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Implications for the Role of the University in Economic Development
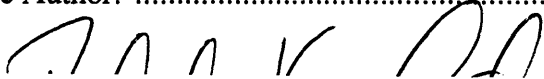
by

Carlos Andrés Martínez Vela

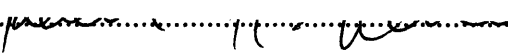B.Sc., Engineering Physics
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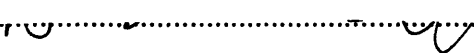
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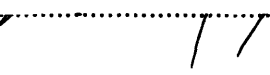at the Massachusetts Institute of Technology

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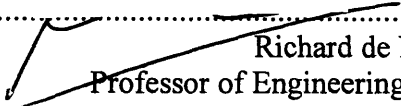
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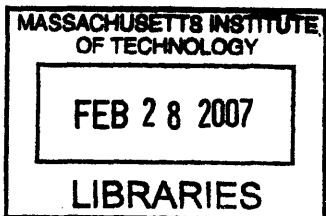
The Duality of Innovation:
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Abstract

The university is increasingly seen as an engine of regional economic development. Since the 1980s the university's role has been framed in terms of its contribution to industrial innovation. The conventional wisdom views this contribution as occurring primarily through the technology transfer model. The university, in this way of thinking, must move closer to industry and the marketplace by translating research into deliverables for commercialization. This dissertation challenges the empirical validity of this view.

Two case studies of industrial upgrading form the empirical core of this research: the machinery industry in Tampere, Finland and the NASCAR motorsports industry in Charlotte, North Carolina. In each case I analyze the university's role from the ground up using a conceptual framework that views the innovation as a social process that has a dual nature: analytic and interpretive. From an analytic perspective innovation is a problem-solving activity. From an interpretive perspective innovation is an ongoing conversation.

I find that in neither case is the university's most important contribution to each industry's upgrading made through the technology transfer model. In Tampere, whose core innovation process is interpretive, the local university creates spaces for interaction and conversation that enable knowledge integration, provides interlocutors for exploratory conversations, and educates engineers. In Charlotte, whose innovation process is analytic, the local university plays essentially no role. NASCAR teams rely on business partners for technology transfer and attempts to make the university active in technology transfer for the industry have yet to succeed.

The duality of innovation helps to explain the university's role in the Tampere case and its absence in the Charlotte case. I argue that the technology transfer model implicitly assumes that innovation is analytic and thus misses the interpretive side of innovation. The case study findings suggest three things. First, the university has a distinctive ability to make interpretive contributions to industrial innovation. Second, practices emphasized by the technology transfer model, such as patenting and technology commercialization, do not account for the university's interpretive role. Third and finally, too much emphasis on the technology transfer model may put at risk the university's interpretive capabilities and hence its most distinctive contribution to industrial innovation.

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Acknowledgements

I was asked recently what is the origin of my love for the university and I could not give an answer. I later thought that the university has been part of my existence since before I was born. My two grandfathers and my father were (among other things) academics and Deans in the School of Medicine at the University of Nuevo León in Monterrey, México, my hometown. Through my mother I was exposed to the university since before I was born. She found out she was pregnant with me the same day she was granted a scholarship to begin college. She would go on to pursue graduate studies and become an academic herself. Through both my father and my mother I experienced what it means to have a passion for higher learning.

But my belief in the university and my desire to understand its transformative and humanizing power in society is, in the end, my own. It started in my college years at Monterrey Tech, when I was deeply involved in student life. It was nurtured there after I finished college, when I discovered how much I love teaching, how academic research can contribute to innovation, and how challenging it is to manage a university. In the Fall of 1996 I came to MIT for the first time with only an incipient interest in better understanding the role of the university in economic development. Since then, the university has been a consistent companion in my life and has been joined by a deep fascination with the how people innovate. The road has been neither straight nor easy. Along the way, there were many without whom this document would not be what it is and perhaps would not exist altogether.

The first note of gratitude goes to my dissertation committee. Richard Lester, my advisor, welcomed me into the MIT Industrial Performance Center. He created the conditions without which this pursuit would not have been possible: financial support, physical space, interesting problems, a community of scholars, intellectual inspiration, endless curiosity, pragmatism, challenge, honesty, trust, and a lot of patience. Without Michael Piore's friendship, trust, patience, insight, honest critique, and unwavering support and guidance in times of personal and intellectual discovery, consolation, and desolation, I would not be writing this sentence. I am indebted to Richard and Michael for introducing me to the duality of innovation. David Mindell sowed the inspiration to enter the fascinating world of the history and sociology of technology. His belief in my work, insightful feedback, and financial support in the last stage of this work were vital to bring this to completion. Markku Sotarauta has made possible my close and continuing involvement with Finland. In Tampere he provided not only a fascinating intellectual endeavor. He made me part of a welcoming community of scholars and friends. His expertise on regional development issues has been fundamental. During the early stages of my doctoral work the intellectual guidance and support of Richard Chait from the Harvard Graduate School of Education, were essential to deepen my understanding of the complex tasts of managing, leading, and transforming a university.

This dissertation stems from my participation in the Local Innovation Systems Project, an international research partnership based at the MIT Industrial Performance Center. Having been part of this project made me able to pursue this research. My Local

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List of Acronyms

CNC	Computer Numerical Control
CoT	Car of Tomorrow
ICT	Information and Communications Technologies
IHA	Institute for Hydraulics and Automation
LIS	Local Innovation Systems
MIT	Massachusetts Institute of Technology
NASCAR	National Association of Stock Car Auto Racing
R&D	Research and Development
Tekes	Finnish Funding Agency for Technology and Innovation
TUT	Tampere University of Technology
UNCC	University of North Carolina at Charlotte
VTT	Technical Research Center of Finland
WWII	World War II

Believing is where learning starts. We know first, act on such knowledge and then get to know more. We may acquire sharper knowledge, built around reasons, causes and calculations, or vaguer knowledge, in which hopes, enigmas and alluring problems form the thread. The two ways often go together, for the activity of getting to know is compounded of feelings as well as of intellectual curiosity, of hunches as well as of facts.

– Robin A. Hodgkin
Playing and Exploring:
Education through the discovery of order

1 Introduction

Since the 1950s innovation policy has been formulated with two predominant models of innovation in mind. Each model is closely associated with a theory about the relationship between technology and the economy and a guiding rationale for the design and implementation of science and technology policy.

The first model is the linear model of innovation. In this model innovation flows sequentially from basic research to applied research, product development, and finally the marketplace. This model, sometimes referred to as "science-push," was set out for the first time in Vannervar Bush's now classic report, *Science: The Endless Frontier* (Bush, 1945). The linear model is associated with the market-failure rationale for government involvement in the promotion of innovation (Branscomb and Florida, 1998; Mowery and Ziedonis, 1998). This rationale was theoretically justified first by Arrow (1962) and later by endogenous growth theories (Romer, 1990).[1] The policy instrument associated with the linear model and market-failure rationale is public investment in basic research, which would eventually translate into economic prosperity (Martin, 2003).

The second model is the interactive or systems model of innovation. In this model the interaction of multiple individuals, organizations, and institutions results in more innovation. This model is associated with the systems-failure rationale for policy design and implementation (Lipsey, 1998; Edquist, 2001; Teubal, 2002), theoretically justified by the innovation systems approach (Lundvall, 1992; Nelson, 1993; Edquist, 1997). In a

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[1] Mowery (2005) suggests that Bush's argument anticipated the market-failure rationale that Arrow (1962) would later articulate.

conceptual shift from its neo-classical predecessors, this approach builds on evolutionary

theories of the economy and technological change (Nelson and Winter, 1974; Nelson and

Winter, 1982), and gives a prominent role to institutions in the process of innovation

(Edquist and Johnson, 1997; Moreau, 2004). In addition to investment in basic research,

this rationale's policy prescriptions also include the creation of organizations and

institutions (the "institutional set-up for innovation"), and the implementation of policies

and incentives to foster interactions among the components of an innovation system

(Edquist and Johnson, 1997; Edquist, 2001).

Views about the role of the university in regional economic development and the

public policies to foster that role follow the changing models of innovation.[2] In *The*

Endless Frontier, Vannevar Bush articulated a vision in which the university's

contributions to the economy and society emanated primarily from basic research and

called for a more active government role in funding basic academic research. Between

1945 and the late 1980s the linear model combined with the market-failure rationale were

the bases for policies that focused government investment in basic research in academia

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[2] Attention to the university's role in economic development is not new. Prior to 1945, the expansion of American higher education that began in the mid 19th century was fueled, at least in part, by such an idea (Lee, 1996). With the passage of the Morrill Act of 1862, the origin of what today are known as "land-grant" higher education institutions, the Federal government granted land to each state to create and maintain "at least one college where the leading object shall be, without excluding other scientific and classical studies, . . . to teach such branches of learning as are related to agriculture and the mechanical arts" (Hofstadter, 1961 as cited in Geiger, 1986 #360). Universities also had close ties with industry in the late 19th century and up until the 1930s. Fields such as electrical and chemical engineering were developed within universities as a response to technical development in industry (Rosenberg and Nelson, 1994), with MIT a flagship example of close ties with industry during that period (Matkin, 1990). A shift in the idea of how a university contributes to economic development and its relations with industry took place during and after WWII.

(Martin, 2003). This investment was deemed necessary and sufficient to promote innovation (Mowery and Sampat, 2005).

The view of the university's role in economic development evolved with the emergence of endogenous growth theories. In this view academic research creates "knowledge spillovers" that would ultimately benefit the economy (Jaffe, 1989; Jaffe, Trajtenberg et al., 1993; Feldman, 2000; Feldman, Feller et al., 2002). Further evolution in our understanding occurred with the emergence of interactive and systems views on innovation. The perception about the university's contribution to economic development changed from the post-WWII emphasis on basic research to comprise more direct contributions to industrial innovation.[3] The "Mode 2" (Gibbons, 1994) and "Triple Helix" (Etzkowitz and Leytesdorff, 1997; Etzkowitz and Leydesdorff, 2000) perspectives adopt a highly interactive view of the university in relation to communities of academic researchers and practitioners in other organizations, and between the universities, government agencies, and companies. In the innovation systems approach, universities are crucial components of the system and play a key role in enhancing the innovative capacity of business and the overall system performance (Nelson, 1993; Edquist and Johnson, 1997; Feldman, Feller et al., 2002; Mowery and Sampat, 2005).

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[3] The rise of Japan and other newly industrialized economies in Asia prompted a shift in discourse towards the idea of competitiveness and innovation in science and technology policy (Branscomb and Florida, 1998). The competitive advantage of those countries was perceived to be technological innovation. There was also empirical evidence that such advantage stemmed not just from investment in research, but from an institutional framework conducive to innovation. In particular, interactions between industry, government agencies and public research and educational institutions were key to building this advantage (Freeman, 1995; Nelson, 2000; Saviotti, 2001). At the same time, innovation became more distributed, involving the interactions of multiple organizations and sources of knowledge and technology (Lundvall, 1985; Lundvall, 1992; Gibbons, 1994).

The current wave of interest in the university's role is usually framed in terms of their contribution to the formation and strengthening of "high-tech" innovation-intensive geographically concentrated industries (Mowery and Sampat, 2005).[4] With the rise of the "knowledge economy" and "technology-based economic development" universities embrace a "third mission" of regional economic development to supplement research and education. This transformation in has been referred to as a change in the social contract for higher education (Guston and Keniston, 1994; Martin, 2003) and a "second academic revolution" that is moving universities from an ivory tower to an entrepreneurial paradigm (Clark, 1998; Etzkowitz, Webster et al., 2000).

At the heart of the "new social contract" is the idea of technology transfer, which has rapidly become the model of how the university contributes to industrial innovation.[5] The meaning of technology transfer is hard to pin down since it is used in multiple ways

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[4] The theory of "industry clusters" articulated by Porter (1990) triggered interest in initiatives to build clusters anchored by universities. Two empirical examples are usually cited as the models: first, the past development of Route 128 and the current growth of life sciences in Boston, with MIT and Harvard acknowledged as major contributors to their growth. The second example is Silicon Valley in California's Bay Area, in which Stanford is credited with a crucial role in the development of the information technology industry (see Saxenian, 1994 for a classic analysis of both Boston and the Bay Area). More recently the life sciences industries around San Diego, California and the Research Triangle (Raleigh-Durham area) in North Carolina are also cited as examples and used as models. The regional emphasis on the university's role is not new. In the U.S. regionalism has been a defining characteristic of higher education since the establishment of the first land-grant universities, many of which developed research and educational programs focused on regional economies, at least initially (Feller, 1999).

[5] In the United States patenting by universities started as early as 1925 and increased during the 1970s (Matkin, 1990; Mowery and Sampat, 2005). Around 1980, Federal and State policies began to actively foster technology transfer. At the Federal level, the passage of the Bayh-Dole Act of 1980 legitimated university patenting and technology transfer as a tool for economic development. Today virtually all states have some type of "technology creation" policies or program that promote university–industry partnerships, and tap into higher education institutions to attract and create high technology industries, foster the growth of industry clusters, and the formation of start-up firms (Geiger and Sá, 2005). University technology transfer policies and practices spread rapidly on a global scale. Many OECD and less developed countries have created policy frameworks to emulate the Bayh-Dole Act and to organize practices like science and technology parks and the creation of university technology transfer offices and business incubators. In all emulations there is an emphasis on intellectual property rights and technology commercialization as a way to foster the university's role in regional economic development (Mowery and Sampat, 2005).

(Matkin, 1990; Bozeman, 2000), so it is best defined by its meaning in practice. What I will refer to as the *technology transfer model* entails a very specific set of practices that prescribe an ideal view of how universities contribute to industrial innovation. When policymakers and academic administrators talk about technology transfer, they refer to the translation of research into patents and products that can be taken up by existing enterprises to improve their processes and product offerings, or taken up by entrepreneurs to form new businesses. The keystone of the technology transfer rationale is intellectual property. In an academic setting, intellectual property entails codifying research results into patents that are then made available through licensing. Three organizational arrangements are usually associated with technology transfer initiatives in higher education technology transfer or technology licensing offices: business incubators to nurture new businesses or "start-ups," industrial liaison programs, and the creation of technology or science parks. These initiatives "share the premise that universities support innovation in industry primarily through the production by universities of 'deliverables' for commercialization (e.g., patent discoveries)" (Mowery and Sampat, 2005, p.225).

Behind the technology transfer model there is a working assumption about the nature of interactions over the course of the innovation process. While the innovation systems approach has involved a shift from a linear to an interactive model of innovation, the understanding of technology transfer interactions among individuals and organizations is very narrow. In the linear model, the assumption is that innovation involves primarily the flow of information from one stage of the innovation process to the next. The interactive

model of innovation has taken this model to the innovation systems level, where the focus is on creating and enhancing flows of information among the organizations of the innovation system. The current focus is, in addition, on the transmission of information via market interactions.

1.1 The duality of innovation

Recent research suggests there is a fundamental *duality* in the innovation process that has important implications for innovation policymaking and the university's role in enhancing industrial innovation. An early articulation of what I will refer to as *the duality of innovation* is Schön's description of innovation as a rational and a non-rational process (Schön, 1967) and between reflective practice and technical rationality (Schön, 1983). More recently, Lester, Piore, and Malek (Piore, Lester et al., 1994; Lester, Piore et al., 1998; Malek, 2000; Lester and Piore, 2004) propose the terms *interpretation* and *analysis* to characterize two different "dimensions" of the innovation process, both closely related to Schön's characterization. I will use these two terms in the rest of this study to refer to each aspect of the duality of innovation.

From an interpretive perspective, innovation is an inherently social process. Innovation unfolds as an ongoing, open-ended conversation in which new ideas and artifacts emerge over time through the language and actions of practitioners–interlocutors. The goals of the conversation are fuzzy or not known at all at the start. Knowledge about the product emerges in practice and social interaction.

From an analytic perspective, technological change unfolds as practitioners solve a sequence of problems presented to them by product designs that are already "out there." Goals are clear at the start of problem-solving, and the point is to act rationally using the appropriate means to reach the specified goals. In this case no new knowledge emerges in interactions. While one interlocutor might learn something new, his or her learning comes from the acquisition of knowledge that already exists codified as information.

From an innovation policy perspective, the duality of innovation suggests two radically different ways the university may enhance industrial innovation. First, from an interpretive perspective, the university would enhance conversations that lead to the emergence of new knowledge. Second, from an analytic perspective, the university would enhance problem solving and information dissemination. Thus, unlike the linear and interactive models of innovation that underpin the technology transfer model, the duality of innovation offers a more nuanced way to examine the university's contribution to industrial innovation and its role in economic development.

1.2 The dissertation

This dissertation takes a step towards understanding the implications of the duality of innovation for innovation policy and for the university's role in regional economic development. To do this, I follow an inductive, qualitative, and comparative case-based approach (as described in Chapter 2) of two locales that are representative examples of local innovation systems. Local innovation systems are defined as

> spatial concentrations of firms (including specialized suppliers of equipment and services and customers) and associated non-market institutions (universities, research institutes, training

institutions, standard-setting bodies, local trade associations, regulatory agencies, technology transfer agencies, business associations, relevant government agencies and departments, etc.) that combine to create new products and/or services in a strategically distinct business. (Braczyk, Cooke et al., 1998)

The first case is a study of innovation in the machinery industry concentrated in the city-region of Tampere, Finland. The region is home to approximately one dozen companies that are leaders in their global market niches, ranging from forest harvesting machinery, to glass manufacturing machinery, to paper machinery automation systems. The second case study examines the NASCAR motorsports industry concentrated near Charlotte, North Carolina. The region is home to the vast majority of professional NASCAR teams and to more than 450 supporting businesses. In both cases, the industries under study may be seen as traditional industries in the region, in the sense that their origins in these locales are decades old. As such, both cases are illustrations of *innovation-based industrial upgrading*. I define innovation-based industrial upgrading as the process by which companies in an established industry absorb technical and scientific knowledge, product development techniques, and production technologies previously alien to the industry and integrate them into an existing base of processes and products, yielding enhanced production processes, improved product performance, novel product functions and/or uses that result in sustained or expanded competitiveness and business opportunities.

While Tampere's machinery industry and Charlotte's NASCAR motorsports industry are both cases of innovation-based industrial upgrading, there are two fundamental differences between them. First, the innovation processes that have driven upgrading are

radically different and are representative of each side of the duality of innovation. In Tampere, the core innovation process behind industrial upgrading is *interdisciplinary integration*, which entails the integration of electronics, control, information, and communications technologies into the machines. This process, I will demonstrate, is primarily interpretive. In Charlotte, the core innovation process behind industrial upgrading is *optimization*, in which NASCAR teams are working within a tightly regulated product architecture to optimize racecar performance. I will show that this process is primarily analytic.

The second difference between the cases is the institutional setup for innovation in each industry. In Tampere, a local set of innovation-supporting non-market organizations has been critical to the ability of local companies to reinvent themselves. More specifically, the Tampere University of Technology (TUT) has been critical to the ability of machinery companies to take up and integrate new technology into machinery, both through research and education. The interactions between TUT and the local machinery industry are a model of a fruitful university-industry relationship. However, the interactions contributing to industrial upgrading through interdisciplinary integration look nothing like the technology transfer model. In Charlotte, on the other hand, not a single local innovation-supporting non-market organization helped to enable local NASCAR teams to remain competitive. Interactions similar to the technology transfer model are important for the industry's continuous upgrading, but NASCAR teams rely primarily on suppliers and the racing divisions of auto manufacturers to take up new technology and solve problems. The local research university, the University of North Carolina at

Charlotte (UNC Charlotte), even though it has a research and education program in motorsports and automotive engineering, has played no role in the industry's upgrading. Recent efforts by local civic, government, and industry leaders to bring UNC Charlotte and NASCAR teams closer together in innovation-supporting partnerships did not work.

