based innovation. *–Nanobusiness founder, interviewed by Kathryn Aten*

The concept of a socio-semiotic space is derived from the data in this research. As do organizational researchers, participants in the emerging nanotechnology domain struggled over what to term the "space" they acknowledged they were creating. I began with their term "space" and drew "socio-semiotic" from the field of social semiotics to convey the notion of signs as resources that represent designed and interpreted meanings within a changing social system. This concept serves to describe the meaning and interaction construction zones that are constructed to support domains of commercial activity emerging around science-based technologies and may or may not become organizational fields.

Projecting a Technology Frame

By constructing a limited socio-semiotic space, this group was able to define the situation for their desired constituents, gain their support, and use the resources these activities generated to project their frame into the larger discourse, as shown in Figure 6.

Figure 5: Projecting a Technology Frame



Hallet (2003) defines "the power to define the situation in which interactions take place" symbolic power. Hallett (2003) argues that cultural contexts are negotiated structures that emerge through interactions between people. However, all negotiators do not have equal power. Certain negotiators can gain disproportionate power over the negotiated structures that comprise the cultural context. Individuals gain power when they engage in practices that are valued, others imbue them with legitimacy by showing dereference defined as "a symbolic means by which appreciation is regularly conveyed to a recipient" (Goffman, 1967:56 in Hallett, 2003). Thus, for example, the general press imbued the focal VCs in this study with legitimacy when reporters referred to the VCs as experts, leaders, and pioneers.

A technology frame is a negotiated understanding of what a technology is and how it should be used. The focal VCs in this study gained the power to define nanotechnology, symbolic power, by creating sources of legitimacy. In an emerging industry the constituents and practices that will confer legitimacy are unclear. By constructing a socio-semiotic space the VCs in this study were able to gain enough symbolic power to define nanotechnology business and legitimizing practices within that space. They were then able to position themselves as experts within the space further enhancing their legitimacy, which allowed them to translate nanotechnology into nanobusiness for their desired constituency. This in turn, further enhanced their legitimacy eventually allowing them to deploy symbolic power to define nanotechnology for a larger audience.

The constructed niche-space provided a venue for specialized business interaction and discourse. Founders were able to use this specialized space to engage in practices and claim those practices as legitimate within the confines of the space. The resources within the space enabled founders to position themselves as experts in order to generate and claim additional resources and broaden their influence. As they become recognized as experts, the founders gained more resources and greater power to define the situation until, as explained by one participant,

> They marketed nanotechnology…How do you explain to people what nanotech is, make people care about it, make teachers want to teach it the universities, make people want to invest in it make people want to start companies in it. All of that you have to make people care. At the end of the day that's the question, I always say who cares. Until people care about something, anything, whether it's a product or an industry, it doesn't matter. And they made people care. They made people care about nanotech.

By describing ambiguous and complex scientific discoveries in terms of business opportunities applications, the founders gained symbolic power as experts in nanotechnology business. Business people, government leaders and the press came to them for explanations and their stories were cited and repeated. Constructing, positioning and translating can thus imbued a small group with symbolic power to project a technology frame.

Conclusion

Most research on the emergence of technologies and commercial domains around them begins with an assumption that market needs exists and entrepreneurs recognize and take advantage of them (Constant II, 1987; Schoonhaven and Romanelli, 2001). Additionally, with few exceptions (e.g. Hargadon and Douglas, 2001; Mcguire and Granovetter, 2003), the attention of technology management research has focused technologies for which for a product applications are defined (e.g. Garud and Rappa, 1994; Tripsas, 1997; Munir and Philips, 2005). Many significant technological innovations are born in the realm of basic science long before a product or specific application exists. Science-based technologies traverse a difficult path from discovery to a marketable product or useable process during a period of pre-emergence. During this period meanings and interactions, which influence technological trajectories and domains are formed (Kaplan and Tripsas, 2008). Because most research begins with the assumption of a product and market, and neglects this pre-emergent period, our explanations of the emergence of technologies and commercial domains around them are incomplete.

In this study, I examine the pre-emergent period of nanotechnology, when business proponents of the technology are beginning to organize. This setting provides an opportunity to focus on a previously neglected stage in the development of technologies and emergence of domains of commercial activity. The data and my analysis reveal that business proponents engage in three sequential activities in their attempt to create an infrastructure to support the development of commercial activity around nanotechnology; constructing a socio-semiotic space, positioning themselves as experts within the space, and translating scientific, futuristic and opposition discourse for their desired constituents.

I introduce the concept of a socio-semiotic space, a meaning and interaction construction zone, which may or may not become an institutionalized field. I also used grounded theory methods to develop a process model describing three mechanisms (constructing, positioning, translating) that participants invoked sequentially to create a socio-semiotic space that promoted the emergence and commercial development of nanotechnology. By constructing a socio-semiotic space, positioning themselves as experts within the space, and translating scientific, futuristic and opposition discourse for their desired constituents, a small and relatively disadvantaged group of technology proponents were able to project a nanobusiness frame into the general discourse. By constructing a limited socio-semiotic space, this group was able to define the situation for their desired constituents, gain their support, and use the resources these activities generated to project their frame into the larger discourse.

Conceptualizations such as an industry, identity, or category, imply a lasting and enduring quality of an institutionalized entity that has come to be taken for granted. These concepts don`t describe the emergent, changing and impermanent nature of the "space" that nanotechnology proponents credited themselves with creating. Nanotechnology is not an industry, an organizational field or technology field as defined in the management literature, but the data show that nanobusiness become a legitimate frame and participants credit themselves with creating a "space" which they used to gain recognition and resources from their desired constituents.

Greater understanding of the processes of this pre-emergent period, and in particular of technology framing, contributes to our understanding of how new technologies emerge. By explaining how technology proponents create the sociopolitical infrastructure necessary for emerging technologies to thrive, this study provides guidance to business people and policy makers seeking to develop and support such technologies and the domains that emerge around them.

CHAPTER VII

DISCUSSION AND CONCLUSION

How technologies and domains of commercial activity based on them evolve has been a topic of interest to management and organization scholars for some time (e.g. Dosi, 1982; Tushman and Andersen, 1986; Utterback 1994). However, the early emergence of such entities remains under-explored despite calls for research (Meyer, Gaba, and Colwell, 2005). Given the economic importance of emerging technologies and ventures founded to commercialize them, it is not surprising that after decades of research this question remains critically important to both researchers and managers (Kaplan and Tripsas, 2008). Nor, given the difficulties of studying emerging domains, is it surprising that most research neglects this period. However, without explanations that consider the processes that shape the early emergence of technologies, our knowledge of the technology development cycle and the emergence of commercial domains based on technologies is incomplete. Scholars' neglect of the period of early emergence often results in explanations that imply technological determinism and ignore the role of human agency.

In this dissertation I investigated the processes through which scientific discoveries become the basis for domains of commercial activity. I focused on the period of early emergence, when the understandings of proponents, opponents, users, scientists, and designers of technologies begin to form. These understandings influence the end design and the success or failure of commercialization attempts. The analysis of this period and the findings of this dissertation contribute to our knowledge of the technology development cycle by identifying and explaining the understudied processes of early emergence, in particular, technology framing. I contribute to our theoretical knowledge of how science discoveries become the basis for fields of commercial activity by explaining the process through which technology proponents project a technology frame into the public discourse. The findings of this dissertation can provide guidance to managers and policy makers grappling with rapid technological change.

Process Theory and Boundary Conditions

In this dissertation, I adopt a process approach (Mohr, 1982; Langly, 1999). The emergence and commercialization of technologies, the evolution of technology trajectories, and the institutionalization of technology and organizational fields are processes. To understand these processes, how things evolve over time, and why they evolve in the way they do, research must pay particular attention to events and time sequences (Poole, Van de Ven, and Dooley, 2000). Process data deal with sequences of events, involve multiple levels and units of analysis, are temporally embedded, and are often eclectic including in addition to events, changing relationships, thoughts, and interpretations (Langley, 1999).

In this dissertation, I developed a process theory explaining the role of technology framing in the emergence of a commercial domain by identifying the sequence of events that leads to the projection of a technology frame. I documented the emergence of competing nanotechnology frames in the period prior to the identification of product applications. I identified three sequential activities of nanotechnology business proponents: constructing a socio-semiotic space, positioning as experts within the space, and translating scientific, opposition and futuristic discourse for a target audience.

I also introduced the concept of a socio-semiotic space, a meaning and interaction construction zone, which may or may not become an institutionalized field. By constructing a socio-semiotic space, positioning themselves as experts within the space, and translating scientific, futuristic and opposition discourse for their desired constituents, a small and relatively disadvantaged group in terms of their initial resources may project a technology frame into the general discourse. By constructing a limited socio-semiotic space, the small group may be able to define the situation for their desired constituents, gain their support, and use the resources these activities generate to project their frame into the larger discourse.