Through these two case studies I address the following research questions:

- What are the implications of the duality of innovation for the university's role in economic development and university–industry interactions?

- How do variations in the innovation process affect the role that the university plays in one case and its absence in the other?

    o In Tampere, where the university plays a critical role, what is the university doing, if not technology transfer?

    o In Charlotte, where technology transfer is crucial to upgrading, why is the university absent?

In this dissertation I use "the university" as a proxy for an organizational actor within innovation systems. I acknowledge that this is an idealization. Universities are complex organizations in which multiple departments, schools, and research centers pursue different agendas. The university's creative energy comes from independently-minded and driven individuals. In this sense, my use of "the university" should not be taken to mean that the multiple actors that constitute a university act monolithically. Universities also vary along the dimensions of research intensity, the balance between basic and applied research and the balance between teaching and research activities. Different

universities too, have different levels of commitment to economic development and industrial innovation. The university's role in economic development, as the case studies in this thesis will show, occurs at the level of individual departments, research centers, and personal relationships between academic researchers and industry practitioners. My use of "the university" is thus a simplification.

1.3 Bringing the innovation process back in

I propose that in order to understand the implications of the duality of innovation it will be necessary to provide additional insights into the nature of the innovation process. Most studies of innovation policy and innovation systems focus on inputs (e.g. research dollars, trained professionals), outputs (e.g. patents, new products), and on how interactions between organizations, institutions, and firms affect the ability of the system to yield more outputs. However, what goes on between the inputs and outputs remains a black box. In other words, the innovation process itself – how practitioners actually innovate and how the individuals, organizations, and institutions interact over time during the innovation process – is missing from policy discussions in general, and from university-industry partnerships in particular. As a consequence, we cannot really say how universities actually affect the innovation process of firms or how differences in the innovation process reflect in university–interactions and the actual role that universities play to support the innovation process.
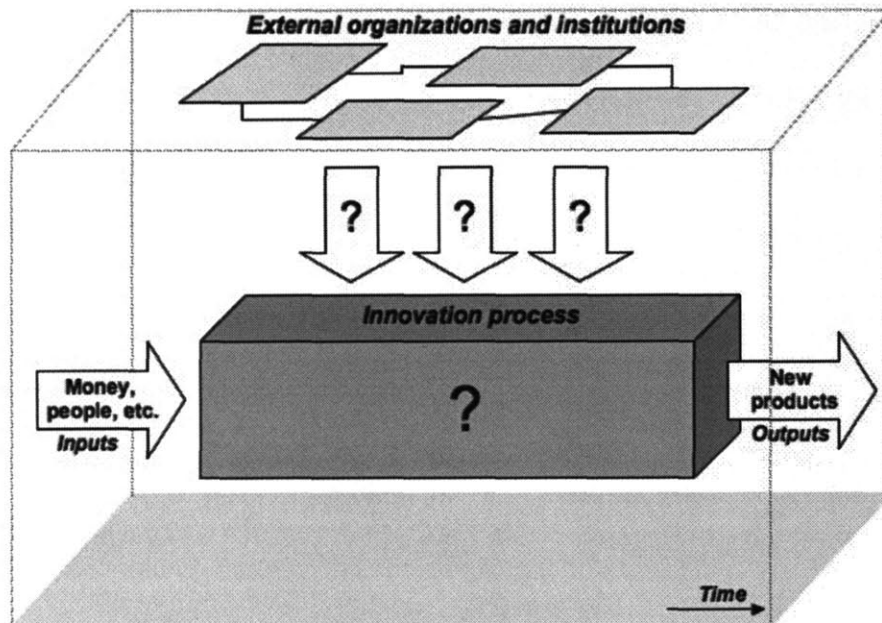
Figure 1-1 Most studies of innovation systems and in general, of the effects of organizations and institutions in enhancing regional innovation, do not examine the innovation process.

To overcome this limitation I approach each case from the ground up. First, I introduce the context in which the two local industries are located, including a brief characterization of each industry's structure and anchoring firms. Second, I open up the black box of innovation to examine more closely the nature of the innovation process in each industry. To do this I rely on interview data, secondary sources, and observation in a subset of companies within each locale. Third, I examine external interactions and innovation-support organizations that play critical roles in each industry's innovation process. In Tampere, I focus on external interactions that affect the process of interdisciplinary integration in machinery companies. In Charlotte, I focus on external interactions and organizations that affect the ability of NASCAR teams to optimize racecars. Fourth, I examine to what extent the nature of the innovation process in each

case affects the university–industry relationship, placing this relationship in a broader constellation of innovation-support interactions that companies have with other organizations.

1.4 Overview of the dissertation

Chapter 2 offers a detailed account of the research approach and methodology followed during this investigation.

Chapter 3 introduces the duality of innovation as a conceptual framework to understand the nature of the innovation process in the case studies that follow, and as a way to offer a more nuanced understanding of the innovation process to inform innovation policy in general and university-industry partnerships in particular.

Chapter 4, the first case study of the dissertation, is an account of how Tampere's mechanical engineering industry "became high-tech" through the infusion of new knowledge and technology into machinery. Building on 39 interviews and secondary data, the case presents a grounded understanding of how a subset of leading companies in the region have organized the innovation process. Then, it examines which organizations in the local innovation system have played important roles in the innovation process. Finally, it discusses the role of the Tampere University of Technology.

Chapter 5 is an account of how professional NASCAR teams in the Charlotte region innovate. Building on 60 interviews, secondary sources, and observation, the case study first introduces the relevance of the NASCAR motorsports industry to the economy of the Charlotte region. I next examine the nature of the innovation process in NASCAR teams.

Then, I examine how external interactions and organizations affect the innovation process within the teams. Finally, I discuss why the university is not part of those interactions, suggest avenues to build partnerships between the NASCAR industry and higher education, and reflect on the potential for motorsports as a hotbed for innovation.

Chapter 6 compares and synthesizes the findings from the two case studies. As a step towards understanding the prominent role of the university in one case and its absence in the other, the analysis focuses on how variations in the nature of the innovation process affect the university's contributions to industrial innovation in each case. I suggest how the duality of innovation helps to explain why the university is critical in one case and not in the other. I discuss some broader implications of this work towards the university's role in regional economic development. Finally, I discuss limitations of this study and directions for further research.

2 Research approach and assumptions

2.1 The paradigms of social research

Thomas Kuhn transformed the understanding of science by introducing the idea of a *scientific paradigm* (Kuhn, 1962). At any given epoch there exist validated and taken-for-granted scientific ideas and methods that have reached wide acceptance and stability in science mainly for three reasons. First, they successfully enhance our ability to understand and manipulate the world through science. Second, they open numerous questions to motivate further research. And third, scientists mobilize to form communities around them. Scientists believe and make believe in these paradigms, they write in journals that advance and reproduce the associated ideas, and they police notions of right and wrong. There is room for innovation in ideas and methods within a paradigm but there are certain sacred tenets that are not to be violated if a scientist wants membership and acceptance within a paradigmatic community. Eventually, a new revolution in science may come, and only then does a paradigm lose relevance. Scientists reinvent themselves and regroup around new ideas that hold the same promise of paradigmatic stability –until the next scientific revolution.

Although Kuhn developed the idea of scientific paradigm in the natural sciences, the idea equally useful to understand the social sciences. In this realm different paradigms constitute diverse world-views that allow the world to be understood in different ways. Using organizational analysis as an example, Burrell and Morgan (1979) articulated the existence of four sociological paradigms. What differentiates one paradigm from another is the set of assumptions about the social world on which they rest. The first set of

assumptions is ontological and refers to how we think about the essence of the phenomenon under investigation. The second set is epistemological, referring to what knowledge is, how one is supposed to come to an understanding of the world, and how this knowledge is communicated to others. A third set of assumptions, inextricably linked to ontology and epistemology, refers to human nature and to the relationship between human beings and their environment.

The different assumptions in each of these categories can in turn be associated with two grand views about social science that Burrell and Morgan call objectivism and subjectivism. Reality, knowledge, and what it means to be human take on different meanings depending on where on this spectrum one is standing.

From a purely objectivist perspective reality is a hard, pre-determined fact that is "out there." Knowledge exists a priori, is explicit, and is akin to bits of information that can be captured and re-transmitted to other human beings. Objectivism tends to be determinist, which means that human beings are conditioned by their circumstances and react and adapt to the reality they encounter as an external, hard fact. From a pure subjectivist perspective, on the other hand, reality does not exist independently of our perceptions and our ability to talk and think about it symbolically, particularly in language. Knowledge is not only "out there;" it is also embedded in our practices and is not necessarily articulated in symbolic form. Knowing the world means arriving at an understanding. In addition to what is already known new knowledge can emerge as humans interact with each other and with the reality around them. Human beings are assumed to create reality as they think, talk, and act. Even if that reality appears as

external and predetermined, it is assumed to be a social product. There is an objective reality; there are hard facts, but those hard facts have a history of human thought, language, and action.

The assumptions associated with objectivist and subjectivist social science have profound methodological implications. Depending on where the researcher is coming from he or she takes different paths to investigate the social world. The objectivist researcher is an observer of a pre-existing reality. He or she looks for causal relationships and regularities and seeks ways to express them in universal laws, often quantitatively. His approach is nomothetic (related to abstract and universal statements and laws) and draws from methods created to study the natural world to model the social world (Burrell and Morgan, 1979). Objectives, theories, models, and concepts are clearly defined and operationalized beforehand. The research process seeks to answer questions formulated a priori. The researcher is a distant observer and an expert on the subject (Andersen, 1995).

In contrast, the subjectivist researcher "stresses the importance of the subjective experience of individuals in the creation of the social world... The principal concern is with an understanding of the way in which the individual creates, modifies and interprets the world in which he or she finds himself" (Burrell and Morgan, 1979, p. 3). The methodology is *ideographic*. Research means getting close to the subject and exploring its background and history, and discovering *how* that reality is lived and created. One seeks to understand the world from the inside rather than the outside (ibid, p. 5). Research objectives are tentative at the start of the research; they serve to guide and

initiate discovery and they can change as the research progresses. Theory is emergent, constructed concurrently with the research process. The researcher is an involved interpreter instead of a distant observer (Andersen, 1995).

2.2 Qualitative research on innovation systems

Several innovation systems scholars have argued that there exists a quantitative bias in our understanding of innovation and innovation systems, as reflected in the policy focus on technological and economic outcomes such as patents, products, and revenue. They have also suggested that there is a tendency to generalize findings. Edquist (2001, p. 55-56) has argued that in order to draw conclusions and policy recommendations from studies of what in practice are very different innovation systems, it is vital to compare different systems of innovation. He also suggests that since there is no ideal or optimal innovation system, such comparisons have to be deeply grounded within existing systems of innovation. These comparisons, he says, "must be genuinely empirical and very detailed" and are the basis for policy formulation and to identify opportunities for intervention. A historical perspective is also necessary (Edquist, 1997). "To have a historical perspective is not only an advantage when studying processes of innovation, but also necessary if we are to understand them. This is because innovations develop over time. History matters very much in processes of innovation as they are often path dependent" (ibid., p. 19).

These recommendations echo Freeman's call for a more qualitative understanding of innovation systems and processes within them (Freeman, 1995). The post WWII emphasis on the linear model of innovation and investment in research is limited, he

argues. As an example, he cites the example of attempts to understand Japan's success in

the 1980s. In that case, "quantitative indicators could not explain *how* R&D led to higher

quality of products and processes, shorter lead times, and rapid diffusion of technologies

like robotics... It was obvious that qualitative factors affecting national systems had to be

taken into account as well as the purely quantitative indicators" (ibid, p. 11-12).

Edquist and Freeman highlight the need to develop a more subjectivist or interpretive

understanding of innovation systems to fill conceptual, analytical, and empirical gaps that

exist in our understanding of innovation within these systems and the way in which

institutions affect the innovation process.

2.3 Interpretive research

My research approach is well described by what Burrell and Morgan call the interpretive

paradigm of social research, which is a subjectivist approach.[1] Interpretive social

research seeks to understand the world as it is at the level of subjective experience. "It

seeks explanation within the realm of the individual consciousness and subjectivity,

within the frame of reference of the participant as opposed to the observer of action... It

sees the social world as an emergent social process which is created by the individual

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[1] To the objectivist/subjectivist spectrum Burrell and Morgan add a distinction between the *conflict* and the *order* views of the social world. From these two axes of classification (objectivist-subjectivist and conflict-order) emerge four paradigms of social research. In Burrell and Morgan's classification the interpretive paradigm is a subjectivist perspective oriented towards order. The objectivist counterpart is functionalism. The intellectual roots of interpretive social science are in the German Idealism, which in turn is inspired by the romantic movement that transformed the literature and the arts in the mid 19th century. In the same way that romanticism was a reaction to enlightenment values, in the social sciences the interpretive paradigm may be seen as a reaction to the belief that only "positive" science is knowledge and only the scientific method is the way to arrive at valid knowledge, a fallacy that Habermas called "scientism." In social research, the interpretive paradigm challenges the ontological assumptions underlying functionalist approaches to sociology in general (Burrell and Morgan, 1979).

concerned... It is a quest for the fundamental meanings which underlie social life" (Burrell and Morgan, 1979, p. 31).[2] The purpose of interpretive social science is to make clear and to make sense of an object of study (Taylor, 1979, p. 25). The researchers is an interpreter whose task is to *give meaning*. In the search for meaning the researcher enters a reality that is in some way "confused, incomplete, cloudy, seemingly contradictory in one way or another, unclear. The interpretation aims to bring to light an underlying coherence or sense" (ibid.).

The interpretive researcher searches for meaning by engaging in a process called the *hermeneutic circle*. This process is analogous to the interpretation of texts, and its origin is the interpretation of Bible, or biblical exegesis. The idea is that the interpreter reads ("enters") the text and tries to make sense and create meaning out of it. But the interpreter looks for more than the literal meaning of the words and sentences. He or she gradually builds new meaning by merging the literal meaning of the words, a deep contextual understanding of how and where the text was written (i.e. the author, the historical context, other chapters and surrounding sentences), and his or her own life experience and context. The interpreter iterates between the text and his or her own

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[2] The interpretive paradigm is a close relative of phenomenological sociology, which is concerned with studying the world as it is. Phenomenological research is interested in the way human beings experience their world, what it is like for them, and how to understand them (Tesch, 1990). Husserl is one of the fathers of the phenomenological tradition, later continued by Heidegger, Gadamer, Arendt, Merleau-Ponty, Sartre, and Derrida (Moran, 2000). Although each phenomenologist had a different agenda and often became a critic of the previous dominant figure, they all sought to create a view of reality and existence expressed in terms of the "lived-experience" rather than on vocabulary derived from scientific theories about experience. Heidegger, for example, wanted to find the "true essence of being." His work is a radical departure from dominant conceptions about human nature at the time of his life. A framework of social analysis built around phenomenological ideas was elaborated by sociologists like Alfred Schutz, Herbert Blumer, and Georg Simmel. Ethnography, which requires "entering the world of the other," is closely associated with this tradition.

reality to create an interpretation that is gradually refined in order to reach a plausible understanding —one that "gives meaning" and uncovers an "underlying coherence or sense" in the text (Taylor, 1979).

In a way analogous to that in which the interpreter "enters" a text by reading it, an interpretive researcher enters the reality under investigation and "reads it" to gain deep familiarity with the specific phenomenon he or she is studying and the context in which it unfolds. In interpretive social research the objects of study are texts or, in a broader sense, text-analogs (Taylor, 1979, p. 25). "Field-work" and all the forms of data collection that it may entail is one way of entering the text-analogs of interpretive research. The field is the text. After field-work (i.e. after reading the text) the researcher exits the reality to interpret his or her observations and start making sense of the documents read, the stories gathered, the data collected, and the observations made. The result of this sensemaking process is an interpretation that is gradually refined in an iterative way. After creating an initial theory, the researcher re-enters the phenomenon under study by carrying out additional "interview rounds," re-analyzing the data, learning more about how an object came into being, comparing with other investigations or conducting thought experiments. The purpose is gradually to reach a plausible interpretation that sheds light on a reality or concept about which we had a limited understanding or no understanding at all before the research started.

For the interpretive researcher interpretation is not only a method but also a process inherent to the unfolding life of humans in the world. The premise is that "individuals act towards things on the basis of the meanings that things have for them, that meanings arise

out of social interaction, and that meanings are developed and modified through an interpretive process" (Boland, 1979, p. 260).

These meanings resemble words, and in that sense they can only be identified in relation to others (Taylor, 1979). The relationality of meaning implies that interpretive research seeks to increase understanding of a phenomenon within a particular context (Orlikowski and Baroudi, 2001). My concern is with situated action, that is, "action situated in a cultural setting, and in the mutually interacting intentional states of the participants" (Bruner, 1990, p. 19). Since the interpretations of the actors involved in the reality under investigation occur in a social matrix or a web of significance (Mazlish, 1998, p. 97), a situated action approach "is built on the sociological understanding that a full theoretical explanation of the action of any social actors needs to take into account, to the greatest extent possible, the fact that individual activity, choices, and action occur within a multilayered social context that affects interpretation and meaning at the local level" (Vaughan, 2002, p. 29).

The phenomenon and the actors under investigation are not only situated in the preceding sense – in a place, in a web of significance or in a social matrix. Human beings are, in addition, embedded in time. History matters. This means that every action that takes place, every institution in a given region, every company within it and every product they make is not defined only by what it appears to be today. It is also defined by its past (its origin), by how it came into being, by its present (where it is located, what is the current line of business, what are the daily problems confronted, what regulations are in place), and its future. Of past, present, and future, perhaps the future is the most

elusive. But every individual has hopes, expectations and plans for the weekend; every company has a vision that gives it a certain strategic direction and performance targets to meet. Hopes, expectations, visions, targets and plans for the weekend are all in the future and without them there is no moving forward.

2.4 Interpretive research and technology

What does it mean to study technology and innovation from an interpretive perspective? Objectivism has guided a great deal of research in the management of technology and innovation. A common assumption in this line of scholarship is that technology evolves along "trajectories." Behind this idea there is a particular assumption about the relationship between technology and human beings. Artifacts are understood as organisms that belong to technological species evolving by a process akin to natural selection along these trajectories, outside of human control. Once the artifact is "out there" the marketplace will determine whether it survives or not. The beast may need to be regulated to stay under control. What corporations do –and their managers and engineers– is keep up with technological trajectories and adapt to exogenous forces of technological change. You adapt and catch up, or you die. This idealized view of the relationship between technology and society is known as technological determinism. It means that technology is a determinant of social processes.[3]

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[3] For a substantive reflection on this perspective, see (Smith and Marx, 1994). A good example of technological determinism in the management of technology and innovation literature is *The Innovator's Dilemma* by Clayton Christensen (Christensen, 2000). The core of the argument is that technologies are evolving along performance trajectories. While most of the innovations are incremental or sustaining, at some points there are substantial shifts in the technology, or disruptive innovations. A firm's ability to survive depends on how it responds and organizes around the evolution of technology to cope with both sustaining and disruptive innovation. Technology determines how to organize and manage. Another

As pervasive as this assumption may be, technological determinism falls apart rather quickly if one looks at where artifacts came from in the first place. Technology is neither independent nor fully determining of social processes. In corporations artifacts usually come from product development teams, and teams are made of people. While the marketplace might "select" the ultimate fate of a product, it is the engineers and managers within a team and a corporation who create or detect ideas, who create alternatives and choices, who choose what is worth pursuing, who come up with a product design, who decide which components to include, who will make manufacturing decisions, and who will target a specific market. To be sure, their choices are constrained by multiple factors (i.e. available technologies, costs, timing, access and state of the markets), but even within these constraints they make choices and these choices shape what the product will look like.[4]

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current example is the modularity movement, in which there is a distinction between modular and integral product architectures. The best way to organize product development depends on the product architecture. In the idealized scenario, there are organizational modules that mirror product modules. Once again, the product –the technology– determines how to organize.