This dissertation is a study of the emergence of science-based technologies. Not all commercial domains emerge around science-based technologies. Commercial domains may emerge around new services, business models, or product introductions that are not based on scientific discoveries. For example, express shipping and craft brewing introduced commercial domains that were not based on scientific discovery. As explained in this dissertation, science-based discoveries and the domains that emerge around them are likely to be particularly susceptible to linguistic, cognitive, and social processes. Additional research will be required to determine to what extent the process described in this study applies to other types of technologies and commercial domains.

Contribution to Theory

How domains of commercial activity emerge, whether termed markets, industries, organizational fields or technology fields, is a difficult yet important question. New domains are the basis for new organizations, new technologies, and economic growth. However, organizational theory provides only limited explanations of how entities emerge. Studies typically focus on either change in existing domains or begin after the social, cognitive and linguistic foundation on which new domains are based has been constructed.

The predominant methods of organizational research are not well suited to the study of emergence (Meyer, Gaba, and Colwell, 2005). Meyer, Gaba, and Colwell (2005: 470) speculate that researchers avoid asking questions about emerging social systems because systems in flux violate "dogma about rigorous methodology." They explain that because much social scientific theory and methodology begin from the assumption of equilibrium, fields in flux are unappealing research settings. "Like earthquake victims, researchers steeped in equilibrium assumptions usually run for cover, wait for the tremors to stop, and then return cautiously to sift through the debris" (470).

Most accounts of the emergence of technologies begin when a product is introduced or a use for a technology becomes widely accepted. Researchers often assume that a technology develops and then a field and associated institutions form. Because most research focuses on the later stages of emergence, it is hard to challenge claims that the existing reality is an inevitable consequence of a technology. However, as I show in this dissertation, when viewed in real time, it is apparent that some elements of technologies and organizations that in hindsight appear inevitable are in fact constructed, negotiated and contested.

New commercial domains for science-based technologies begin as imagined futures. The data collected and analyzed for this study show that individuals, guided by their imaginations, build the social, cognitive, and linguistic infrastructure that influences technology trajectories and supports the emergence of commercial domains. Visionaries, proponents, and opponents begin to speculate on the potential benefits, consequences, and structure of possible domains long before they exist. People begin to experiment with language to describe technologies, stories that exemplify potential applications, and metaphors that suggest the possible implications of technologies. Speculative labels, (his)stories, metaphors, and exemplars are repeated, and if collectively accepted, they begin to be taken for granted. Collective fantasies can begin to gain structure. When a new domain has emerged and gained recognition as an industry, it may appear to have been the inevitable consequence of a new technology. However, as the data in this study show, this may not be the case.

Early experimentation occurs in settings that permit the enactment of an imagined future, such as in science fiction, at conferences, and in specialized texts. Some of the earliest mentions of nanotechnology in the *New York Times*, for example, are in reviews of science fiction novels. Early conferences attracted futurists and offered a setting in which it was acceptable to talk of extreme life extension as a real and imminent opportunity. Attendees at futuristic conferences discussed "how," not if, humans will deal with immortality. Similarly, attendees at the earliest Nanotechnology Investing Forums talked about "the nanotechnology industry" and listened to presentations by representatives of a trade journal representing an industry that did not exist.

Experimentations in such settings form the basis for the cognitive and structural elements that can subsequently become new domains. At this early stage, an emerging domain is constituted of webs of meaning communicated through language and action, rather than flows of resources. The ideational network precedes the organizational network. As Sir Edmund Leach argues, "The world is a representation of our language categories, not vice versa" (Leach, 1964: 34). A socio-semiotic space is the setting that technology proponents construct with, and for, their experimentations. I introduced the concept of a socio-semiotic space to describe and define the agglomeration that comes before an institutionalized field.

Because in its earliest emergence a new science-based technology domain exists in the realm of the imagination, the use and construction of language—word choice, stories, metaphors, labels—are key processes. The methods and setting I selected for this study are well suited to the exploration of language and meaning construction and, thus, also well suited to provide theoretical insights into the early emergence of commercial domains. Focusing on a single case allowed me to collect rich data and situate the case in its history. By studying events as they unfolded, in real-time during the significant period of the early emergence of a commercial domain, I was able observe participants' experimentations. An interpretive, grounded theory approach revealed the role of understudied social, cognitive, and linguistic processes in the emergence of technologies and commercial domains. The findings of this study contribute to theories of technology and innovation management, organizations and management, and entrepreneurship.

Technology and Innovation Management (TIM)

As explained in Chapter II, the dominant model of technology evolution, which has been tested and found robust in many industries, is based on a life cycle metaphor. A new technology elicits competing designs that usher in an "era of ferment." The competition and uncertainty ends with convergence on a dominant design. This model begins with the competition between designs—products or applications compete for dominance in a market. The model thus assumes the existence of both products and market. As discussed in Chapter II and above, the model and the assumption of a product and market ignore the earliest stage of technology development.