[4] I was confronted with this fact as soon as the fieldwork started in Tampere. When making interviews it was very useful to talk about where artifacts came from. When talking about artifacts, engineers and managers talked about people, ideas, technology and institutions at the same time. It was in these narratives where the various elements of the local innovation system came alive during the innovation process. Talking about artifacts, technology, and how people worked became a deliberate strategy as the research progressed. Intellectually, this motivated me to start looking into the history and sociology and technology in more depth, and I realized that a few scholars have started advocating for this approach as a way to study innovation. While for management and policy scholars this is an uncommon view, the scholars in the field of science and technology studies (STS) have been writing about innovation and technological change for decades. Their writings hold numerous insights to understanding innovation in a more nuanced way, in which the context and agency are integral in the process of technological change. It would be a mistake, however, to try to rediscover the wheel. Decades of scholarship on technology and society already exist to inform future research, thanks to the historians and sociologists of technology. See Staudenmaier (1985) for an account of the various research approaches pursued by scholars in *Technology and Culture*, the journal of the Society for the History of Technology. Over the past three decades, a more sociological line of research has been advanced. An early synthesis of this work can be found in *The Social Construction of Technological Systems*, a classic edited volume by Bijker, Hughes, and Pinch (1987). See also Barry and Slater (2002) for an argument about why the study of the new economy needs to take

Studying technology and innovation from an interpretive perspective means recognizing the fact that technology emerges from the minds, activities, and interactions of human beings. Agency is behind technological change, not the other way around. And since agency is assumed to be situated in a multi-layered social context and embedded in time, technological change is also situated and contingent upon the agents' creative capabilities, their environment, and their history. Technology is not a black box. Reality is hybrid or heterogeneous, made of materials, texts, bodies, skills, and devices (Callon and Law, 1995). Innovation is an inherently social process of heterogeneous engineering, in which many elements – artifacts, ideas, people, instruments, etc. – are mobilized and converge towards the creation and construction of a technological artifact.

Artifacts are embedded in a network of social and technical relations that brings them into being and renders them stable (Law, 1987); they are not external to the social world but a constitutive part of it. As such, they represent moments of closure and stabilization in an ongoing process of technological change (Pinch and Bijker, 1987). They materialize human thought and action or, in Latour's words, they are "a sublimation of the contradictory wishes and needs of humans and non-humans" (Latour, 1992). From this perspective artifacts are windows into social reality. They freeze in time the

seriously the scholarship in the history and sociology of technology. Geels (2002) is an example of application of these concepts to research on innovation and technological change, but published in Research Policy, an innovation/technology policy journal. An example of some of these concepts applied to policy thinking is in Sørensen and Williams (1992). Over the last decade a structurational perspective on technology that bridges the positions of whether "technology drives history" or history (and context) drive technology. From this view, technology at the same time shapes and is shaped by social processes in a recursive way. This research has mainly taken place in the realm of information technology, with Wanda Orlikowski from MIT as one of the main proponents. See (Orlikowski, 1992). This work builds on Anthony Giddens theory of structuration. See (Giddens, 1984).

decisions, relationships, behavioral patterns, and institutional arrangements that affected the work of the agents that brought them into being.

If this is the case, it should then be possible to "unfreeze" artifacts; to gain access to decisions, relationships, behaviors, and institutional arrangements by gathering stories (and data more generally speaking) about how artifacts came into being; in other words, stories about the innovation process. One way to do it is by "entering" the places where the artifacts are created, seeing the artifacts themselves and understanding them, getting close to practitioners and gathering accounts of how they experienced their creation, and understanding the context in which they were created. This means assuming that practitioners are not the same everywhere, and that each place has a unique reality worth deciphering and understanding. In the sections that follow I describe in detail one approach and research process that captures what it means to study institutional effects on the innovation process from an interpretive perspective.

2.5 Case studies

The empirical core of the dissertation is two case studies of innovation in mechanical engineering-based industry clusters: machinery in Tampere, Finland and motor sports (NASCAR) in Charlotte, North Carolina, USA. A case study is "an empirical inquiry 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, p. 23). Case studies are a form of *process research*, which is concerned with understanding how things evolve over time and why they evolve in a particular way (Langley, 1999). The appropriate research

questions for case studies are *how* and *why*. For gathering evidence the case study relies

on similar techniques to history, but adds direct observation and systematic interviewing

(Yin, 1984). The data gathered in case study research is *process data*, which consists of

stories about what happened and how it happened, and may include qualitative and

quantitative data gathered from interviews, archives, questionnaires, and observations

(Eisenhardt, 1989).

As one form of interpretive research a case study aims to describe, test theory, or

build theory (ibid.). My purpose here is to build, from the ground up, an understanding

of the innovation process and the role of the university in enhancing such process within

lead firms of Tampere's machinery industry and Charlotte's NASCAR motorsports

industry.[5] Following Weick's choice of definition (1989), by theory I mean "an ordered

set of assertions about a generic behavior or structure assumed to hold throughout a

significantly broad range of specific instances" (Sutherland, 1975, p. 9). More

specifically, I build a *process theory*. A process theory provides explanations "in terms

of the sequence of events leading to an outcome... Understanding patterns in events is

thus key to developing process theory" (Langley, 1999, p. 691).[6]

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[5] Theory building from empirically grounded case studies recognizes what Andersen et al. (1995) call "the principle of complementarity." Practitioners in the field are themselves creators of meanings and that the "use of common-sense concepts represents a process by which the inhabitants develop theories, which make it possible for them to cope with everyday life" (ibid. p. 174). Articulating these "practical theories" constitute the bases of the work and intellectual contribution of interpretive researchers.

[6] Process theories contrast with *variance* theories, which "provide explanations for phenomena in terms of relationships among dependent and independent variables (e.g., more of X and more of Y produce more of Z)" (Langley, 1999, p. 691). To this effect, Bruner (1990, p. xiii) says that "to insist upon explanation in terms of 'causes' simply bars us from trying to understand how human beings interpret their worlds and how we interpret their acts of interpretation... Are not plausible interpretations preferable to causal explanations, particularly when the achievement of a causal explanation forces us to artificialize what we

The theories and explanations of case studies are primarily presented as stories. In the same way that narrative is "the primary form by which human experience is made meaningful" (Polkinghorne, 1988, p. 1), by crafting a story the researcher gives meaning to the phenomenon under investigation. These stories are in between the field and the reader: the researcher interprets the field and converts it into texts that are actively interpreted by the readers who disclose meaning in light of their own background (Golden-Bidle and Locke, 1993). In some case studies the purpose of the research is to create a "thick description." In those cases it is enough to have a good story (Dyer and Wilkins, 1991). But as Langley (1999) points out, "most of us expect research to offer more explicit theoretical interpretations" (p. 697). The task is thus not only to offer a good story, but also good theoretical constructs (Eisenhardt, 1991). In this sense the case stories not only describe the reality under investigation in each locale. My purpose is to go under the surface of the story and develop themes that serve as sense-making devices that will become explicit theories by the end of the process (Langley, 1999, p. 697). The challenge is to move from surface structure to deep structure, to "recover a single objective account from multiple, partial, subjective, and even conflicting accounts" (Pentland, 1999, p. 712) in order to highlight relationships, connections and interdependencies in the phenomenon under study (Weick, 1989).[7]

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are studying to a point almost beyond recognition as representative of human life?" A process theory helps to minimize "artificializing" the phenomenon.

[7] Brian Pentland (1995), building on insights from Weick (1979) and Drazin and Sandelands (Drazin and Sandelands, 1992), proposes a grammatical model of organizational processes. These ideas come from Noam Chomsky's transformational grammar. The original idea of a deep structure suggests that multiple "surface forms" (sentences) can derive from a single underlying form. A sentence corresponds to the deep structure paired with the surface structure derived from it. For Pentland (1995) the appropriate unit of analysis in a grammatical model is a process (ibid., p. 546). A grammar, he warns, is not a structure that

2.5.1 Research process and logic of exploration

Drawing from the combined insights of Eisenhardt (1989), Weick (1989), Andersen (1995), Langley (1999), Smith (2002), and my own experience and learning, in this section I describe the research process that I follow in this project. The process as depicted here is an idealized image, a result of "retrospective sensemaking" near the conclusion of my research. Theory building from case studies, and indeed all forms of qualitative research, as structured and formalized as it may be, does not proceed in a linear way through a series of steps. As Eisenhardt (1989) points out, the process is iterative, moving forward after several iterations between steps. It is a dialogue between the field, the evidence, the literature, the researcher's insights, and the constructs that emerge along the way. Furthermore, in addition to the research objectives and the data available, imagination and taste have also played a role in my research (Langley, 1999, p. 707). Openness to the unexpected, insight, imagination, and inspiration (Weick, 1989; Langley, 1999) have been essential.

Let us also keep in mind that this dialogue is not assumed to be value-free. As an interpretive researcher I am also situated in my own reality and embedded in my personal history. Hence my assumptions, beliefs, values, and interests have intervened to shape my investigation (Orlikowski and Baroudi, 2001). Carrying out interpretive research calls on the researcher to be deeply aware of this undeniable fact. It "requires a high degree of self-knowledge, a freedom from illusion, in the sense of error which is rooted

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determines anything. Instead, "they generate the set of possibilities for the agents in the situation. As a result, it is helpful to think in terms of constraints and affordances" (ibid.).

and expressed in one's way of life; for our incapacity to understand is rooted in our own self-definitions, hence in what we are" (Taylor, 1979, p. 71).

2.5.2 Case selection

In most qualitative research the purpose is not to generalize results in a statistical sense, so sampling is not probabilistic. Case selection is instead purposive or criterion-based (Merriam and Merriam, 1998). The researcher establishes selection criteria and cases are selected to learn as much as possible about the phenomenon under study. The first case is selected for its evident relevance to the research problem and not all the cases need to be selected beforehand. In this study I have relied on theoretical sampling (Glaser and Strauss, 1967). The problem itself is in flux during the early stages of the research and is refined, and often redefined completely, as the research advances. The purpose of data collection is to generate theory with analysis unfolding concurrently as the data collection proceeds. It is an ongoing process of discovery in which emergent theory guides further exploration. As the theoretical constructs evolve in tandem with data collection and analysis, new evidence is collected to refute or increase the validity of the theory (Glaser and Strauss, 1967; Merriam and Merriam, 1998). Subsequent cases are selected to replicate previous cases, extend emergent theory, fill theoretical categories, and provide examples of polar types (Eisenhardt, 1989).

The overarching criteria for the initial selection of the case studies was guided by the Local Innovation Systems Project, an international research partnership based at the MIT

Industrial Performance Center.[8] The purpose of LIS Project research is to elucidate how local economic communities survive and prosper in the global economy, with a particular focus on the role of universities. The empirical core of the project is a portfolio of more than 20 regionally circumscribed, industry-centered and technology-specific case studies in Finland, Japan, the United States, the United Kingdom and Norway. My own participation in the LIS Project was motivated by a strong personal and intellectual interest in science and technology policy and the role of universities in economic development. The LIS Project offered an ideal setting to pursue these interests in the context of a large-scale research project.

Case selection in the LIS Project was guided by a priori knowledge of (1) the presence of a world-class industrial concentration in a particular region within these countries, (2) a regional economic transformation in which an industry declined, emerged, upgraded or was transplanted to the region, and (3) evidence that educational and research institutions within the region were playing a role in attracting or creating new enterprises or enhancing the ability of existing companies to innovate. These same selection criteria led me to Tampere, and as the research progressed the emerging theory informed the selection of the Charlotte case.

2.5.2.1 Selection of the Tampere – Machinery case

As a member of the LIS team, I was exposed to Finland early on. My involvement in Finland began after an initial reconnaissance trip that took place in December 2001, which led me to discover that Finland has been repeatedly ranked among the most

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[8] A detailed description of the LIS Project is at http://web.mit.edu/lis.

innovative, competitive, and technologically advanced nations in the world. After World War II and particularly during the 80s and 90s, Finland transformed itself from an agricultural economy into the home of a wide variety of high-tech enterprises in the telecommunications, engineering, and forestry sectors among others, many of them concentrated around specific regions. While entrepreneurs and corporations have been the core of this transformation, government plays an active role in promoting innovation. These combined facts awakened my interest in learning about the industrial culture and institutional setup for innovation in the country. Finland, in other words, offered an evidently ideal national "laboratory" to study innovation and science and technology policy.

I was motivated to study Tampere, Finland, because of the existence of a world-class concentration of mechanical engineering (machinery) companies in the region and the prominent role of local educational and research institutions in the ability of companies to innovate. A major strength of the companies concentrated in the region is the design and manufacturing of mobile machinery and process automation systems, with several global market leaders working in specialized niches located there. In addition, the mechanical engineering industry in Tampere offers an opportunity to study how an old industry has reinvented itself and "become high-tech." As I describe in more detail in Chapter 4, the roots of the mechanical engineering industry in the region date back to the 19th century. More recently, WWII was an important catalyst for the industry's development. Tampere became the center of weapons manufacturing and, after the war, the heart of the industry

that produced the goods – many of them production machinery – that were paid as war reparations to the Soviet Union.

The key insight to emerge from the first set of interviews in the Tampere case study was that the core innovation process underlying technological change and the survival of the industry has been the integration of new knowledge and technology into machines that in many cases have been manufactured and marketed for several decades. By comparing this finding with other industries and locations, it became evident that the ability to integrate mechanical, electronic, and information technology systems is a major – if not *the* major – competitive strength of local machinery companies. If they had not succeeded at doing this, the industry would have probably been wiped out by global competition in the same way the American machine-tools vanished due partly to its failure to integrate CNC technology (March, 1989). In this way the inquiry about the role of the university in enhancing the ability of machinery companies to innovate focused specifically on interdisciplinary integration.

2.5.2.2 Selection of the Charlotte – Motorsports case

The criteria that guided the Charlotte-NASCAR selection were the same as the Tampere case: to find another regional concentration of world-class industry in the United States where universities might be playing an important role in the ability of companies to innovate. With the Tampere case study well underway, selection was also motivated initially by a desire to test and extend insights and theories in that case. To do so I started searching for a concentration of mechanical engineering expertise and machinery companies in the United States. Preliminary research suggested that such a concentration

existed in Charlotte due in part to its proximity to what used to be the heartland of American textile and apparel manufacturing. With that in mind I traveled to Charlotte in February of 2003 for a intensive round of interviews that were organized with the assistance of the Office of the Chancellor at UNCC. The Charlotte Region is also home to the majority of the teams that participate in the NASCAR league of automotive racing, today the 2nd most popular sport in the United States. Within a 50 mile radius of the Lowe's (formerly Charlotte) Motor Speedway one finds not only the teams, but a wide variety of specialized suppliers of parts and services.

But I did not know anything about NASCAR or its presence in Charlotte prior to this reconnaissance trip. In a process typical to this interpretive research the field itself "told me" what was important and pointed in this direction. The second interview in Charlotte, at 3:15 P.M. on February 12, 2003, was with former Chancellor Jim Woodward. 42 minutes into the interview, he said "[N]ow, you are talking about mechanical engineering [in reference to my work in Tampere]; well the center of motorsports in the country... is the Charlotte region." This awakened my curiosity, and the remaining 14 minutes of the conversation focused on NASCAR racing. In subsequent interviews during the following day other members of the UNC community brought up NASCAR once again. Upon returning to Boston on February 14, I did more research into the nature of this industry and its size in Charlotte region. After a few days, I concluded and agreed with my advisor that this was a potentially fascinating case, and I decided to pursue it. One month later, in late March 2003, I returned to Charlotte with my colleague Kimmo Viljamaa to do the first round of 20 interviews focused on NASCAR motorsports.

During the first round of interviews in Charlotte it emerged that a key element in the ability of NASCAR teams to compete is the infusion of electronics and information technology. In contrast with Tampere, however, the integration of information technology and engineering science is taking place in the product development and manufacturing process, not on the cars themselves. Although the architecture of the cars and the engines have changed little for decades, such integration of new technology and engineering science to the product development and manufacturing process has gradually enhanced the ability of teams to speed up the innovation process and increase the speed and reliability of racecars. Coupled with this process of integration in NASCAR teams is the blending of craft and science. Up until the early 1990s there were no professionally qualified engineers working with NASCAR teams, and today they cannot do without them. What used to be a craft and a hobby has evolved into sophisticated business and technological operations that require a great deal of engineering science. Doing this has involved another type of integration: the blending of the skills and knowledge of craftsmen and engineer-scientists.

A striking difference emerged when inquiring about the role of UNCC in the NASCAR industry. We found that a role which was incipient and had in fact been non-existent until very recently. In contrast with Tampere neither the university Charlotte nor any other educational or research institution in the Charlotte region had played any significant role on the uptake of new knowledge and technology of NASCAR teams. This contrast offered a fundamental point of comparison for to advance our understanding of the contributions of universities to industrial innovation and, the nature

of this role, and the conditions under which universities matter and can participate in an industry's innovation process.

2.5.3 Level of analysis and unit of analysis

My fundamental objective in this dissertation is to understand how the university affects the innovation process of the firms in each locale. In sociological terms, what I am trying to elucidate is the macro-micro link, a task that Vaughan has suggested is a problem of research design and data availability (Vaughan, 1992). For this reason my research is not limited to a single level of analysis. Instead, I pursue a multi-level approach. Case studies are ideal for this purpose because in addition to their ability to handle diverse sources of evidence, they also allow for multiple levels and units of analysis within a single study (Yin, 1984; Eisenhardt, 1989; Langley, 1999). The boundaries across the levels are more of a continuum than a hierarchy or a clear classification (Langley, 1999, p. 692).

The logic of exploration in my data collection, analysis, and theorizing is guided by the need to elucidate the macro-micro link. My goal is to capture circumstances and interactions at the institutional level of the innovation system (the macro level) and understand how they affect the how practitioners innovate on the ground (the micro-level). I have taken for granted that institutions matter, both because I am examining each case as an innovation system approach (see Edquist and Johnson, 1997), and because I am assuming that human action is situated in a multi-layered social context (see Section 2.3). The question is thus not whether institutions matter, but *how* institutions matter. To uncover this I approached each case via three *entry points*: the region, the

firm, and specific products. In the regional entry point my purpose was to understand and apprehend the industrial history, the culture of the innovation systems and the policy, and institutional frameworks for innovation in place within each location, if any. In the first write-ups of the case studies I used data from the second entry point – the firm – to construct "cases within the case" or what Yin (1984) called *embedded cases*. In these embedded cases I took a close look at the third entry point: the micro-level innovation process within specific firms.

While the approach is explicitly multi-level, the primary unit of analysis is the third entry point: the *innovation process* that brings products into being. In other words, there is a clear focus on the micro-level as the "place" to observe the role of the university and other institutional effects on the innovation process. As Immergut (1998) and Coulter (1996) have suggested, institutions can best be observed through their effects and micro-level practices are a window into the macro-social. Building on the constructivist view of technology outlined in Section 2.4, in both case studies I examine the history of artifacts (machines and racecars) and inquire about how new products come into being – first as a new idea and then as a material artifact. In this fashion I elucidate the ways in which the organizations, processes, interactions, institutions, and events not directly related to the development effort within the firm affect the innovation process.

2.5.4 Data collection

The primary method of data collection in this dissertation was a series of interviews conducted between 2002 and 2006 in the two research sites. I conducted 99 interviews: 39 for the Tampere case and 60 for the Charlotte case. The interviews ranged from semi-

structured to open ended, depending on the interviewee and the stage of the research.[9]

Although there was an initial detailed list of questions for different types of interviewees,

soon after the start of the project the research was instead guided by a list of broad

themes that was used to formulate the questions in the tone and order that made sense for

the specific context of the interview or background of the interviewee. Often the content

of the interview itself provided the anchors to explore the main themes of the research or

suggested new themes of exploration as the research progressed. A fundamental premise

during the process – especially during the early stages – was openness to emergent

themes and markers to delve into issues that reflected emergent patterns across

interviews, issues that seemed particularly interesting in the context of the interviewee, or

in which the interviewee had an evident interest or expertise that echoed themes of the

research.

The broad themes that guided each interview included the organization of innovation

and product development, the inner events associated with the experience of innovation,

and the contextual factors that affected these inner experiences and ways of organizing.[10]

An investigation of the history of new ideas and product concepts to elucidate the process

that brought a product into being, including relevant technologies, knowledge bases, and

actors involved was central to the inquiry. Emphasis was placed on critical moments and

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[9] For an extensive discussion on interviews as a form of social research and the associated procedures see (Weiss, 1994) and (Merriam and Merriam, 1998). Chapter 4 in the latter discusses the spectrum of interviewing strategies ranging from highly structured to informal conversation.

[10] The idea of "inner events" is elaborated by Weiss (1994). Inner events accompany the outer events of an actor's experience. They include "perceptions, what the respondent heard or saw; cognitions, what the respondent thought, believed, or decided; and emotions, how the respondent felt and what strivings and impulses the respondent experienced. They can also include the respondent's preconceptions, values, goals, hopes, and fears" (Weiss, 1994, p. 75).

concrete examples of products and experiences. Some questions were directly aimed at eliciting micro-macro connections, for example "do the local universities educate engineers capable of interdisciplinary teamwork?" or "how does [government agency X] facilitate the convergence of these individuals in these project?" In other cases the macro-micro link was indirectly elicited by seeking descriptions of micro-level processes in which the connections between the process of innovation with the broader institutional environment naturally emerged. For this reason, when interviewing engineers, scientists, or managers familiar with the evolution of products and technology, questions often sought detailed descriptions of the ways of organizing, the people, the technology, and the knowledge bases that converged in the creation of a new product.

The first case study I carried out for the dissertation was the Tampere machinery case. The first round of data collection occurred in late March and early April 2002 during a four-week stay in Tampere. As a visiting researcher in the Research Unit for Urban and Regional Development Studies (Sente), I used this period to gain as much familiarity as possible, via journals, magazines, books, internet sources, and conversations with my colleagues at Sente, with the science and technology institutions and policies of Finland at the national level, as well as at the regional (Tampere) level. I also studied in detail previous articles written about innovation in Tampere and other regions of Finland. After two weeks of building up this background, I started the first round of interviews, which included a sample of local businesses, policy makers and academic institutions. The first interviewees were selected with the help of the Tampere Region Centre of Expertise in Mechanical Engineering, with interlocutors suggested by the director of the program, an

engineer who became a manager and then a policy maker with long familiarity with the industry. A second round of fieldwork took place during the second half of June 2002 and a third round during November of the same year. The last round was a series of repeat interviews with interlocutors from specific companies and was carried out with the purpose of confirming insights and enriching the embedded cases that looked in detail at specific innovations and products generated by particular companies.

Data collection for the Charlotte NASCAR case began with a series of reconnaissance interviews during the second week of February 2003. This visit included some interviews with policy makers in Raleigh, the capital of North Carolina, and attendance at a forum on the role of innovation and university-industry partnerships for the state economy. I also spent 2 days in Charlotte interviewing university officials. With the data collected during these interviews I decided to focus the study on NASCAR motorsports and started gathering additional information on potential interviewees. By reading background documents and gathering information from the internet, I selected a group of initial interviewees that included engineers and managers from race teams, regional and local development officers, academics from colleges and universities, and an industry association.

The first round of data collection focused on NASCAR motorsports took place during the last two weeks of March 2003. Most of the interviewees selected happened to know each other – a fact discovered after beginning the fieldwork – and some of them suggested and helped arrange additional interviews. A second round of data collection took place during November 2003. Having learned from the Tampere experience, the

order of the interviews in Charlotte had a gradual macro-micro progression in mind. Interviews during the first visit focused on gaining a grounded understanding of the policy and institutional context, the region, the industry, and the patterns of interaction among practitioners and organizations, while the second round focused on firm-specific issues and the innovation process. An additional round of telephone interviews conducted towards the end of this research during July and August of 2006.

The Tampere interviews and about half of the interviews for the Charlotte case were carried out jointly with Kimmo Viljamaa, a graduate researcher affiliated with Sente in Tampere. By carrying out these interviews jointly we brought complementary interests and strengths to the fieldwork. When Viljamaa was present, in the particular case of company interviews my questions tended to focus on the organization of innovation at the firm level and the process of technological change, while his questions focused more on macro-level dynamics of the innovation system. In this way we jointly developed a protocol that allowed us to move across levels and units of analysis, yet emphasizing what was most relevant depending on the context of the interviewee. I applied a similar approach whenever I carried out interviews on my own.

Most of the interviews were taped. When they were not, my colleague and I took notes by hand. Each of us later made transcriptions into the computer and compared them to make sure that we captured as many insights as possible and that these insights were accurate. When the interviews were taped, I transcribed most of them verbatim from the recordings, an exercise that proved extremely useful to process the data and carry out the initial analysis of the interviews and the identification of guiding themes.

In addition to the interviews, other sources of data included company reports collected during visits, policy statements from the cities and regions visited, presentations provided by the interviewees during visits and visits to manufacturing facilities. Preliminary drafts of the case studies were started in between interview rounds. During the preparation of these drafts additional insights were gathered by reviewing existing literature and current web sites on the regions and the industry, as well as more detailed information on specific companies, the technology and the use of the artifacts under study. These sources were used to validate, complement, or draw more solid inferences from the data gathered with the interviews. The final data collection for the NASCAR motorsports case involved close observation of the work of NASCAR NEXTEL Cup teams at the New Hampshire International Speedway in Loudon, NH. I spent three full days, between September 15 and 17, 2006 immersed in the speedway garages and at the pits during races, observing preparations and practice sessions on Friday and Saturday, and the race, activities in the pit stops, the post-race inspection and wrap-up of activities at the end of the day on Sunday.

2.6 Building theory from case studies

2.6.1 Analysis and within-case theorizing

At the highest level, my analysis was guided by two phases: within-case analysis and cross-case pattern search (see Eisenhardt, 1989). The goal of within-case analysis is to gain familiarity with the data, generate preliminary theory, and create a detailed story about each site (ibid.). The purpose is to theorize by intention: "Representative

metaphors are developing a photographic negative, bringing binoculars into sharper focus, or gradually adding light to a darkened room" (Weick, 1989, p.).[11]

At this level my analysis followed a grounded theory approach (Glaser and Strauss, 1967), as adapted by Emerson et al. (1995) and Weiss (1994). The process started with reading the field notes and interviews, followed by open coding to identify ideas, themes or issues and writing them on the margins of interviews and notes. These ideas become core themes that aid further analysis. Analysis then proceeds to focused coding. In this stage themes of particular interest are used as a lens to perform a more fine-tuned analysis of the data; an analysis that involves identifying more detailed themes and beginning to establish relationships between them.[12] I then proceeded to prepare an excerpt file, in which the themes and sub-themes are organized in an outline that includes interview excerpts. The insights that emerge during the process of reviewing, coding, and preparing the excerpts file are then elaborated in integrative memos that describe and theorize about possible causal relations are between the themes. The final phase centers on theory-building to bring together insights from the integrative memos under a coherent, unifying framework and writing the case report.[13]

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[11] The distinction between theorizing by intention and theorizing by extension (which I discuss later), builds on Kaplan's notions of knowledge growth by intention and knowledge growth by extension (Kaplan, 1964), as cited by Weick (1989).

[12] Codes and themes emerging from the data, which are later used for analysis and theory-building, are akin to what Blumer called *sensitizing concepts* (Blumer, 1969). The purpose of the sensitizing concept is to give a sense of direction as the research proceeds, suggesting lines of inquiry. Sensitizing concepts are empirically grounded and may be expressed in the language of the reality under study, but they are abstractions from it and as such, bridge the world of observation and theory (Van den Hoonaard, 1997).

[13] The preparation of integrative memos is what Weiss calls *local integration*. The objective is to make sense and organize the insights and observations that will go into the final report. As Weiss pointed out from her experience, local integration begins as soon as the research starts but becomes more intensive and focused as the need to have a final report approaches. The preparation of the final report is *inclusive*

The main themes that guided my analysis and theory-building process emerged from the Tampere machinery case. Analysis within this case unfolded in three separate stages. During the first phase I read each interview transcript, did the open coding and selected main themes. Early in the process coding was guided by insights and hypotheses that emerged during the first few interviews, though I remained open to new themes suggested by later interviews. I then wrote down the core themes in separate pages and moved into focused coding, going once again through the interviews and writing more numerous and detailed statements in the margins. With these two types of coding I proceeded to create an excerpt file that included approximately 10 main themes and numerous sub-themes and interview excerpts under each of them. Along the way I prepared integrative memos to make sense of the data. The organizing themes that resulted from the coding provided the guiding posts for the writing process. I proceeded to write detailed descriptions of the evolution of technology, product and the innovation process in three companies, drawing not only on the interviews but on extensive background research on the subject. These three narratives were then compared, checked for validity and plausibility with interlocutors from each company, and subject to a new meta-analysis round which resulted in a series of hypothesis and an emerging theory. The final within-case study write-up included these narratives and the emerging theory.

Data gathering for the Charlotte NASCAR case started after concluding the first full draft of the Tampere machinery case. For this reason, the research process in Charlotte was from the beginning influenced by the concepts and the theory developed in Tampere.

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integration, in which the isolated elements resulting from local integration come together in a coherent story. See Chapter 6, Analyzing Data, in (Weiss, 1994).

The Charlotte case thus had the dual purpose of developing an autonomous understanding of innovation in the industry and the local innovation system, and enriching, refining, and extending the insights that emerged from the Tampere case. To do this, I conducted a within-case analysis analogous to the one conducted for the Tampere case. The difference was that I taped and later transcribed most of the interviews. Analysis in this case began with the transcription, which became at the same time an exercise of gaining deep familiarity with the material, coding and building the excerpt file. While I listened to the sound files in the computer and typed the notes into a word processing document, I had one additional file open. As I typed each interview I copied and pasted interview excerpts into this file. Each excerpt was preceded by headings that reflected main themes and focused codes about what it said. After some excerpts I wrote longer statements classified as "ideas," "questions," or "insights." In most cases these statements were based on reactions to what I listened, rather than analysis of it, a piece of advice given by Eisenhardt (1989) for writing field notes. Ideas and insights in this document were early theorizing and became the starting point for the integrative exercise that led to the final within-case write up. In addition, because the preparation of the excerpt file was already informed by the emerging theory from Tampere, this document was also the first step in the cross-case pattern search.

For both the Tampere machinery and Charlotte NASCAR within-case exercises there were intermediate products prepared for external audiences or interlocutors that were very important in the analysis and theory-building process. These included memos and draft reports written for the LIS project group, conference papers, and presentations made

for audiences at MIT and elsewhere, both familiar and unfamiliar with the research. These "pit stops" were central to synthesizing the findings, and analyzing and theorizing at various stages of the research. In addition to writing I also constructed graphic representations of the findings and emerging theories. I drew these graphic in large pieces of paper. When preparing presentations for an audience, I used these representations and created additional graphics. These drawings were always a useful synthetic exercise, especially when a single graphic construct was able to convey relationships among several constructs at the same time. They were also record of key insights that emerged in the theory-building process and, in some cases, as an "outline" to write whole sections of this study.[14]

These preliminary documents and presentations formally brought into the analysis and theory-building process "outside voices" that were "sense-giving" to my own sensemaking process (Smith, 2002). These outside voices came as written reactions to drafts and presentations, email exchanges, and formal and informal conversations about the documents or presentations. Other outside voices came in during chance encounters in hallways, lunch, when someone dropped by my office or when I bounced an idea with someone, or when I was asked about my research. Some of the most important "aha" moments of my research were triggered by unplanned conversations with my advisors and colleagues.

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[14] Creating narratives and visual representations from the raw data are two of the sensemaking strategies that Langley describes in her account of strategies for theorizing from process data (Langley, 1999). She suggests that both narratives and visual mapping strategies are systematic ways of organizing and representing process data that serve as "intermediary databases." Narratives are closer to raw data than visual representations so they usually precede their development.

An important companion during my sensemaking process was a dissertation journal, still in use as I write this text and with twelve blank pages left out of about 200. The first page is dated July 3, 2003. In this journal I wrote insights that emerged while reading papers or relevant literature, newspaper articles, after conversations with colleagues or friends, or at unexpected moments in which I was not explicitly working on my research but I had ideas that seemed relevant. The journal accompanied me to seminars or presentations that in many occasions were sources of ideas, triggered important reflections, led to "aha" moments, and allowed me to contextualize my research in a broader scholarly landscape. The journal was with me during trips to the research sites and during leisure trips. One of the most important moments of synthesis for the Tampere machinery case came two days after a casual conversation with my advisor. I wrote the insights during a ferry ride across Cape Cod Bay. I started an additional journal specifically devoted to keep track of emerging ideas during the dissertation writing process.

Nearing the conclusion of this dissertation I rewrote both the Tampere and Charlotte cases from scratch. Although I built on previous drafts and analysis, this redrafting involved revisiting the data and performing a more focused and fine-tuned analysis of the interviews. For this purpose I used HypeResearch, a qualitative data analysis software.

2.6.2 Cross-case theory building

In qualitative research, data gathering, analysis, and theory-building are concurrent processes that unfold in a mutually transforming dialogue. The researcher is the intermediary engaged in an iterative process in which the emergent theory is compared

with the evidence.[15] Theory building started during the within-case analysis in the Tampere machinery case, in which I generated hypotheses while analyzing and comparing the evolution of technology and the organization of innovation in three companies. The theory that emerged from this comparison became the starting point and object of refinement during and after the Charlotte NASCAR case, when the cross-case analysis and theory-building became more central. This phase focused more on creating additional hypotheses, sharpening construct definition, and refining theory across cases as suggested by Eisenhardt (1989).[16] At this point one enters "theorizing by extension" mode, in which "a relatively full explanation of a small region is . . . carried over to an explanation of adjoining regions . . . Representative metaphors include a mosaic built piece by piece, science as an edifice that is constructed much like an erector set, and a puzzle that is gradually solved as more pieces are put into place" (Weick, 1989, p. 518).

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[15] As Eisenhardt points out, "the process of building theory from case study research is a strikingly iterative one" (Eisenhardt, 1989, p. 546). This insight is confirmed by my experience and by how others have described the theory building process. For Burgeois (1979), iterations occur between "intuition and data-based theorizing" and between "induction and deduction." Langley points to three processes in theory building: "(1) induction (data-driven generalization), (2) deduction (theory-driven hypothesis testing), and (3) inspiration (driven by creativity and insight)" (Langley, 1999, p. 708). Regardless of what the iterations are about, the general pattern and purpose is rightly captured by Weick when he says that theory building is an evolutionary process: "when theorists build theory, they design, conduct, and interpret imaginary experiments. In doing so, their activities resemble the three processes of evolution: variation, selection and retention... Theorists are both the source of variation and the source of selection... [they] control both environmental selection and the criteria for survival of conjectures" (Weick, 1989, p. 519-521). These iterations and this evolutionary process are nothing more than the hemeneutic circle. In the process of variation, selection, and retention the researcher is engaged in that "back and forth" process whose purpose is to refine emerging meanings and reach a stable and plausible interpretation of the reality under study.

[16] This process corresponds to Langley's "synthetic strategy," in the sense that the purpose is to "identify regularities that will form the basis of a predictive theory relating holistic processes characteristics to other variables (e.g. outcomes and contexts)" (Langley, 1999, p. 704). My purpose here was to build a causal model, Langley argues that the result is a variance theory, not a process theory. Her suggestion to respect the process understanding is to be careful "not to ditch the detailed temporal understanding obtained for its shadow" (ibid). In my case, although at the highest level I do construct a variance theory, I "open up" the variables and focus on the processes that bring the variables into being, the actors involved, that factors and agents that affect their operation, and the different ways in which the variables and the relationships between them manifest and operate in different context. In this sense, within the causal model there is a process theory.

This mode of theorizing began as early as I prepared an excerpt file while transcribing the Charlotte interviews.

My theory-building approach has been strongly influenced by Diane Vaughan's *analogical theorizing* approach. Analogical theorizing is "a heuristic, theory-generating, comparative method using qualitative data (e.g. comparative historical, ethnography, interviews). It relies on selecting cases on the basis of some event, activity, or phenomenon of theoretical or substantive interest, [selecting on a dependent variable X] and then comparing it with another example or examples that appear, hypothetically, to share that feature" (Vaughan, 2002, p. 30). The cases may be different social settings with radically different characteristics, sizes and functions, so that similarities and differences in structure are highlighted (ibid., p. 32), so that "what is common appears more clearly and its relevance to different contexts, its generalizabilities, can become clear" (Vaughan, 1992, p. 181). By generating "lots of facts, and radically different kinds of facts," analogical theorizing creates sharp contrasts that allows one to discover, reinterpret, and transform constructs in a unique way. In analogical theorizing it is possible, and even desirable, to shift units and levels of analysis, allowing the researcher to discover macro-micro connections that might remain hidden otherwise. Theory construction is enriched by structured comparisons in different units and levels of analysis.[17] An underlying comparative logic guides the theorizing process.

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[17]A good example of scholarship based on analogical theorizing is Donald Schön's , The Reflective Practitioner (Schön, 1983). In this book Schön builds a theory of "reflection-in-action." He does so via case studies drawing from multiple sources of evidence, of "how professionals think in action." A substantial part of his inspiration is in a theory of design, which he describes as a "reflective conversation" and discusses in Chapter 3 of his book. Then on Chapter 4 he moves into a radically different context:

The Tampere machinery and Charlotte NASCAR are an ideal setting for analogical theorizing. These cases fulfill the criteria of maximum variation (Glaser and Strauss, 1967). Comparison across these cases can reveal shared patterns, whose relevance is enhanced because they emerge out of diversity (Patton, 1980). While the knowledge base and the class of products are similar, the industries are different, the products themselves are different, and the institutional frameworks are radically different.

A prominent difference and opportunity for comparison comes from the radically different configuration of the local innovation system and, as I will show in the case studies, of the innovation process. The Tampere machinery case suggested that pre-competitive collaboration among local companies, the support of research and educational institutions in the region, and public policy support have enhanced the ability of companies to integrate technologies and innovate. The Charlotte NASCAR case study shows a radically different picture, in which companies innovate without any formal institutional support from within the region – at least at first sight. Moreover, in sharp contrast to Tampere's collaborative pattern, NASCAR teams in Charlotte are extremely competitive and secretive and, in addition, there is only an incipient relationship with the

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psychotherapy. There he tries to understand the process of reflection-in-action in the therapist–patient interaction. Based on these two chapters he builds a theory of the structure of reflection-in-action in Chapter 5. Then, he applies his theory to explain phenomena in the science-based professions (Chapter 6), town planning (Chapter 7), management (Chapter 8). In Chapter 9 he explains "patterns" across the professions and concludes with implications for "the professions and their place in society." In this study, Schon developed a theory of one concept by looking at radically different contexts in which it may be present, and from this he explained what he observed in other contexts. Vaughan's work is guided by discovering how signals are interpreted in social setting leading to specific outcomes. She has done this in the context of couples who have broken up because one failed to read the signals that the other was sending (Vaughan, 1986); in the context of NASA, where engineers failed to read the signals that the Challenger disaster might be brewing [Vaughan, 1996 #1]; and more recently in the context of air traffic controllers (see Vaughan, 2002).

local university. And yet, in both Tampere and Charlotte, companies deliver products that are coherent, functional, and competitive.