This study contributes to our knowledge of technology evolution by extending our understanding to include the earliest stage of the technology lifecycle. I document the emergence of technology frames prior to the existence of a concrete application for the technology. The study shows that a nanobusiness frame emerged before widespread commercial activity and that this frame influenced investment in nanotechnology by government and large corporations. Furthermore, this study shows that some versions of nanotechnology were defined as "real" while one was relegated to the realm of science fiction. The meaning attributed to these competing versions of the imagined future assuaged public fears of potential risks, influenced government and corporate investment, and thus influenced the trajectory of nanotechnology's development. This study suggests that to understand how a technology design emerges and becomes dominant, researchers need to pay attention to the earliest language and interactions of participants in an emerging domain.

Organization and Management Theory (OMT)

As I discuss in Chapter II and above, researchers have struggled with the question of how new organizational entities emerge for some time. However, our explanations still focus on predominantly on change, typically brought about by exogenous drivers, rather than emergence. Much recent work has focused on organizational fields, a concept central to institutional theory. The impact of institutions on organizations has received much more attention than their origins (Powell, 1991; Barley and Tolbert, 1997; Chiles, Meyer, and Hench, 2004). Recent interest in institutional entrepreneurship (e.g. Maguire, Hardy, and Lawrence, 2005) has begun to focus attention on earlier stages of emergence. However, even in this literature, the focus usually begins after meaning has formed as a movement or collective identity. This study contributes to this literature by focusing on the early construction of meaning, which forms the basis for a domain if one emerges, and by introducing the concept of a socio-semiotic space as a precursor to an organizational field.

Connections Between Theories of Culture and Institutions

Recent years have witnessed burgeoning interest among management scholars in the role of symbols and systems of meaning in enabling and constraining organizational behavior. This interest is evidenced by a recent call for contributions to an *Organization Science* special issue on organizational culture, and in the discursive turn in institutional theory. Outside of the management field, studies that emphasize organizations as systems of meaning and highlight the cultural-cognitive construction of organizations and practices are included under the broad umbrella of cultural studies of organizations. However, within management, work on culture is found in at least two separate streams of research: organizational culture and institutional theory. This study begins to connect these two streams.

The principal divisions between cultural and institutional approaches in management studies occur at the level and focus of analysis. Studies of organizational culture look within organizations and examine "interactionally-constituted webs of meaning," implying an important role by social actors, while institutional studies focus on interorganizational relationships and examine "institutionalized cultural-cognitive models and practices" (Morrill, 2008). The findings of this study provide ideas for understanding how cultural processes influence the emergence and construction of institutional structures.

Connections Between TIM and OMT

The findings of this study make a connection between the TIM and OMT literatures. The first study of institutional entrepreneurship in the management literature following DiMaggio's (1988) introduction was a study of Sun's sponsorship of a new technology. However, subsequent studies of institutional entrepreneurship have focused on social and cultural change rather than the emergence of technologies or domains of commercial activity. While institutional theorists have long considered technology an instigator of institutional change and technology and innovation researchers have refered to the importance of the institutional context, with few exceptions (e.g Hargadon and

Douglas, 2001; Garud, Jain, and Kumaraswamy, 2002; Munir and Phillips, 2005), researchers have not made connections between the two. Likewise, the limited research on technology framing does not address the creation of technology frames (Hargrave and Van de Ven, 2004) or explore in detail how those who support a particular frame gain an audience. By identifying the activities of technology proponents that result in the projection of a technology frame, this study serves to make a stronger connection between institutional entrepreneurship and technology emergence and evolution.

Entrepreneurship Theory

The findings of this study lend support to recent arguments that entrepreneurs can create markets (Sarasvathy, 2001; Santos and Eisenhardt, 2004) and provides an explanation of how. Traditionally, entrepreneurship literature has focused on identifying traits of entrepreneurs and explaining how entrepreneurs recognize opportunities (Davidsson, 2002). As much technology research assumes the *a priori* existence of a market driven application, research explaining how entrepreneurs recognize opportunities assumes that markets exist to be discovered. This study provides evidence that entrepreneurs use social skills (Fligstein, 1997, 2001) to create opportunities. Additionally, by identifying three sequential activities—constructing, positioning and translating—that technology proponents engage in, this study specifies social skills and explains how skills can lead to the accumulation of resources that support the creation of commercial domains.

Implications for Practice

At the 2007 IBF Nanotechnology Investing Forum, keynote speaker Robert Joss, then Dean of Stanford's Business School, related that under his direction the school had recently undertaken a major revision of the MBA curriculum. Joss explained that he became aware that although Stanford graduates were accepting high-level positions in prestigious organizations upon graduation, many were not successful in those positions. A survey of alumni revealed that they felt unprepared for the demands of the business environment. In particular, Joss listed four challenges that alumni felt inadequately prepared to manage effectively: technological change, government regulation, public opinion and media relations, and globalization. The revised Stanford MBA curriculum, described in *Business Week* (June, 2007) as foretelling the likely future of management education, is focused on preparing students to meet these demands. As Joss noted in his address, attendees at the Nanotechnology Investing Forum were actively involved in managing at least the first three challenges. This dissertation does not address the forth, globalization. The findings of this dissertation have implications directly relevant to the practice of managers and policy makers dealing with each of the other three challenges listed by Joss.

Managing Technological Change

As noted in Chapter II and above, academic management research has focused little attention on earliest stages of technology emergence. However, this study suggests that it is during this period that individuals and organizations begin to influence the emergence of technologies. The entrepreneurs and business professionals in this study know this and have conducted their own research. In some cases their research has been anecdotal but in others, as in the case of Star Venture Capital's two-year investigation of research trends on university campuses, their research has been quite systematic. The founders of each of the VC firms that are the focal cases of this dissertation claimed to have based their strategic decisions on either their research or observations of the development of previous science-based technologies. The willingness of professionals doing the work of managing technology and innovation to conduct their own research shows that they feel a need for knowledge of how managers influence the early emergence of technologies.

This study helps to fill this need. By indentifying the activities that technology proponents engaged in, documenting relationships between these activities and investment by government and large businesses, and by providing an explanation of how these activities influenced the emergence of a commercial domain through the projection of a technology frame, I have developed a theoretical explanation of the patterns that business professionals have observed. This explanation suggests that those seeking to commercialize science-based technologies would do well to become involved in the earliest stages of technology development. And, importantly, business proponents must be concerned not only with end applications and products, but also with the meanings associated with technologies.

Managing Demands of Government Regulation

Because complex technologies often have national consequences, governments are involved in standard setting and regulation (Tushman and Rosenkopf, 1992). In democratic societies, the public may influence decisions regarding regulation and standards. Studies have shown that public perceptions of the risk associated with science-based technologies are ambiguous and often inaccurate and can contribute to the "stigmatization" of technologies (Gregory, Flynn, and Slovic; 2001). Technological stigmatization "represents an increasingly significant factor influencing the development and acceptance of scientific and technological innovation and, therefore, presents a serious challenge to policymakers" (Gregory, Flynn, and Slovic; 2001: 4). Technology stigmatization can elicit burdensome regulations, discourage investment, resulting in the failure of product markets and thereby posing a serious threat to the success of emerging science-based technologies.

Again, business professionals are aware of this challenge. In an interview, a nanotechnology business leader underscored a point he had made in an earlier public presentation concerning the importance of active engagement with politicians:

> The politicians have been very clear. That quote that I used [in the presentation], was very unequivocal. "We're gonna legislate. Your job is to make sure that when we do, we are informed. If you don't, that's going to be your problem." –*Nanotechnology business leader, interviewed by Kathryn Aten*

This study shows that a small group of relatively disadvantaged business professionals, those with relatively few substantive resources, can influence policy. Proactively engaging politicians very early in the development of a technology, demarcating a limited space for business discourse, and framing a technology as a business opportunity can influence government investment and regulation.

Managing Demands of Public Opinion and the Media

The realization of opportunities created by new technologies requires public trust (Aldrich and Fiol, 1994). Public mistrust stemming from a lack of understanding or even fear of a technology among stakeholders may pose a serious threat to the success of new technologies. For example, in the case of electricity, the visible benefits of the technology were offset by the just as visible dangers of electrocutions (Hargadon and Douglas, 2001). Slovic, Fischoff, and Lichtenstein (1980) found that experts tend to equate risk with statistically accurate fatality estimates, but laypeople rely more heavily on subjective characteristics to make risk assessments, including the familiarity and observability of a technology and their knowledge of it. Basic science technologies are not characterized by these traits, and are thus often viewed by the public as risky.

Business people are well aware of this threat. The following is an excerpt from the introduction to a business report sold to large businesses seeking guidance on managing the risks of nanotechnology.