2.7 Transferability, validity and verisimilitude

A common concern in case study research is the ability to generalize the findings (Yin, 1984). This is a valid concern given the subjectivist assumptions of the interpretive researcher's work (see Section 2.3). The knowledge created in a case study is also situated in time and space, just like the phenomenon and the actors within it. Instead of looking for universal laws, the purpose of the researcher is to come to an understanding (Mazlish, 1998, p. 88) and refine an image of the reality under study (Becker, 1998). For this reason, case studies, by definition, do not convey or establish timeless, placeless truths.[18] In case studies the goal of the researcher is to expand and generalize results to theory (analytical generalization) rather than enumerate instances that conform to that theory (statistical generalization) (Yin, 1984). A deep understanding of a phenomenon in one place can then be used to explain other settings (Orlikowski and Baroudi, 2001).

This does not mean, however, that what is learned by theorizing from case studies is so unique that it is only useful in the context where the field research took place. This is especially true when research involves more than one case. Instead of talking about "generalizability," it may serve us better to talk of transferability (Van den Hoonaard, 1997). Rather than making indiscriminate and de-contextualized generalizations, the propositions formulated by theorizing from case studies are useful to explain analogous

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[18] Bruce Mazlish referred in this way to the theories of neoclassical economics in his presentation "Rethinking the Social Sciences" at the conference "The Future of the City of Intellect" that took place in the University of California at Riverside in February of 2000.

processes in different contexts. My purpose here is to construct a theory that is contextually adaptable and that is useful to inform further theory building and decision making in practice. Formal and informal conversations with practitioners in different contexts, organizations, and industries have strengthened the validity and applicability of the understanding I hope to convey.

This approach has profound implications for practice. The applied interpretive researcher – such as the one whose purposes are to create practical knowledge for management and policy – seeks to learn from the phenomenon under investigation lessons that are *contextually adaptable* and insights that can help illuminate phenomena elsewhere and cope with practical situations. The researcher interprets one reality, learns from it, and translates its lessons into new insights and prescriptions applicable to radically different contexts, always aware that just as a sentence cannot retain its meaning if taken out of a book and put into another, applying what is learned from one context will always be affected by the new reality.

2.7.1 Validity and verisimilitude

Gathering data and building theory using interviews as the main method of data collection requires that the researcher validates the data and theory at various levels. First, there is the problem of the validity of the stories told by the interviewees themselves. For the critical parts of the argument in this document, validity was strengthened by triangulation and by performing repeat interviews with key interlocutors knowledgeable about the specific part of the narrative under question. Triangulation in this case consisted of exploring the same theme or asking the same question to

individuals that were familiar with the subject of discussion, but from different professional or organizational perspectives. In addition to triangulating in interviews, critical aspects of the narrative were validated with secondary literature about the company, the technology, or the specific process under scrutiny. Interviews that were carried out with my colleague Kimmo Viljamaa, we both served as sounding boards at the time of transcribing the interview notes, increasing validity and accuracy of the accounts in this way. Then, once narratives were constructed for sections of the case studies, some of these were distributed to key interviewees. They were returned with comments and revisions in some cases, while in others the interlocutors agreed that the content had captured well their own experience.

The theory building process requires an ongoing validation of constructs and inferences. First, the researcher must verify that the emerging theory (i.e. the relationships between constructs) fits with the evidence in each case, understand why the relationships exist, and also make sure that inferences are correct. This helps build internal validity (Yin, 1984; Eisenhardt, 1989). Another level of validation refers to whether the findings have explanatory power beyond a case study or external validity. A logical strategy to enhance the latter is by pursuing more than a single case, as I have done here. The external validity of my findings has also been enhanced by the larger project in which I have been involved during the research process. At the same time that I was gathering data and theorizing, other researchers in the LIS Project were doing the same in other locations and I had access to them and to their research. In addition to being a helpful sounding board for emerging theory, those case studies helped build the

external validity of my findings as I realized that the theory emerging from my cases was helpful to explain observations in theirs.

A comparison with the "enfolding literature" is an essential feature of theory building from case studies and enhances the internal and external validity of the findings. Conflicting literature stimulates creativity, raises the theoretical level, and helps sharpen construct definitions, while similar literature extends generalizability (Eisenhardt, 1989). Before and during this research and well into the writing phase I reviewed a broad range of literature on the management of innovation, innovation systems and the role of the university of economic development. In addition, I reviewed articles and books that captured research related to innovation in the industries and type of products that I studied. Through this review I not only learned what other researchers learned in the past. By comparing the concepts and theory emerging from my cases with existing literature I achieved a higher level of confidence and richness in the theory building process.

A privilege of the qualitative researcher is that the flow of everyday life is in itself a place to make further observations and build theory. In my case, having been in a university all along, working in an interdisciplinary environment, and being a member of a research team, this process was amplified. I was often confronted with situations and questions that reminded me of those I observed in the field or that echoed the emerging theory from my case studies. I could enumerate a number of key events or experiences that I had as a doctoral student that were unintended grounds of observation, theory

building and theory testing. In general, being attentive to the events in my everyday life enhanced the research process.

I have explained that case studies become theories through narratives, and I have argued that the purpose of this work is not to convey a timeless, placeless truth or establish universal laws. This is an interpretation and the goal is to make it convincing and plausible. As Bruner has pointed out, narratives convince for their lifelikeness and their verisimilitude (Bruner, 1986). The first test of verisimilitude is whether it makes sense to the people who live in the everyday reality that the theory is trying to capture and illuminate; whether it helps them understand themselves, what they do, and that reality in a new way; and whether it enhances their ability to act and gives them a better understanding of why some courses of action are better than others. In this case, the theory presented here has passed preliminary tests of verisimilitude by being well received in numerous conversations, presentations, and seminars, and by the positive feedback received, often with a sense of "aha" from the practitioners themselves. Preliminary reports and presentations of this research to audiences outside of the research site and the research team have also been well received.

The data and the theory may be valid and have verisimilitude, but what makes for a good theory? For Weick "[A] good theory is a plausible theory, and a theory is judged to be more plausible and of higher quality if it is interesting rather than obvious, irrelevant or absurd, obvious in novel ways, a source of unexpected connections, high in narrative rationality, aesthetically pleasing, or correspondent with presumed realities" (Weick, 1989, p. 517). Here, I specifically seek to convey a sense of (1) authenticity, meaning

that the reader will know that I was in the field and was able to apprehend the phenomenon and how practitioners made sense of it; (2) plausibility, meaning that the outcome echoes practice and helps make sense and act upon situations that practitioners may encounter; and (3) criticality, meaning that it makes practitioners reexamine taken-for-granted assumptions (Golden-Bidle and Locke, 1993).

3 The duality of innovation

3.1 Introduction

One shortcoming of innovation systems research and most studies about the contributions of the university to industrial innovation is the absence of a nuanced understanding of the innovation process. In the case of innovation systems research, the focus on institutions, organizations, interactions, inputs and outputs at the system level overlooks the innovation process itself –that which the institutional set-up of the system is meant to influence. In the case of the university's contribution to industrial innovation, the focus is on outputs such as patenting and technology transfer activities. Behind this view there is a working assumption about the nature of interactions over the course of the innovation process. While the innovation systems approach has involved a shift from a linear to an interactive model of innovation, the understanding of interactions among individuals and organizations is very narrow. A common assumption is that innovation involves the flow of information from one stage of the innovation process to the next. The interactive model of innovation has taken this model to the innovation systems level, where the focus is on creating and enhancing flows of information among the organizations of the innovation system. The current focus is, in addition, on the transmission of information via market interactions. Technology transfer is a good example of these two assumptions in practice: it involves the codification of research results into information (patents) that can be exchanged in a market transaction with other actors in an innovation system.

The innovation systems literature suggests that there are two types of interactions in innovation systems. In both its national and regional incarnations, the innovation systems

literature makes a distinction between "market" and "non-market" institutions, organizations, and interactions. Lundvall, for example, argues that a crucial step in the development of the innovation systems approach "was to realize explicitly that the relationships and interactions between agents had to involve non-price relationships" because pure market interactions could not convey "qualitative information" (Lundvall, Johnson et al., 2002, p. 218). This insight led him and his colleagues to the idea of interactive learning as a form of interaction in innovation systems that contrasts with market transactions (Lundvall, 1985; Lundvall, 1992). Lundvall et al. (2002) further argue that the view of rational human behavior of the neo-classical model is not sufficient for interactive learning.

> In standard economics it is assumed that instrumental and strategic rationality is always dominating human behavior at least in the private economic sphere. It is correct that economic transactions between anonymous agents and a capitalist environment tend to support instrumental rationality. In a context where learning new skills through interaction with other agents is important for success, it is, however, no longer the only kind of behavior that might be selected in the evolving economy. If instrumental rationality were completely dominating the interaction between professors and students, masters and apprenticeships as well as between engineers from R&D labs belonging to different firms, very little learning would take place. Therefore, innovation systems where communicative rationality (Habermas, 1984) played a major role in certain types of activities in the private sector might be better off in the long run than the standard exchange economy. The actual mix of rationality in an innovation system may affect its conduct and performance. (Lundvall, Johnson et al., 2002, p. 220)

There are also indications of two types of interactions in research done at the regional level of innovation systems. A classic distinction, for example, is between traded and untraded interdependencies (Storper, 1995). There is also a debate about whether firms come together in industry clusters to reduce transaction costs (Scott, 1985; Scott, 1988), or whether firms agglomerate to be part of a learning region (Morgan, 1997; Maskell and

Malmberg, 1999). In innovation policy, Metcalfe makes a distinction between "optimizing" and the "adaptive" policymaking, two radically different approaches that emerge depending on whether one adopts a market failure or an evolutionary perspective on innovation policy (Metcalfe, 1995).

These insights suggest the existence of two equally important yet contradictory forms of interaction within innovation systems. In this dissertation I refer to this view as *the duality of innovation*. Beyond knowing that the duality of innovation exists, we know little about how it actually plays out in the innovation process and even less about its implications for the design of organizations, institutions and policies in innovation systems. In this chapter I propose a conceptual framework to apprehend the duality of innovation. Understanding the duality of innovation is an important step towards a more nuanced understanding of innovation systems and of the university's contributions to industrial innovation.

3.2 The duality of innovation

In his pioneering work on the nature of "invention" (to use his term) Schön identified two views of the innovation process: rational and non-rational (Schön, 1967). In later work on engineering design he made a distinction between technical rationality and reflective practice as two distinct approaches to professional work (Schön, 1983). From the perspective of technical rationality engineering design and innovation is a problem solving process, a view that has also been proposed by Simon (1969). From a reflective practice perspective engineering design is better conceptualized as a conversation between the designer, the object and the context that gradually brings a design and object

into being during practice. For Dorst and Dijkhuis (1996) the radical differences between the "Simon" and "Schön" views shows the existence of two conflicting paradigms to organize and apprehend design. More recently Nonaka and colleagues argued that firms are "dialectical beings" whose existence within contradictions is at the heart of their ability to create new knowledge (Nonaka and Toyama, 2002). Taken together, these insights suggest that the innovation process has two contradictory yet equally important facets. I propose that these two facets are the micro level foundations of the duality of innovation identified and articulated in innovation systems research.

To characterize the duality of innovation, in this chapter I build on recent research that has identified the existence of two different "dimensions" of the innovation process: *interpretation* and *analysis* Lester, Piore, and Malek (Piore, Lester et al., 1994; Lester, Piore et al., 1998; Malek, 2000; Lester and Piore, 2004). Having been part of this research program throughout my doctoral studies, and having used them in previous research (see Martinez-Vela, 1998), these concepts have been crucial to my understanding of innovation and my approach to empirical research. I complement the discussion bringing in related work to sharpen the conceptual lens. Nonaka and colleagues' recent work on knowledge creation is particularly relevant (Nonaka, Toyama et al., 2000; Nonaka and Toyama, 2002; Nonaka and Toyama, 2005).[1]

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[1] In what has come to be known as the SECI model, converting knowledge between tacit and explicit in an evolving spiral around socialization, externalization, combination, and internalization (hence the SECI acronym) is a mechanism for knowledge creation (Nonaka, 1994; Nonaka and Takeuchi, 1995).

3.2.1 Interpretation: innovation as an ongoing conversation

From an interpretive perspective innovation unfolds through interactions that are akin to a conversation (Lester and Piore, 2004).[2] Meaning emerges in dialogues as practitioners learn about each other and synthesize their views and understandings (Nonaka and Toyama, 2005). I will refer to these conversations or dialogues as interpretive conversations. What human beings do while engaged in interpretive conversations is *create meaning*. Interlocutors and practitioners merge their separate understandings about technology, markets and themselves to create a new, joint understanding that takes the form of a shared image or story of what is or what could be. Meaning –and new knowledge– is created in the context of language –the vocabulary and grammar that we know– and through language –the stories practitioners tell to each other. From an interpretive point of view, innovation is akin to the creation of a new story, and if it is radical enough, the emergence of a new language (i.e. "iPod" and "podcasting"). Seen through this lens, at the heart of innovation is the creation of new meaning.

When practitioners come together in an interpretive conversation they do not have clear goals. The purpose of the conversation is to explore and come up with a new concept that does not exist a priori. They might have an idea to get them started but the

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[2] The concept of interpretation in the innovation process is closely related to Schön's idea of engineering design as reflective practice. The difference between the two is that Schön emphasizes practice, while Lester and Piore emphasize language. The concept of sensemaking (Weick, 1995) is another close cousin of interpretation. The process is similar, but the purpose is different. Practitioners engage in sensemaking to make sense of surprises or breakdowns in organizational process by constructing a retrospective understanding of events. Practitioners come to a halt, make sense, and keep going. In contrast, practitioners do not need to cope with a breakdown in order to engage in interpretation. In sensemaking practitioners use the past to make sense of a present event. In interpretation practitioners draw from past and present experiences to construct a stories or images of alternative futures. Interpretation, in the connotation being used here, is thus inherently projective. It is a future-oriented process that enables practitioners to orient themselves towards a vision of what could be. Weick (1995) goes to great lengths to separate the concept of sensemaking from interpretation. See Chapter 2 in (Weick, 1995).

conversation is open-ended and open to the unexpected. The end point may be envisioned but never fully anticipated. Such ambiguity gives interlocutors the freedom to imagine alternative futures, new products, consumers and markets that do not exist yet. The open-endedness and exploratory nature of an interpretive conversation always has the potential of yielding a radical new idea, and as such, interpretation is a fertile ground for radical innovation.[3]

Within organizations and across their organizational boundaries, the locus of interpretive conversations is *interpretive space* (Lester and Piore, 2004). Interpretive space refers to the various arenas for conversation, exploration and interpretation that firms create or participate in.[4] Nonaka and colleagues call these spaces of knowledge creation *ba*, which is the Japanese term for "place" (Nonaka, Toyama et al., 2000; Nonaka and Toyama, 2002; Nonaka and Toyama, 2005). R&D labs are an example of interpretive spaces created within the firm. Interactions with universities, participation in the regulatory process, and presence in an industrial district are examples of how interlocutors within a firm engage in an interpretive conversation across organizational boundaries.

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[3] The distinction between radical and incremental innovation is a keystone of the management of innovation literature. "An innovation is said to be radical if the technological knowledge required to exploit it is very different from existing knowledge, rendering existing knowledge obsolete... At the other end of the dichotomy is incremental innovation. In it, the knowledge required to offer a product builds on existing knowledge" (Afuah, 1998, p. 15). The concept was first propose in (Tushman and Anderson, 1986).

[4] In a more abstract sense interpretive space refers to the space that language itself is as a constitutive feature in human existence. In the flow of life we are immersed in the ether of language. But language is also a space in the sense that it is bounded by the limits of vocabulary and the rules of grammar. And yet, although bounded, it is a generative and open-ended platform whose repertoire of words offers infinite possibilities for the continuous disclosure of meaning through interpretation and conversation. In this sense, all conversations unfold in interpretive space.

In this study I identified a third modality of interpretive space that is created in practice. By this I mean that while firms might have formalized divisions or departments that fulfill the function of interpretive space, practitioners create interpretive space by "carving out" space and making time to experiment and discuss future-oriented ideas. In this sense, my observations closely resemble *ba* as a space that is fluid and not necessarily physical or bound to a certain space and time (Nonaka et al., 2000, p. 9). The Tampere case study illustrates this type of interpretive space. Section 4.3.1 offers and account of how new products emerged when engineers created a "hole" within the company to come together and explore new ideas. Other examples in Tampere include meetings, seminars and planning sessions that bring together interlocutors to discuss ideas about new products, product features or market opportunities.

Fruitful interpretive conversations require an environment of trust and openness. Lester and Piore (2004) argue that the interpretive process "is inherently in conflict with the economic environment in which business operates," and hence interpretation is often pushed to the margin of business organizations. Firms thus need to actively create and shelter interpretive spaces because "interpretation involves cooperation, transparency and disclosure," while economic competition "fosters opportunism, secrecy and confidentiality" (ibid., p. 119). The ideal interpretive space is a *public space* sheltered from the appropriation concerns associated with economic competition.[5]

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[5] See Chapter 6 in (Lester and Piore, 2004) for a detailed discussion on the nature of public space. In a study of the Israeli military's role in the growth of that country's IT industry, Breznitz (2005) offers an empirical characterization of the nature of public space. Breznitz defines *collaborative public space* as "structured social space imbued with high mutual trust within which different actors and groups regularly study, cooperate, share information, and partake in collective learning" (ibid., p. 36). The idea of public

3.2.2 Analysis: innovation as a problem-solving activity

From an analytic perspective, innovation is a problem solving activity.[6] Solving problems does not mean that there is no creativity or that no new knowledge enters the innovation process. Problem solving has been cited as one motivation for practitioners to innovate, and as a creative act in itself. It is one of the most important ways in which engineers bring new knowledge to a design task (Vincenti, 1990) and change their way of thinking about the task at hand (Laudan, 1984). In contrast to an interpretive conversation that starts without clarity of goals, the creative process during problem-solving is directed towards a goal that exists prior to the start of the process.

From an analytic perspective interactions are transactions of pre-existing artifacts or bits of information. When practitioners engage each other in a transaction no new knowledge comes into being. One party might obtain something that he did not have or know, but this is already "out there." When practitioners engage in a transaction they have clear goals. The purpose of the interaction is to solve a problem that is already known or to procure the missing piece of a product whose design is set and final shape is known. Practitioners are constrained by the requirements of the product or the problem to look for specific pieces of the puzzle. This means that in contrast to an interpretive conversation, they have little if any room to explore. Interactions occur in a discrete

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space transcends the interpretive side of the duality of innovation. Public space is also important for the dissemination of information and existing knowledge. In the case study of innovation in the NASCAR motorsports industry presented in Chapter 5, the racetrack is a good example of A public space that enhances innovation by disseminating existing information. See section 5.4 for a discussion on the role of the role of the racetrack as a public space in NASCAR motorsports.

[6] The analytic perspective on the innovation process is closely related to the idea of technical rationality proposed by Schön. "From the perspective of Technical Rationality," he says, "professional practice is a process of problem *solving*. Problems of choice or decision are solved through the selection, from available means, of the one best suited to established ends" (Schön, 1983, p. 39-40).

one-on-one basis between parties who know with some clarity what they will get from or offer each other in the pursuit of their specified goal. They might explore alternatives or solutions, but they are constrained when it comes to imagining alternative ends. Since the knowledge or technology is already out there and has value in itself or contributes to the value of the final product, the parties coming together in a transaction have a sense of ownership. Parties share only what is needed to complete the transaction.