> Imagine two futures…it's 2015 and nanotechnology is all around you. You drive to work in a car with a scratch-proof clear coating enabled by silica nanoparticles, you listen to a portable music player with carbon nanotube-powered memory chips, and your television's backplate is made from silicon nanowires. The nanotechnology field encompasses dozens of start-up ventures that have developed these technologies and hundreds of large manufacturers that make use of them, together employing thousands of people.
>
> Or…it's 2015 and nanotechnology has been has been mostly forgotten. After public opinion turned against nanotech in the late 2000's, the incentives to develop nano-enabled products evaporated. Large corporations found that any product associated with nanotechnology faced a firestorm of controversy and decided that the gains from using it weren't worth the reputation risk and likely market failure. Without these players

> bringing products to the consumer market, the path to commercialization for start-ups dried up along with their access to capital. Products containing nanoparticles disappeared (paraphrased from Nordan, 2005).

The report goes on to explain that both actual and perceived risks are likely to influence the development of nanotechnology. As suggested by the above quote and as noted by Robert Joss in his keynote address, practicing managers today must be able to effectively address public opinion.

Organizational impression management refers to purposeful actions to influence an audience's perception of an organization's image; the character and demeanor organizations attempt to project (Elsbach, Sutton, and Pincipe, 1998). The organizational impression management literature provides "...a relatively elaborate picture of the forms, uses, and effects of remedial impression management by organizations" (Elsbach, Sutton, and Pincipe, 1998). However, few studies have examined how organizations use impression management to avert undesirable responses to upcoming events (Elsbach, Sutton, and Pincipe, 1998) and thus scholars can provide little guidance to managers.

This study begins to fill this gap by documenting and explaining the efforts of technology proponents to turn aside opposition to nanotechnology. The study complements the findings of Hargadon and Douglas' (2001) finding that innovators can reduce opposition to innovations by positioning them within existing institutions. Hargadon and Douglas explain how Edison designed his lighting system to mirror the existing gas system in order to support its adoption. This study documents and explains similar efforts by nanotechnology proponents, but is noteworthy in that the efforts came before an application was known. Technology proponents actively attempted to manage the meaning of nanotechnology, positioning it as the next step in a long history of innovation. They lobbied successfully to eliminate federal funding for research streams that were incongruent with this frame. This suggests that technology proponents can play a role in shaping the public opinion and framing technology in a way that supports commercial development. I explain how proponents can gain access to the public discourse through constructing, positioning, and translating.

This dissertation contributes to our knowledge of technology evolution by focusing on the understudied period of early emergence and the sociopolitical process of technology framing. I contribute to our knowledge of how science discoveries become the basis for fields of commercial activity. The findings of this dissertation provide knowledge that can assist business people and policy makers seeking to develop science-based technologies and the commercial domains that emerge around them.

Future Research

The question of how technologies and commercial domains based on them emerge and evolve has been of interest to scholars for some time. Despite this, our knowledge of this problem is limited. This dissertation has begun to fill this theoretical gap and also has implications for practice. However, this study has also revealed additional unanswered questions. I detail these below.

How do founders of a socio-semiotic space capture the value of the resources they generate? Which strategies are likely to lead to greater success? Firm competitive advantage is influenced by constituents' perceptions, which drive decisions to provide or withhold resources (Rindova and Fombrun, 1999; Barnett, 2006). Successful strategy in emerging domains requires that founders generate social acceptance of emerging technologies (Shane and Venkataraman, 2003). However, because the social acceptance necessary for the emergence of technologies and the definitions, boundaries and identities on which it is based, are public goods (Roa, 1994; Barnett, 2006), all who operate in consonance with these elements may garner like benefits. However, technology proponents do not undertake domain-building projects out of altruism. Rather, they seek to establish an infrastructure that will contribute to their private advantage (DiMaggio, 1988). Research suggests that firms with strong reputations may be better able to shape the development of an emerging domain (Sherer and Kyungmook, 2002). Competitive advantage may result from tactics intended to build firm reputation (Barnett, 2006).

Firms responsible for initiating collective projects in emerging domains may gain reputation benefits. As a consequence of a firm's involvement in collective projects, constituents may perceive it as a leader in the domain resulting in increased financial resources and better information. Although both theory and observation indicate that founders undertake domain-building projects to garner private advantage, extant studies touching on collective projects and private advantage are limited and generally focus on technology standards battles. Future research is needed to identify firm level strategies for garnering benefits from investments in collective projects undertaken to generate social acceptance.

While at this time it is too early to identify the financial outcomes of the investments made by firms in this study, the funds they initiated will be reaching their culmination in the next few years. It will then be possible to assess the financial performance of the funds and to relate performance to firm strategies.