3.2.3 Two epistemologies

The duality of innovation is one manifestation of a long tradition of philosophy and social research that has articulated the existence of a fundamental epistemological and ontological duality deeply ingrained in the very essence of Western thought (see Burrell and Morgan, 1979; see Bruner, 1986; Schön, 1991; Mazlish, 1998; Nonaka and Toyama, 2002). It is thus not surprising that these two sides appear repeatedly in different contexts and levels of analysis other than innovation research. This deeply ingrained duality is manifest in the paradigms of social research discussed in the previous chapter. Nonaka and colleagues have recently argued that objectivity and subjectivity, the same two epistemologies that Burrell and Morgan (1979) associated with those paradigms, are at work during a firm's creative process (Nonaka and Toyama, 2005). The epistemological assumptions of these two paradigms (see Sections 2.1 and 2.3) are also consistent with Lester and Piore's (Lester and Piore, 2004) in their characterization of interpretation and analysis.

To apprehend the innovation process through an interpretive perspective it is necessary to adopt the epistemological assumptions that I previously associated with the

subjectivist paradigm of social research. From this perspective reality does not exist independently of our perceptions and our ability to talk and think about it symbolically, particularly in language. Knowledge –and reality itself– emerges as humans interact with each other and with the reality that surrounds them. Knowing the world means arriving at an understanding (Burrell and Morgan, 1979). Knowledge also exists in a pre-linguistic form, embedded in our practices and not necessarily articulated in symbolic form. Human beings are assumed to create reality as they think, talk, and act. Even if reality appears as external and pre-determined, it is assumed to be a social product. From this perspective action does not involve the separation of means and ends. The ends themselves might emerge over the course of interaction.

In contrast with the subjectivist assumptions behind interpretation, the analytic perspective on innovation builds on the same epistemological assumptions associated with the objectivist paradigm of social research. From this perspective knowledge exists a priori, is explicit, and is akin to bits of information that can be captured and re-transmitted to other human beings. Reality is a hard, pre-determined fact that is "out there." Objectivism tends to be determinist, which means that human beings are conditioned by their circumstances and react and adapt to the reality they encounter as an external, hard fact (Burrell and Morgan, 1979). Action is motivated and guided by strategic rationality, by which I mean that human beings are expedient and instrumental. Means and ends are clearly separated and that humans know both the ends of their actions and choose the best means to pursue them.

Table 3-1 A comparison of the interpretive and analytic perspectives on innovation. Adapted from Lester and Piore (2004)

	Interpretive perspective	**Analytic perspective**
Mechanism for search and generation of knowledge	Conversations	Problem-solving
Outcome	An understanding, a new idea or a vision	A problem solved, a product
Knowledge	Emerges in interactions	"Out there" as information
Primary form of interaction	Interpretive conversations	Transmission of information
Ambiguity	Desirable	Undesirable
Clarity of goals	Ambiguous or non-existent Goals emerge during interactions	Goals are known a priori and problems well defined
Purpose of interactions	Discovery Creation of meaning	Solve a problem Transmit information
Rationality	Narrative or communicative	Instrumental Clear separation of means and ends

3.3 The duality of innovation and the product lifecycle

Dorst and Dijkhuis (1996) and Lester and Piore (2004) associate the duality of innovation with the product lifecycle. They argue that interpretation and reflection-in-action are crucial early in the life of a product when practitioners are in the process of coming up with new ideas. As the innovation process moves towards transforming ideas into

products and delivering them to market analysis and rational problem solving become more important.

A senior engineer from a leading provider of machinery and automation systems in Tampere shared this view. As we discussed how his company organizes innovation he made a clear distinction between two very different phases and the language he used to describe each phase reminds of the distinction between interpretation and analysis. He called the first phase "chaotic" and the second one "mechanistic." In the first phase the goal is "to have lots of discussions... but no decisions yet" and, he added, "different kinds of inputs to open possibilities" are needed. As the project unfolds in time and moves towards "implementation," he argued, the innovation process changes from "non-rational" to "rational and systematic." While freedom reigns in the chaos stage, order is important in the implementation stage. He also pointed out that in the early stage knowledge is "emerging and tacit," while in the second it is "explicit and codified." Each of these two phases, he pointed out, call for different kinds of organizational models and different kinds of people.

The distinction between two phases of the innovation process has been examined at length in the new product development literature (see Clark and Fujimoto, 1991; Iansiti and Clark, 1994; Cooper, 2001; Schulze and Hoegl, 2006 among others). In this study I adopt the terms *concept development* and *implementation* to discuss these two phases, as proposed by Iansiti and Clark (1994).
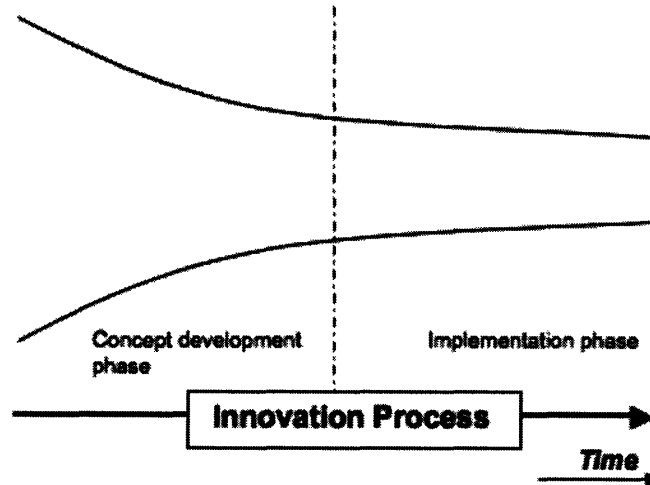
Figure 3-1 **A senior engineer from one of Tampere's companies made a clear distinction between two phases of the innovation process. Building on the analysis of Iansiti and Clark (1994), I will refer to these two stages of the innovation process as concept development and implementation.**

Like Dorst and Dijkhuis and Lester and Piore, I suggest that interpretation is more important for concept development work while analysis and problem-solving become more important for implementation. While the empirical findings of this study provide evidence for making this separation, the reader should keep in mind that this is an idealized model helpful to apprehend and analyze empirical reality, but does not mirror it fully.[7] In this study this separation was a useful conceptual device that allowed to disaggregate and characterize the nature of the innovation process in each case, to apprehend how companies under study interact with other firms and innovation-support

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[7] In this sense, the characterization of each side of the duality of innovation presented in this chapter is an *ideal type*. An ideal type is a device to facilitate empirical analysis in case-based comparative research. An ideal type is neither a faithful description of reality nor a hypothesis. Its purpose is to enable some degree of generalization from empirical investigations (Smelser, 1976). The construction of ideal-types is one of the most important strategies proposed by Weber to enable the comparison of different historically-contingent and context-dependent situations. An ideal type is an analytical tool "formed by the one-sided accentuation of one or more points of view and by the synthesis of a great many diffuse, discrete, more or less present and occasionally absent concrete individual phenomena, which are arranged according to shoe one-sidedly emphasized viewpoints into a unified analytical construct" (Weber).

organizations, and how these interactions vary for different purposes and at different points in time. Practitioners seldom make a clean transition from one phase of the innovation process to the next. Instead they iterate between phases as they move forward and different phases may go on concurrently. In addition, firms that sell more than one product are developing and marketing different products at the same time. Moreover, even for existing products firms often need to engage in concept development work to make design changes or add new features to existing products. In practice this means that concept development and implementation activities as well as interpretive and analytic work overlap and coexist. How this interplay unfolds in practice varies across industries and companies.

Focusing on the evolution of a single product, this research suggests that the transition from concept development to implementation with a shifting emphasis from interpretive to analytic work is both conceptually and empirically plausible. With this clarification in mind, an overview of what firms do to organize concept development and implementation gives additional insight about the duality of innovation and its relevance for different facets of the innovation process.

In the concept development phase activities "focus on identifying possible courses of action, conceptualizing desired outcomes and laying out an overall architecture for the creation and implementation of specific types of knowledge" (Iansiti and Clark, 1994, p. 562). In contrast, in the implementation phase "the firm creates and captures new knowledge in the form of additional skills, new technical systems or modifications to the managerial systems within the firm" (ibid.). In the concept development phase the

product might be completely unknown, at least for a while. As Iansiti and Clark (1994) put it, during concept development "the organization moves beyond what it knows" (ibid., p.565). What practitioners are developing is a concept, not a product. The goal is to generate *new ideas*. A transition occurs towards the implementation phase, from "emerging and tacit knowledge" to "explicit and codified" knowledge. The concept is translated into a blueprint or a design to work with; pieces are manufactured and brought together, fine-tuning the design and solving problems that might arise along the way. The outcome of implementation is a product.
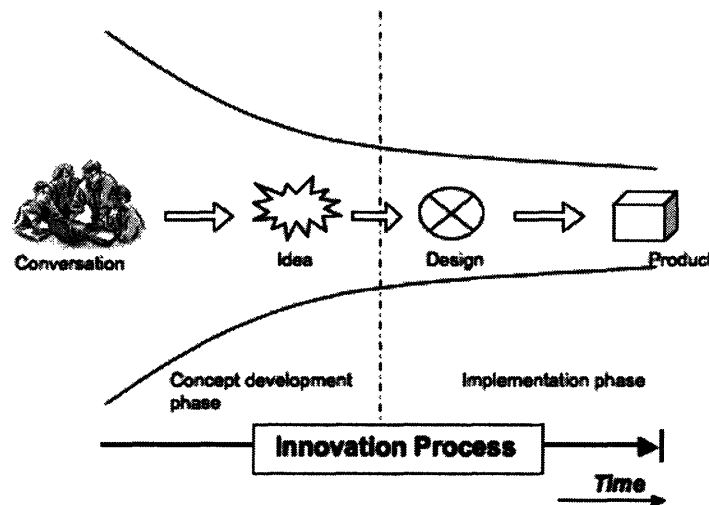
Figure 3-2. **The outcome of the concept development phase is a new ideas. The outcome of the implementation phase is a product. Author's conceptualization.**

What happens during the implementation phase is well known. A useful synthesis of the most important activities during that phase is well described by Prencipe's definition

of static or synchronic integration (Prencipe, 2003). In this stage, the task is to "set the product concept design, decompose it in modules, coordinate the network of suppliers, and then recompose the product within a given architecture" (ibid., p. 116). The strategic challenge for a firm in the implementation phase is "to dovetail the work of suppliers to meet consumers requirements" (ibid.). The implementation phase is about *exploitation*, which includes "refinement, choice, production, efficiency, selection, implementation, execution" (March, 1991, p. 71). All of these activities have been the subject of numerous studies. Most of what firms do and how practitioners manage the innovation process during implementation is well researched, articulated, and understood. The nature of these processes unfolding during the implementation phase of the innovation process suggests that it is better conceptualized through the lens of analysis.

The clarity of our knowledge about what firms do to organize for implementation contrasts with the fuzziness of what we know about concept development. It comes as no surprise that this early phase is often referred to as the "fuzzy front-end." What are practitioners doing in this early stage of innovation? The senior engineer quoted above said that what matters is to have discussions and freedom to explore and open possibilities. Examined through the interpretive perspective, the the social processes of concept development come into broad relief. A close reading of Iansiti and Clark (1994) suggests that conversations are important during concept development.[8] Out of these

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[8] This insight emerges from a close reading of Iansiti and Clark's account of NEC's entry into the supercomputer business. Their graphic conceptualization of several product generations (p. 596), all place in the concept development phase of the funnel activities such as "discussion of options," "discussion of integrated systems" and "system discussions." Coupled with the extensive use of the word discussion, the authors describe the early stages of concept development as "exploration."

conversations new product concepts emerge, which are later translated into designs and finally into new products. Research in the context of a project-based engineering industry has found that face-to-face conversations and working with others in projects were the sources of ideas highest rated by practitioners (Salter and Gann, 2003).[9] Concept development involves *exploration*, which includes "search, variation, risk taking, experimentation, play, flexibility, discovery, innovation" (March, 1991, p. 71).

3.4 Interpretive flexibility and closure

Two useful concepts that help make sense of the shifting relevance of interpretation and analysis in the transition from concept development to implementation are *interpretive flexibility* and *closure*, important contributions of the social constructivist view of technology (Pinch and Bijker, 1987). Interpretive flexibility exists when an artifact is open to interpretation. This means that designers and users can attribute multiple meanings to an artifact. An artifact that is interpretively flexible in use means that the user can attribute more than one meaning and hence make more than one use of it. Interpretive flexibility presupposes a measure of ambiguity. When the artifact approaches *closure* the meanings attributed to an artifact become less ambiguous and openness to interpretation reduces.

In this study I to use the concept of interpretive flexibility to describe the transformation of innovation process, not just the artifact. Used in this way interpretive flexibility would be high during the early stages of the innovation process. For designers

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[9] Out of 112 respondents in their single-company case study, 84% rated "talking to colleagues" and 81.2% rated "working with others on projects" as important or very important sources of new ideas for engineering design activities (Salter and Gann, 2003, p. 1314).

this implies the possibility to imagine multiple ways to design a product and also to imagine alternative uses and markets for it. As the process moves into the implementation phase, interpretive flexibility drops if not altogether disappears. There is no longer ambiguity about what the product is, what it can do, or what needs to be done to bring it to market. The task is to solve a series or problems. There are still iterations between design and prototyping, but the purpose of these iterations is to reach an optimal solution to specific problems, not create a new idea or reach an understanding. Once in the market both designers and consumers can discover unexpected uses, problems, or opportunities and reinterpret what the product is or what to do with it. But the point is that prior to this reinterpretation there is a necessary period of closure to finish the product and bring it to market.

The reduction of interpretive flexibility is coupled with a shift in relevance between social and technical factors in the innovation process. When practitioners come together in an interpretive conversation they are the creators of a yet-to-emerge outcome. Social interactions drive and give direction to the process of technological change. Once the product design is set product and market needs motivate practitioners to act and interact. The *internal logic of technology* becomes a supplier of problems for practitioners (Vincenti, 1990). "Once a device or system and its goal have been decided on, physical laws and practical requirements (including cost) take over and mandate that certain things be done and certain design problems solved" (ibid., p. 204).

One implication of this shift is that practitioners ought to think differently about how to organize innovation during concept development and during implementation. The

practitioner from Tampere was well aware of this when he referred to the early stage of innovation as "chaotic," and the second phase "mechanistic" and "systematic." There is freedom to organize and bring different interlocutors to an interpretive conversation in concept development. During implementation the artifact becomes a protagonist of the innovation process and the problems it presents affect how practitioners organize and how and who they interact with. Intellectually, this shift requires a transition from a social constructivist view of technology towards a view of technology as a conduit that channels action in specific directions. In Orlikowski's (1992) structurational perspective on information technology and organizations, this transition reflects the *duality of technology*.

> Technology is the product of human action, while it also assumes structural properties. That is, technology is physically constructed by actors through the different meanings they attach to it and the various features they emphasize and use. However, it is also the case that once developed and deployed, technology tends to become reified and institutionalized, losing its connection with the human agents that constructed it or gave it meaning, and it appears to be part of the objective, structural properties of an organization. (ibid., 406)

A good example of what this means in practice comes from the proponents of modularity, for whom the transition from integral to modular product architecture goes hand in hand with a transition in the organization of product development that mirrors the product architecture. Ulrich (1995) suggests that integral architectures require assigning work to multi-disciplinary teams and "constant interaction is required, focused on the whole." On the other hand, modular architectures call for the separation of design tasks, specialized groups with a narrow focus, and performance evaluation is done relative to pre-specified standards and targets (ibid.).

As Orlikowski's insight suggests (see above), the reduction of interpretive flexibility, the increased relevance of technical considerations, and the notion that the artifact "presents" problems to practitioners and channels actions and interactions does not mean that the innovation process is "no longer social." In his analysis of project-based organizing Pinney offers an enlightening discussion of the nature of this transition.

> In the early stages of a project "basic investigations involve individuals, small groups, and modest, largely informal volumes of communication. These are craft processes, with identities and skills shaping how the work gets done. As a product or process passes into development, more people join the work and the volume of communication increases. Technical relationships multiply. In order to organize and manage interactions, the work is taken apart and people are assigned to distinct tasks. At this stage, requirements can be set for when, between whom, and in what form communication should take place, but these can only be loosely defined and the content of communication remains unforeseeable. Conferences and progress reports allow for timed but open-ended interactions. As the nature of the artifact under construction and the organization producing it stabilize, more interactions can be specified. With full, "mature" production, most communication becomes routine exchange of operating data, disrupted only by unanticipated maintenance and incremental improvements to the process. (Pinney, 2001, p.30)

Pinney argues that the point is that "the construction of a technology is a social process that is *more* social at some times than at others" (ibid., p. 34).[10] Technical considerations involved in the task of transforming a design into a product and bringing it to market affect the social process of innovation and constrain the ability of practitioners to make choices. Innovators, however, are still making choices and decisions as they

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[10] Lester and Piore (2004) also describe this transition not just at the product, but at the corporate level. Pinney (2001) goes one step further by documenting this transition at the industry scale. In the management of innovation literature, this industry-level transition has been documented by Abernaty and Utterback (Abernathy and Utterback, 1978) and Tushman and Rosenkopf (Tushman and Anderson, 1986). As summarized by Alan Afuah (Afuah, 1998, p. 32-34) Abernathy and Utterback describe the evolution of technology from a fluid to a transitional and finally to a specific phase. What defines the specific phase is the emergence of a *dominant design*, which is "one whose major components and underlying core concepts do not vary substantially from one product model to the other" (Afuah, 1998, p. 32). Tushman and Rosenkopf (1986) argue that after a technological discontinuity an industry enters an *era of ferment*. When a dominant design emerges an era of *incremental change* sets in. Tushman and Rosenkopf clarify that the influence of social factors depends on the complexity of the product.

move forward. The nature of the interactions of the social process of innovation changes as the interpretation becomes less important and analysis more important. Rather than generating new ideas and goals through interpretive conversations, interactions involve the transmission of information aimed at reaching a solution of more or less clear problems guided by a product design that is already out there.

Table 3-2 The relationship between the duality of innovation and the product lifecycle. The division of the innovation process in the concept development and implementation phases comes from (Iansity and Clark, 1994).

	Concept development	**Implementation**
Nature of the process	Interpretive Conversation	Analytic Problem solving
Interpretive flexibility	High Ambiguity is source of creativity	Low Ambiguity is undesirable
Knowledge about the product	Emerges in interaction	"Out there" codified
Social-technical relationship	Social processes and organization drives technological change	Technical requirements influence social processes
Freedom of exploration	Ambiguous or inexistent goals give room to explore	Constrained by product requirements and known goals

3.5 Positioning the case studies

The empirical observation motivating this investigation is a sharp contrast in the institutional set-up for innovation operating in Tampere's machinery industry cluster and Charlotte's NASCAR motorsports cluster. Both industries have gone through a process

of upgrading, but there are striking differences in the roles that external organizations, institutions and policies have played in the upgrading process. One of the most important differences is the role of the university. In the first case, the Tampere University of Technology has been an important partner in the innovation process. Charlotte has a local university whose economic development and industry orientation is comparable to TUT. It also has research and educational programs in motorsports and automotive engineering. But in contrast to TUT, UNCC has been absent from the innovation process. How do variations in the innovation process relate to variations in the role of external organizations in the innovation process? More specifically, what are the implications for university-industry interactions? In this dissertation I explore specifically how the duality of innovation relates to these variations. Each case study in the next two chapters is representative of one side of the duality. This correspondence between the two cases and the duality of innovation emerged inductively over the course of this research after several iterations of writing, within-case analysis, and theory building.