What is the role of conferences in the emergence of commercial domains? In particular, how do conferences influence the creation of technology frames, professional identities, and symbolic resources such as labels and narratives? Conferences are an excellent setting to observe, interact with, and interview field proponents (DiMaggio, 1991; Fligstein, 1997). They are microcosms of emerging industries. Relationships are forged, networks are constructed, boundaries defined, and standards are proposed (Meyer, Gaba and Colwell, 2005). Attendees from trade associations, economic development agencies, and networking organizations are actively engaged in efforts to build new domains. Proponents compete for adherents, meaning, and media attention, while collaborating to generate legitimacy for emerging technologies and financial support for their commercialization. Conferences are construction sites where collective identities are proposed, contested, and enacted. Conference organizers thus play an influential, and largely unrecognized role in the emergence of new domains.

Conferences can also serve to reconfigure domains. In 2005, the mass media and the venture investing community embraced the term "cleantech" in reference to business activities undertaken to commercialize a family of new technologies that promised both benefits to the natural environment and attractive financial returns. One prominent venture capitalist pronounced cleantech "the greatest opportunity of the 21st century" (O'Rourke and Parker, 2006). IBF launched a cleantech conference. Nanotech entrepreneurs and camp followers emigrated to the cleantech space, where participants drawn from many of the same occupational groups were plunging into now-familiar debates about cleantech's meaning, boundaries, and identity.

As explained in previous chapters of this dissertation, imprecise definitions and nebulous boundaries are characteristic of emerging domains and pose challenges for proponents. Social movement scholars have found that identity and meaning construction are a requirement for collective action (Polletta and Jasper, 2001). To date, social and organization theorists had said little about the role of conferences in collective efforts to construct labels, boundaries, and identities in support of emerging domains. The data collected and organized for this dissertation could be used to explore of the role of conferences in the creation of these symbolic resources.

How do characteristics of technology frames influence their adoption? The findings of this dissertation provide insight into this question. but further research could elaborate on the effects of specific frame characteristics and competing strategies by comparing the frames and strategies of the social groups identified in this dissertation.

My findings suggest some characteristics of technology frames that may influence their appeal and adoption. In my content analysis of the *New York Times* articles, I identified the descriptions of potential tangible applications of nanotechnology. These descriptions represent stakeholders' goals for the technology. In addition to the findings reported in this dissertation, I identified two dimensions in the data, familiarity and time frame. Familiarity refers to the degree to which an application is similar to existing products and uses and is likely to change life activities or social relationships. Timeframe refers to when the application is likely to come to fruition. Future research should better explain how characteristics of the technology frames identified in this study, beginning with familiarity and timeframe, influence the adoption of technology frames and provide specific guidelines for managers and policy makers. Further analysis of electronic and print articles and reports I have collected could be used to explore this question. Additional data on the historical cases (e.g. computers, biotech, genetically modified food) could be collected in order to conduct a comparative case study.

More generally, as noted earlier in this chapter, additional research will be required to determine to what extent the findings of this study apply to other types of commercial domains and to test and extend the theory developed here. Research should compare and contrast various types of commercial domains and domains emerging from different science-based technologies. For example, as I have discussed, the findings of this research suggests that characteristics of technology frames may influence the acceptance of technologies and researchers have found that characteristics of technologies influence public judgments. Recent studies have explored the role of national culture in judgments about technology and science risk and suggest that national culture may also influence public judgments (Nelson, 2001; Finucane and Holup, 2005; Guehlstorf and Hallstrom, 2005). A comparison of the role of technology framing in the emergence and commercialization of genetically modified foods and nanotechnologies could begin to test the theory developed here. A comparison of the sociopolitical processes related to the emergence of these technologies in different countries could further explicate the boundary conditions that apply to the findings presented here and could provide guidance to managers dealing with the globalization of science and technology.

In conclusion, early in my career as a doctoral student, I commented in a seminar that I am fascinated by how science fiction becomes reality. A fellow student remarked that this research problem could take a career to investigate and implied that it was therefore not a good choice. I concur with the statement but not the implication. This problem may take a career to investigate. To me, this is an advantage. I view this dissertation as the beginning, rather than conclusion, of my exploration of technology and the emergence of commercial domains. I expect the ideas, methods, and data presented here to provide a solid foundation for my future work.

APPENDIX A

SAMPLE INTERVIEW PROTOCOL

Goal of research: My early research has indicated that field leaders can influence the development of technology domains. I want to understand how founders in the nanotech domain participated in collective efforts to build infrastructure and if/how they gained from their efforts.

Approach: I am using public data sources to understand evolution of the field and identify leaders and interviews with leaders and attendance at conferences to understand tactics, rationale, results of efforts.

The identity of informants will be kept confidential and the findings will be reported in way that preserves the confidentiality of and private information. Do you mind if I tape record our conversation?

I will ask fairly open-ended questions in 2 areas. First I would like to know about [firm name] and your role in creating/supporting the nanotechnology domain. Next, I will ask more specifically about initiatives to build the nanotechnology domain.

First, imagine that you are writing a novel about [firm name]. Please tell me the story of the company and address changes in its mission and focus over time.

Can you tell me about the decision to focus on nanotechnology? How did this decision come about, what was the rationale behind it, how was it implemented?

What have been the costs/benefits of this decision?

Please tell me more specifically about the decision to [specific domain building undertaking]? Please tell me the story of how the decision came about, what was the rationale, how was it was implemented?

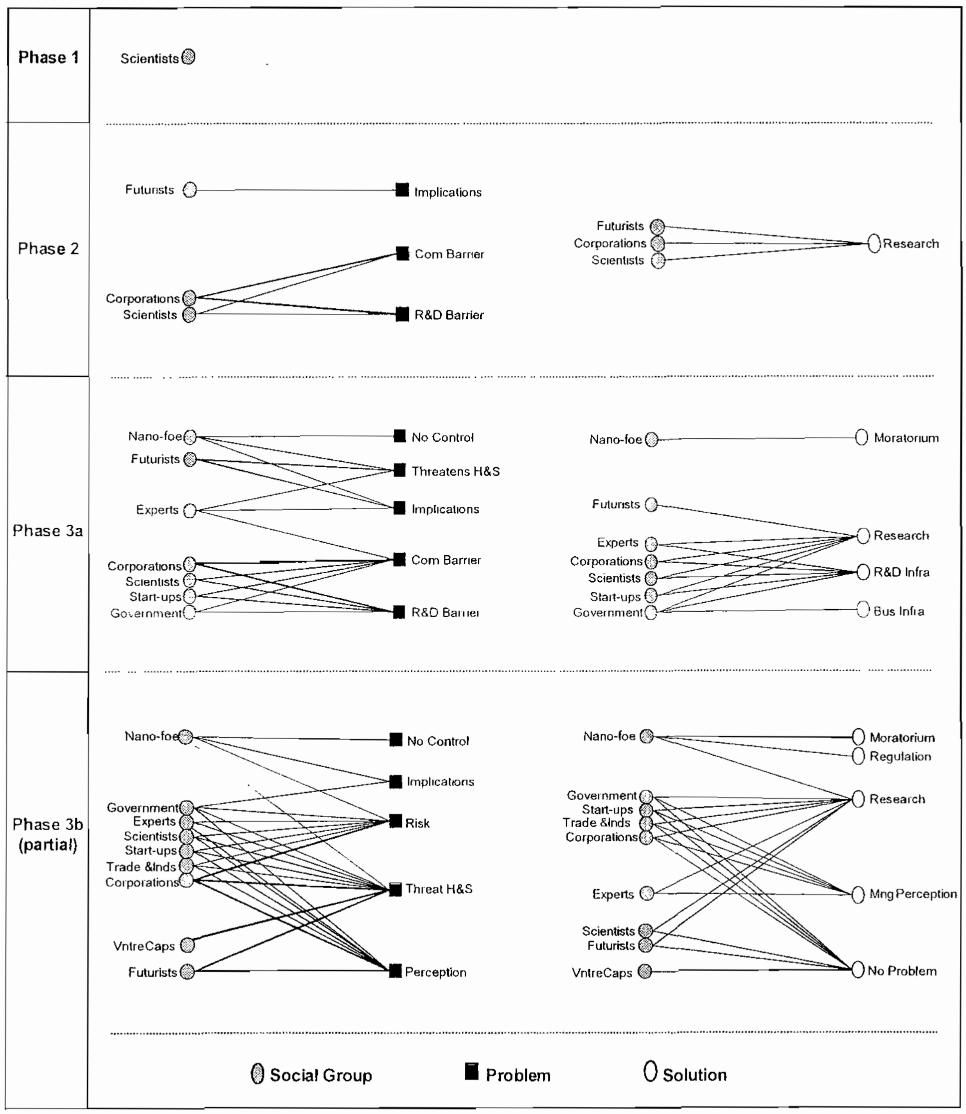
Were there any changes in the objective from [the firm's] point of view?

What were the costs/benefits to [firm] as a result of [the undertaking]?

Can you give me sense of how the benefits/costs have changed over time [for example, how have the number and/or quality of proposals changed since your inception]?

APPENDIX B

EXAMPLE VISUAL MAP



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