The exploration of the innovation process in the first case study of the machinery industry located in Tampere, Finland (Chapter 4) illustrates interpretive processes. The technological upgrading of Tampere's machinery industry has involved integrating measurement devices, control systems, software, and wireless technology into their products. This process, which I call *interdisciplinary integration*, begins in early stages of the innovation process. Practitioners from different backgrounds come together in interpretive spaces to engage in open-ended conversations that have interpretive

flexibility. Through these conversations they generate ideas about new or improved products, processes, or services and decide to initiate a project. The outcome of these interactions is a new idea or a vision that did not exist a priori. Although often working with existing products, they use them more as triggers for interpretive conversations. Rather than being a cage that constraints their thinking, existing machines are akin to a drawing board in which practitioners can draw new things.

The innovation process in the second industry case study of NASCAR motorsports in Charlotte, North Carolina (Chapter 5) illustrates analysis and problem-solving. The process of innovation in NASCAR teams consists in the incremental improvement of stock-cars. Through an ongoing process of *optimization*, NASCAR teams have increased engine power and improved other parameters of the car such as aerodynamic drag coefficient. NASCAR teams push the frontiers of knowledge and technology through an intensive experimentation and problem-solving process iterating between design, testing, product, and racing. Practitioners in the industry have little if any room for exploration. They innovate within a predefined product architecture that is tightly regulated and constrains what they can do with the product. There is no interpretive flexibility. The goals of interactions are usually clear. Practitioners are driven to innovate by a single and immutable goal: the desire to win. They work in an environment of secrecy and opportunism. The intensive racing schedule and rapid dissemination of secrets makes this industry inherently short-term oriented. Competition is the driver of innovation.

Table 3-3 Relationship between each case study and the duality of innovation.

	Machinery industry in Tampere, Finland (Chapter 4)	NASCAR motorsporrts industry in Charlotte, North Carolina (Chapter 5)
Case study	Machinery industry in Tampere, Finland (Chapter 4)	NASCAR motorsporrts industry in Charlotte, North Carolina (Chapter 5)
Core innovation process	Interdisciplinary integration	Optimization
Nature of the innovation process (emphasized)	Interpretive	Analytic
Interpretive flexibility	More flexibility, more room to explore	Less flexibility, less room to explore

The close correspondence between each side of the duality and each case study does not mean that the innovation process in Tampere is exclusively interpretive and in Charlotte exclusively analytic. I emphasize on purpose the dominant aspects of the innovation process –interdisciplinary integration in Tampere and optimization in Charlotte– that emerged during this research as central to the competitiveness of the

subset of companies examined. The duality of innovation perspective will enable

comparing the innovation process in each industry and examine, from the ground up, how

it relates to variations in external relationships and university-industry interactions. But as

I said above, both interpretation and analysis are necessary to innovate and unfold in a

complex interplay over the course of the innovation process. Figure 3-3 illustrates the

logic of exploration in each of the following chapters.
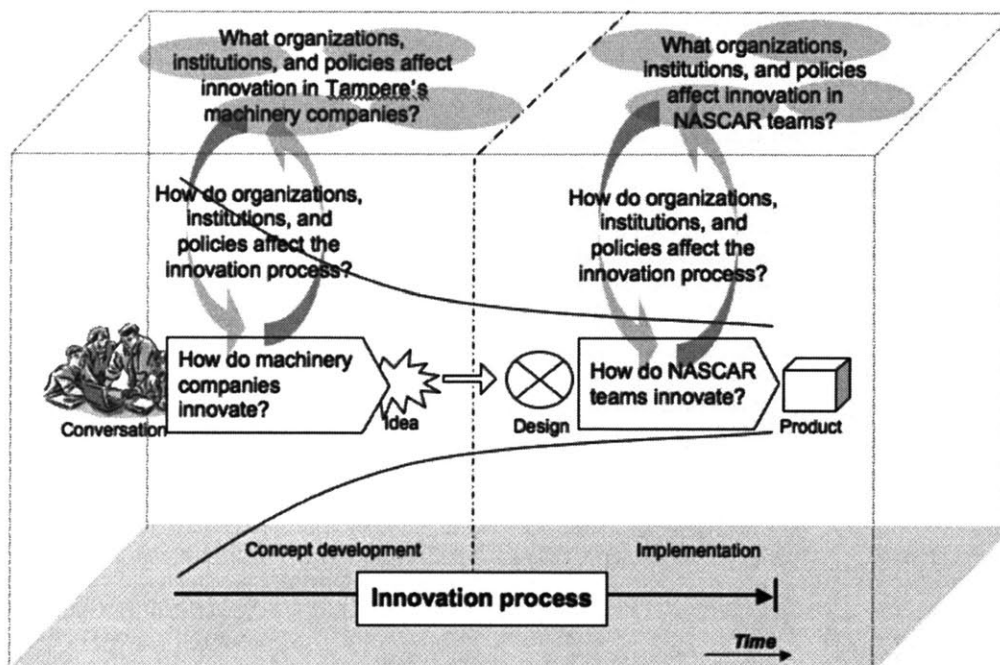
Figure 3-3. The logic of exploration in each case starts with an analysis of the innovation process and proceeds to examine the external organizations and interactions that affect the process.

4 Making space for innovation: How the mechanical engineering industry in Tampere, Finland, became high-tech

4.1 Introduction

Finland's recent economic history is one of the most fascinating stories of economic reinvention and self-renewal in Western Europe. From a primarily agricultural economy in the 1950s, the country has transformed itself into a high-tech powerhouse that has been rated the world's most competitive economy several times since 2000.[1] The information and communications technology sector (ICT), led by Nokia's success, is Finland's flagship example of industrial transformation. But a closer look at the Finnish economy reveals a more nuanced story. ICTs account for approximately one third of Finnish industrial exports, but Finland is the world leader in the forest industries, which accounts for another 30% of Finnish exports, and is also a leading developer, manufacturer, and exporter in engineering more generally and mechanical engineering industries in particular.

Multiple social, structural, political, and economic changes have facilitated the transformation of Finland from an agricultural economy into a knowledge economy. In the specific case of innovation, the post war period saw the gradual emergence of a set of *institutions* that have been crucial to the ability of Finnish industry to become high-tech.[2]

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[1] According to the World Economic Forum Competitiveness Index. http://www.weforum.org/en/index.htm

[2] During an international conference on local innovation systems hosted by MIT in December 2005, Esko Aho, a former Prime Minister of Finland and current President of the Finnish National Fund for Research and Development (SITRA), reflected on the industrial transformation of Finland in the post WWII period. His account noted that investment in infrastructure and capital were a priority between 1944 and 1974, coupled with investments in human capital through increased support for higher education and the creation of new universities to support regional development. Noting that at the end of the 70s, despite investment in physical and human capital, what he called 'adjustment ability' remained low, a national dialogue started which resulted in a national consensus that the next step was to invest in technology, and that such

The emergence of a variety of institutions to support innovation, their recognized role in enhancing the ability of Finnish industry to innovate, and the emergence of Nokia as a leading global player in mobile telephony, have made Finland a noted example in science and technology policy circles of how institutions can enhance the ability of industry to innovate and compete.[3] In the late 1980s, Finland was an early adopter of the systems approach (see Teubal, 2002) to think and formulate science and technology policy (Ylä-Anttila and Palmberg, 2005). Being a small, advanced industrial economy with a well-defined set of institutions supporting industrial innovation makes Finland a noted example from which much can be learned about national innovation systems.

The story of Finland's transformation is also the story of the economic reinvention of its regions. Of these, one of the most interesting examples is the city of Tampere, the largest inland urban center in the Nordic countries and the heart of an urban region of approximately 300,000 inhabitants located 170 km northwest of Helsinki, Finland's capital city.

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investment was coupled with the creation of institutions: "Sometime in the late 70s that process started. We had a special parliamentary committee on technology. If I remember correctly that committee made its proposal in 1980 and it proposed, to be short, that Finland has to invest in technology. And we started to make both institutional and financial reforms. For the first goal we created institutions. In Finland, we have had since the beginning of the 1980s a special institution called the Science and Technology Policy Council. It is a governmental body led by the Prime Minister, but all the stakeholders in science and technology policy are represented in this council. This council has played an important role to integrate both public sector and private sector actors to those goals set in STP. Then this committee proposed that we have to increase substantially our goals for R&D. Tekes was established in 1980s, and it took a major role in promoting and financing technology. Simultaneously the Academy of Finland and VTT received substantial new resources. And what is very important is that there was broad consensus that this strategy should be implemented; despite changes in political structure this was implemented. In 1980, when we started, Finland was below average in investment in R&D, and yet in year 2000 it was as a goal in 1980. Collaboration between universities and companies expanded rapidly. Finland became a model country in this respect, at least in Europe." (Aho, 2005)

[3] See (Lemola, 2002) for an analysis of the "convergence" of Finland's technology policy with models from other OECD countries.
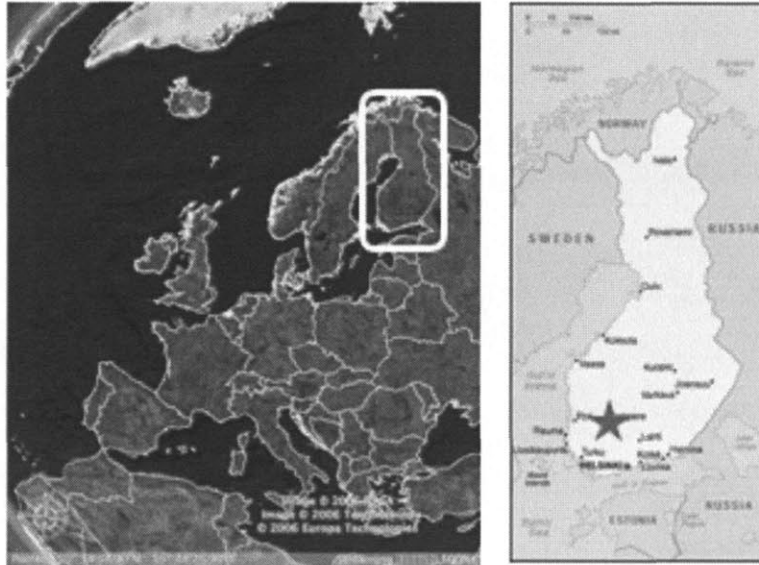
Figure 4-1. **Tampere is 170km Northwest of Helsinki, as indicated by the star on the right map. Sources: Google Earth and CIA Worldfactbook.**

Tampere, founded on October 1, 1779 by charter of King Gustav III of Sweden, has been a cornerstone of Finnish industry since the 19th century. The potential for industrial development in Tampere's current location was recognized early on. When the king was deliberating where to place the new town, he deliberately chose the banks of the Tammer rapids, which cut through the isthmus between Lake Näsi and Lake Pyhä, because he realized the power production potential of the fast-moving stream (Rasila, 1988, p. 379-398 as cited by Kostinanen and Sotarauta, 2003). Tampere was also founded as a "free town," meaning that trade and industrial enterprise was unrestricted (Seppälä, 1988).[4]

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[4] The rest of this brief history of Tampere's industry draws mostly from (Kostianen and Sotarauta, 2003). Their account draws from (Jutikkala, 1979; Rasila, 1984; Rasila, 1988; Seppälä, 1988; Rasila, 1992).

Figure 4-2. **Tampere was founded on the shores of the Tammerkoski rapids. The rapids empty Lake Näsi into Lake Pyhä, which have a 20m altitude difference. King Gustav III of Sweden he saw the potential for industrialization on the banks of the Tammer Rapids. Old industrial sites, including Finlayson's, are still along the rapids. (Sources: Google Earth and Tampere Technology Centre Ltd.)**

In the summer of 1819, two decades after Finland switched from 700 years of Swedish rule to what would be slightly more than 100 years of Russian rule, James Finlayson, a Scottish industrialist, visited Tampere and recognized the potential for industrial development. Finlayson submitted a petition to the Tsar for the establishment of textile mills as well as for a foundry that would manufacture machinery for the handling of textile fibers. He also applied for freedom from customs and ownership of the rapids. His petition was granted, making Finlayson the birthfather of large-scale industry not only in Tampere, but in Finland as a whole (Kostianen and Sotarauta, 2003). Tampere's place as the engine of Finland's industrial revolution was further enhanced in 1821 when the Tsar lifted limitations on the establishment of new industrial enterprises and manufacturing in Tampere by eliminating taxes and tariffs.

The industrial history of Tampere is closely linked to the birth, growth, and survival of companies specialized in metalworking and machinery. Tampere's mechanical industry was born in 1842, when the first paper machine ever manufactured in Finland was ordered from England. In 1856 inland water ships started to be manufactured in Tampere, and at about the same time a broadcloth factory opened in town. The owners of inland water ship manufacturers and the broadcloth factory, both in debt, decided to combine their operations, resulting in the founding of Tampere Linen and Iron Industry Ltd. This company came to be known as Tampella, and remained one of the most important mechanical engineering companies in Finland until the 1980s (Kostianen and Sotarauta, 2003).

The mechanical engineering industry continued to flourish during the 20th century. In 1931 the State Airplane Factory came to Tampere, an arrival that is widely regarded as a catalyst for the development of the mechanical engineering industry. The industry expanded during WWII through the manufacturing of weapons, vehicles, and components. By 1943 the metal and mechanical engineering industries became the biggest industrial sector in the region, employing over 27% of the workforce (Jutikkala, 1979, cited in Kostianen and Sotarauta 2003). After the war a substantial share of Finland's industrial infrastructure was devoted to paying war reparations to the Soviet Union. Tampere was the production center of metal products and machines. Tampella made the largest contribution of all Finnish companies, producing over 14% of all the machinery and devices manufactured for reparations in the country (Rasila, 1992, cited in Kostianen and Sotarauta, 2003). After war reparations were paid in full, Tampere's

machines continued to have an export-market in the Soviet Union, which was the main buyer of Finnish machinery exports until 1989.

After WWII, Tampere's economy transitioned from a mix of agricultural and industrial economy into a knowledge economy (Kostianen and Sotarauta, 2003). Geography and favorable tax and tariff arrangements helped give birth to Tampere's industry in the 19th century and World War II, and the war's aftermath drove industrial innovation during the middle of the 20th. Geography and war behind, Tampere's economic transition after the 1960s has been catalyzed by the emergence of an institutional set-up for innovation. Higher education organizations, public research institutes, a technology park, technology transfer agencies, the active involvement of local authorities and civic leaders in industrial and business development, the local influence and presence of national science and technology policy agencies and instruments, have supported the innovative capabilities of emerging regional agglomerations in biomedical and media industries, as well as established concentrations in ICT and mechanical engineering.[5]

Almost two centuries after Finlayson brought industry to Tampere, the resilience of Tampere's mechanical engineering industry continues to stand out. The sector has not been immune to decline and suffered greatly after the collapse of the Soviet market in 1989. But the industry has reinvented itself and is the only one of the traditional

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[5] The institutional infrastructure and agglomeration of companies makes Tampere a recognized archetype of what is variously known ,building on the ideas of industrial districts (Marshall, 1890; Piore and Sabel, 1984) and innovation systems (Lundvall, 1992; Nelson, 1993; Edquist, 1997), as an industry cluster (Porter, 1990), local industrial system (Saxenian, 1994), regional innovation system (Cooke, Uranga et al., 1997; Cooke, 2001), learning region, (Maskell and Malmberg, 1999; Morgan, 2004).

industries in the region that has successfully weathered the storms, upgraded, and become globally competitive (Kostianen and Sotarauta, 2003).[6] Today machinery and equipment manufacturing is the largest employer and the second biggest producer in the region, accounting for one fifth of all industrial workers.[7]
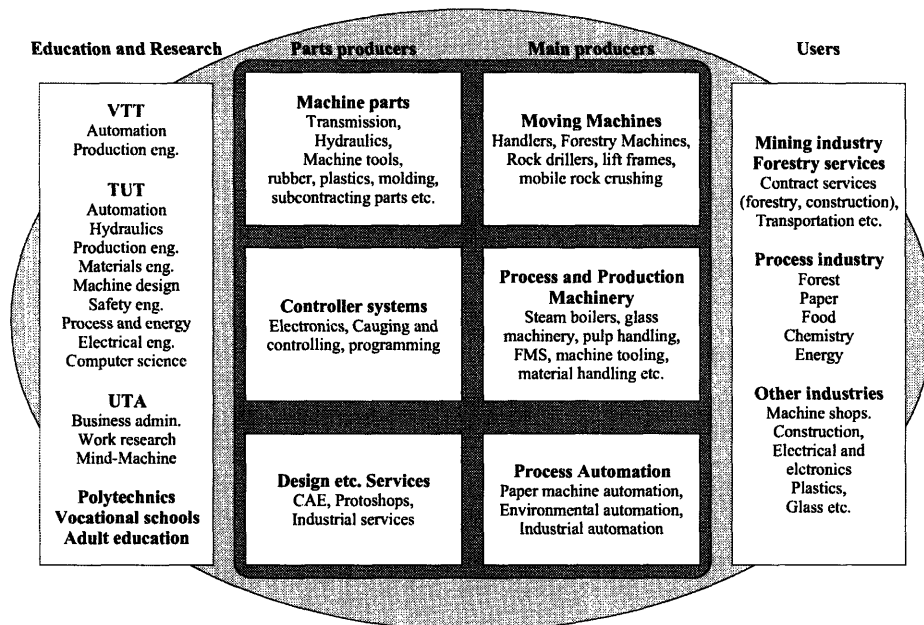
Figure 4-3. **Tampere's industry cluster of mechanical engineering and automation, including educational and research institutions that play key roles in its support. Source: Tampere Region Centre of Expertise.**

The sector is made up of several machinery and equipment manufacturers, supported by a concentration of subcontractors and parts providers. Customers are firms in other

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[6] This does not mean that the industry is still anchored by the same companies. Tampella closed in 1985, Valmet has been restructured and broken up, with most of it within what is now MekAutomation Corporation, and several local companies have been acquired by national or global players. Tampella and Valmet left behind business units that have become separate enterprises, as well as a pool of expertise and entrepreneurial spirit that gave rise to new mechanical engineering and other related companies.

[7] Between 1975 and 1995 productivity in the industry increased over 25% even as almost half of the jobs in the sector were lost (City of Tampere, 1999). The technological specificity, industrial agglomeration and institutional support in the mechanical engineering sector make Tampere an example of a region with a sectoral innovation system (Breschi and Malerba, 1997; Malerba, 2002).

industries, mainly forestry and paper, electronics, mining, construction, transport, and

specialized utility vehicles. Several companies have either the largest share or their

market or occupy a leading position in global markets (see Table 4-1 below). Innovation

in products and more recently in services is at the heart of Tampere's mechanical

engineering industry's upgrading and technological competitiveness.

Table 4-1 Some leading engineering companies in the Tampere region, with market share and products. Source: Tampere International Business Office.[8]

Company	Global Market Share	Products
Kalmar, Cargotech	50%	Container handling machinery
Sandvik-Tamrock	35%	Mining and construction machinery
MekAutomation	15%	Automation for process industry
MekAutomation Minterals	15%	Mobile rock crushers
Kvaerner-Pulping	30%	"Green" boilers
PCE-Engineering	15%	Hollow core slab machinery
Tamglass	50%	Safety glass machinery
MekaTree / TreeGlobal	47%	Forest machinery
Bronto Skylift, FSC	60%	Fire and rescue platforms
Fasterms	70%	Multilevel FMS
Ata Gears	50%	Spiral bevel gears for marine applications
Tamrotor, Gardner Denver	30%	Marine compressors
Avant Tecno	40%	Mini loaders (<1 Ton.)
Rotex, Atlas Copco	30%	Overburden drilling bits
Sisu Diesel, Acgo Group	10%	Diesel engines

Three organizations in Tampere's institutional setup for innovation are recognized by

practitioners as playing a substantive role in the upgrading and survival of Tampere's

mechanical engineering industry. These organizations are the Tampere University of

Technology (TUT), VTT Technical Research Centre of Finland, and the Finnish Funding

Agency for Technology and Innovation, Tekes. In a more indirect way, through its

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[8] http://www.professia.fi/investintampere/business_opportunities/mechanical_engineering_and_autom/

support for basic research in mechanical engineering at TUT, the Academy of Finland (the Finnish equivalent of the American NSF) also has played a role. This chapter examines how these three organizations, with an emphasis on the Tampere University of Technology, have affected the ability of local companies to innovate. Two research questions guide this investigation:

- How did machinery companies in Tampere organize their innovation efforts?

- How did the Tampere University of Technology contribute to the ability of local machinery companies to integrate new technology into machines?

The first round of interviews in Tampere showed that the technological reinvention of the industry has hinged upon the ability of companies to infuse new technology into their products. Interviews with industry practitioners and academics also suggested that the role of TUT escapes the technology transfer model of the university's contribution to industrial innovation. Thus, this study will focus on better understanding the role of the Tampere University of Technology in facilitating the process of integration at the heart of the industry's competitive advantage.

The core empirical data for this case study consists of 39 semi-structured interviews that included technology managers and engineers from leading mechanical engineering firms; professors, researchers and administrators of relevant academic and research organizations; and science and technology policy makers. Using the research approach and methodology described in Chapter 2 (see sections XXXX in particular), this investigation proceeds from the ground up, first examining the innovation process and

then analyzing the effects of the institutional set-up on the process, with the role of the university at the center of the inquiry. Following this logic of exploration, the chapter is structured as follows. Section 3.3 introduces the institutional framework for innovation in Tampere. In Section 4.2 I describe the evolution of products in two local companies in order to illustrate the nature of the innovation process. Section 4.3 opens the black-box of innovation to provide an in-depth look at how a subset of machinery companies organize the innovation process behind the evolution of technology. Section 4.4 examines the effects of the institutional set-up for innovation on the innovation process. The role of TUT, VTT and Tekes is discussed in detail. In Section 4.6 I analyze in more detail the role of the Tampere University of Technology and the nature of the university-industry relationship. Section 4.6 discusses some challenges in preserving TUT's role as a space for creativity and innovation in Tampere.

4.2 Technological change in Tampere's machinery

The strongest sub-sectors within Tampere's mechanical engineering industry are process automation, machinery, and various types of mobile working machines. Examples include companies specialized in mobile forest machinery; mobile mining machinery; and container handling machinery. This study explores innovation in a subset of companies specialized in mobile and production machinery.[9]

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[9] Production machinery falls into a product category that Prencipe (1997) and others call product-systems. Product-systems are multi-component and multi-technology products characterized by complex interactions between components and subsystems, and product performance depends on both the components and the interactions between them (Prencipe, 1997).

Figure 4-4 Among Tampere's leading machinery companies are those specialized in mobile machinery for various industries. Shown to the left, one of Sandvik-Tamrock's rock-drilling machines. To the right, a container handler machine made by Kalmar Cargotec. Sources: Sandvik MediaBase and Cargotec ImageBank.

In this section I describe the technological upgrading in two of Tampere's leading companies in the sector. I will refer to these companies as MekaTree and MekAutomation. In each company I will describe the evolution of specific products.

MekaTree is the world's leading forest machine manufacturer, with a global market share of approximately 47%.[10] Turnover was approximately 470 million USD in 2005. In addition to machines the company supplies information systems for logging optimization, management and logistics. In April 2000 MekaTree, became a part of Worldwide Construction & Forestry division of a large American multi-national specialized in agricultural and construction machinery. Engineering R&D for forest machinery is concentrated in Tampere. New concepts and fundamental engineering

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[10] Source: Tampere International Business Office.
http://www.professia.fi/investintampere/business_opportunities/mechanical_engineering_and_autom/

research and development is carried out by IntelliTree, a separate organization that is part of the group and is in the same location as MekaTree in Tampere. The product line of MekaTree includes feller bunchers, skidders, log loaders, harvesters and forwarders.

In 2001 MekAutomation was the world's third largest supplier of pulp and paper industry automation and information application networks and systems and the sixth largest supplier of power plant automation.[11] Operations cover three main areas of process automation: process automation and information systems, automation and control valves, and process measurements and analyzers. The company's main customers are the pulp and paper industry, power generation, and hydrocarbon and chemical industries. The company is part of MekCorporation, and along with fiber and paper technology (MekPaper), and rock and mineral processing (MekMinerals), MekAutomation is one of the core businesses. In 2005 it accounted for 14% of the total sales and 14% of the personnel of the corporation.

4.2.1 MekaTree: Forest harvesting machines

Cutring trees, and many of the early stages of the "wood value chain" remained manual work until the first machine harvesters were introduced in the 1970s. In Finland, axe and

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[11] The roots of the company –and of the automation industry in Finland– date back to 1921, when a workshop for repairing aircraft instruments was founded by the State of Finland in Helsinki. This became the State Aircraft Factory, which moved to Tampere in 1936. In 1945 this company evolved into the State Metal Works. Around this time, in 1944, the development of measurement and control systems for the process industry began, a line that would remain the main expertise of Valmet Automation. In 1951 the State Metal works was named Valmet Oy, and within it, in 1968 Valmet Instrument Works became a separate part of the group. Later this was incorporated in 1988 as Valmet Automation Inc. During the 1980s most of the expansion of Valmet Automation in Europe and North America happened through mergers and acquisitions. In 1999 Valmet Automation merged with Neles Controls Inc., giving birth to Neles Automation. Neles Controls had developed expertise in control valve manufacturing since its origins in the mid 50s, and in 1997 focused on control valves and digital flow control technology. In 2001 the company was renamed MekAutomation.

handsaw were the major tools for felling trees until the early 50s, when the chainsaw

replaced them. [12] Hauling timber through the forest was done by horse until the 1930s,

and logs were often transported to the processing sites by floating them on lakes or

streams. Transporting logs to the processing site changed from floating to truck as early

as the 1930s. Tractors appeared in the end of the 1940s, linking felling and processing

sites via long-distance transport, thus giving birth to the "wood transport chain."

General-purpose tractors were later replaced by especially designed forest machinery.

With the use of harvesting machinery, skidders and loaders for hauling became common,

and then trucks transported logs to processing sites, creating a fully mechanized wood

chain. Mechanization transformed wood harvesting as machines were introduced at all

stages of the wood chain and now a great variety of machines are available for harvesting

and processing of trees.[13]

Forest machinery has been transformed by numerous innovations.[14] Progress has

happened in design, materials, power systems and other elements inherent to all kinds of

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[12] The account that follows draws form a combination of sources, I mention all of them here for convenience. The technology and evolution of forest harvesting machinery was first discussed during interviews in the company. The initial narrative was constructed based on interview accounts. To add more technical detail and accuracy about specific product functions and features several company brochures were consulted.

[13] This brief history draws from a summary prepared by the European Forest Institute. See: "Finland's vast forests: a short history of forest use." European Forest Institute, Forest Information Services for Europe. http://www.efi.fi/fine/Finland/history.html. Accessed online. January 31, 2003.

[14] In the SIC industrial classification, forest machinery falls under code 3523, "Farm Machinery and Equipment." However, forestry differs from other kinds of farming and the harvesting of wood is also different from other crops. The process involves marking the trees to be removed (in selective cutting), felling and processing of trees, and transportation of the wood from the felling site, or stump area, to a roadside storage or a central processing yard (landing) in the forest. There are two harvesting methods, and they differ on the amount of processing that is done on site, in the forest. In longwood harvesting, trees are only topped and delimbed at the felling site. In shortwood or cut-to-length harvesting, trees are completely processed at the felling site and the logs are then transported to a storage yard or site and eventually to the factory. Processing a tree includes top removal (topping), delimbing, crosscutting into logs (bucking),

machinery. Over the past 30 years, the functions and productivity of forest machinery has been enhanced through electronics, control systems, automation, information technology and wireless communications. During the last decade these embedded technologies are changing the management of the wood value chain in the forest industry, improving logistics and enhancing the flow and management of information.

Electronics and automation have been part of forest machinery for a long time. Back in 1972, when microcontrollers were relatively new, Mekatree made early tests with electronic control systems. According to a senior engineer in the company, at that time competitors were using relay controls and there was no customer acceptance but there was one small application niche: measuring the log with accuracy. This was difficult to do with relay controllers, while microcontrollers were simple to calibrate through software. By around 1978 the first machines with this feature were introduced and technology penetration snowballed in the 80s. Computerized control systems became pervasive. During the 90s a similar growth has taken place with automation and information technology. The next revolution came with the introduction of distributed digital control systems in the 1990s, with Controller Area Networks introduced in 1993. The most recent evolution is a PC-based measuring and control system that includes e-mail, maps and GPS capabilities. New product features are increasingly software-based, adding functions to the control systems and ultimately enhancing the performance of the machines. "The quality and speed of software development have, in fact, become one of

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debarking, and sometimes chipping of residues or bad trees. Source: "Wood" Encyclopaedia Britannica. Retrieved January 25, 2003, from Encyclopaedia Britannica Online.
http://www.search.eb.com/eb/article?eu=119326

the most important criteria for successful product development" (MekaTree publication). Software is making possible the management of information produced and utilized in the whole wood chain.[15]

Over the 90s mobile communication has also changed the business by making possible the remote transfer of information between machines and contractors. The use of wireless communications, initially facilitated by the GSM network in Finland and Sweden, integrates the machine to the office and generates a vast amount of information. This technological combination is enabling Mekatree to move from selling machines towards focusing more on selling services. The company sees itself as improving the customer's process from the forest to the factory, and a key has been to know the whole information flow. Improving technology is no longer an end per se, but an enabler to add value to the customer's process. Technology also helps meet reliability requirements and output quality control increasingly relevant as the machine is integrated into the logistics chain.

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[15] The Mekatree 3000 measuring and control system includes, for example, a software based adaptive feed control system that allows to control feed speed, and roller and delimbing knife pressure. It enables communication between the harvester and the contractor, including the bucking instruction files, production results and repair statistics, and diagnostics. Today more resources go into software development than mechanical design, changing the operation and the skill set required by the company. While some software development does take place internally, Mekatree defines specifications and relies on small, specialized companies in Tampere and elsewhere to provide software solutions. (Interviews, Company publications and product brochures).

Figure 4-5 Deere Forestry's 1470D forest harvester. Source: Forestry ImageBank. Photograph: Bo Bakström.

Today's forest harvesting machine is working autonomously in the forest and is linked to the logistics chain and to the office of the pulp mill or the paper mill via a cell-phone modem connection. Each log has a custom value and the trees are cut in the forest according to what is being sold. The sawmill already knows what type of lumber has been sold to the customer –to build houses for example. The operator gets a proposal of how to minimize the driving distance and when he goes out to the forest he already knows what kind of log is needed, including for example diameter and length. The harvester performs an optimization process on site: measurement of the tree, felling, bucking, and color-marks the logs according to the final customer. Managing all this information greatly increases the value of the tree. Since log in one site are not going to

the same place, logistics and transportation is also optimized with all the information at hand. When logs are left on site the harvester sends GPS location information to the forwarder operators, who know with enough accuracy the size and type of the wood. GPS allows forwarders to come and pick up the logs wherever they are, in the dark or in sites covered in snow.

As machines become more sophisticated, knowledge about human-machine interface is more important. It spans issues like user-friendliness to keep the machine easy to use for the operator, as well as aesthetics and occupational safety. Graphic designers and experts in ergonomics work side by side with electronic and software engineers. Different types of knowledge are coming together in this, because technology specialists usually had a narrow scope about this issue. A senior manager said that "the key is connecting people to figure out the best solution."

4.2.2 MekAutomation: Process automation

The product history in what is today MekAutomation serves to illustrate the evolution of automation technology over the past 20 years in the context of machinery for the paper industry. In the 70s MekAutomation (then operating as a business unit of an existing local company) had a product called MekAIRMATIC, which was a pneumatic measurement and control system. This product was transformed by the arrival of electronics, and MekELMATIC was introduced. Instead of using air, it used electrical signals for measurement, changing the operating logics from measurement and opening the door to control systems. With the arrival of microprocessors in 1979 came MekDAMATIC. It was a distributed control system which required networks, software

applications, a programming language and graphical user interfaces. Higher level computer-based controls were on top of it, constituting what was called a Mill Information System.

In 1987 came MekDamatic XD, an automation system whose development had begun in 1983. With it came the need for expertise in configuration because product delivery at this point was more about configuring the systems to specific customer applications than programming new or enhanced features. As it is always the case, R&D focused on programming while engineering focused on configuring customer-specific systems. The engineers are the ones who go out and install the systems. In MekDamatic XD there was a graphical configuration system to support the work of customer project engineers. The 1980s focus on processes, high-level control and machine control, evolved into distributed control systems. MekDamatic XD combined with ordinary automation, high-level controls and machine controls and evolved into a distributed control system. The next product generation came in 1995, called MekPaperIQ, used to take on-line paper quality measurements and enabled by a variety of sensor technologies. MekDamatic XDi came in 1997, incorporating information and knowledge management systems. In 2000 this system evolved towards MekDNA (Dynamic Network of Applications), supported by embedded automation into the process machinery itself.

Today MekCorporation as a whole is expanding from a traditional machine supplier to a comprehensive supplier of know-how and aftermarket services. The idea is to bring together equipment, solutions, software and services to form a comprehensive business concept to plan, develop and maintain customers' core processes throughout their life-

cycle. New technology is central to this corporate transformation, and MekAutomation is playing a key role by providing technology for MekPaper and MekMinerals. The development of wireless devices and communication and information networks, embedded intelligent measurements, open automation application networks and Internet and extranet technologies are central to the company's ability to provide new services. In addition, they are transforming the relationship with the customers, which will be based on long-term partnerships between the supplier and the customer.

4.2.3 Innovation through interdisciplinary integration

The previous account is representative of a pattern of technological change in Tampere's leading machinery companies. It illustrates how, through the successive integration of new layers of technology, machines have evolved from purely mechanical systems into mechatronic systems.[16] I refer to this process as *interdisciplinary integration.* Practitioners in Tampere's companies, research centers and policymaking circles are aware of the relevance of combining technologies for innovation. "It is about translating and combining, and in the future there will be a need to combine things even more than today," said one policymaker. A research manager in VTT shared this vies: Similarly, a senior technology manager from a local company said: "Most innovation happens between technologies, and what matters is to have projects that will combine them."

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[16] This finding is consistent with previous research that has shown that innovation in machinery consists of integrating new or improved components into an existing or a new layout of the system, often requiring recombination in creative ways (Lissoni, 2001). It also confirms previous research findings that show how product-systems have been transformed by embedded information and communications technologies, including control systems and embedded software (Hobday, 1997). The infusion of control systems, electronics, and embedded software makes most contemporary product-systems both multi-component and multi-technology products (Prencipe, 2003).

Today's machines are at the intersection of three spheres of knowledge: mechanical engineering, information and communications technology, and industry-specific expertise. The process of interdisciplinary integration in Tampere's machinery companies unfolded gradually over the course of 30 years. This combination of technologies is now a platform for several of Tampere's machinery and automation companies to move into integrated solutions, playing a more active role in managing the processes of their clients and providing other services.
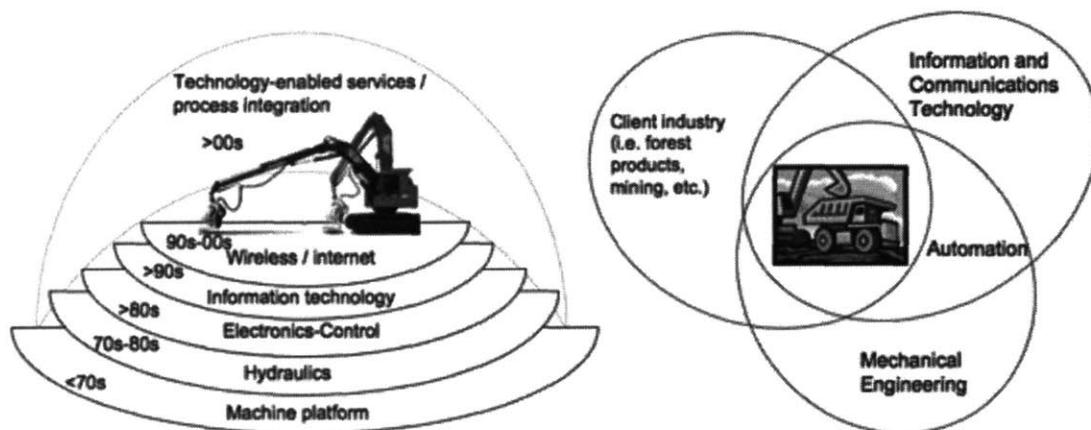
Figure 4-6. **Through the successive addition of layers of technology, machines manufactured by several of Tampere's mechanical engineering companies have become high-tech. Today these machines are at the intersection of three spheres of knowledge: mechanical engineering, ICT, and application-specific knowledge. The ability to integrate these three spheres is one of the most important competitive advantage of Tampere's companies. Source: author's conceptualization.**

This process of integration across disciplinary boundaries is one of the most important capabilities that previous studies identify as central to any firm's ability to

innovate.[17] In the following section I examine the how machinery companies in Tampere organized the social process of interdisciplinary integration behind the evolution of technology just described.

4.3 The innovation process

"How do you get new ideas?" I asked the senior technology manager of MekAutomation. "By bringing together people with different backgrounds," he answered immediately. Specifically citing the case of MekDamatic, he said:

> It was about bringing together the original team working on instrumentation, and the team working with computers. That created a major innovation, with two internal groups working together. In the case of paper machinery, this has happened with machine building. Usually innovations happen when you bring together people from different backgrounds. (Company)

This example, in which groups with different expertise worked together over time to develop a new product, is emblematic of MekAutomation, and is even reflected in the company's slogan, *Linking Innovations*. "MekAutomation has integrated automation and that differentiates us from others and is our competitive advantage," the senior technology manager said. But in reflecting on this experience, he noted that "it took 10 years to make it happen and it was hard for automation people to understand machine

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[17] These have been called integrative capabilities (Henderson, 1994), defined as the ability to integrate knowledge and technology from sources within and outside the boundaries of the firm. Interdisciplinary integration may be considered a specific case of knowledge integration. In industries like machinery, where products are product-systems, interdisciplinary integration is one aspect of systems integration capabilities, defined as "the competence to integrate changes and improvements in internally and externally designed and produced inputs into effective products and production systems" (Granstrand, Patel et al., 1997, p. 19). Integrating knowledge from different fields is a keystone of of systems integration capabilities. This process has been researched in the jet-engine (Prencipe, 1997; Prencipe, 2000), computer (Brusoni, Prencipe et al., 2001), and chemical (Brusoni and Prencipe, 2001), industries among others. Other relevant studies include Iansiti's research on technology integration in the computer and mainframe industry (Iansiti, 1995; Iansiti, 1995; Iansiti, 1997; Iansiti and West, 1997); Kodama's work of technology fusion in machine tools (Kodama, 1986; Kodama, 1992; Kodama, 1995); integrative capabilities (Henderson, 1994) in pharmaceuticals; and integration in mobile telephony, medical devices, and blue jeans (Lester and Piore, 2004).

building…it is difficult to bring people together because there is no common language that would be useful before the project and it takes time for people to understand what they are saying." He pointed out that it takes time to develop a common language, and as a result these types of projects last longer. The key was to keep people working together, and it helps when people are working towards "a clear objective, an idea…it is important that people see it, but the process takes many years."

4.3.1 Making space for innovation

Interdisciplinary integration starts in the early stages of concept development. Interviews with practitioners in several companies showed the necessity of *interpretive space,* a concept introduced in the previous chapter (Section 3.2.1), as the formal or informal arenas for interpretive conversations.
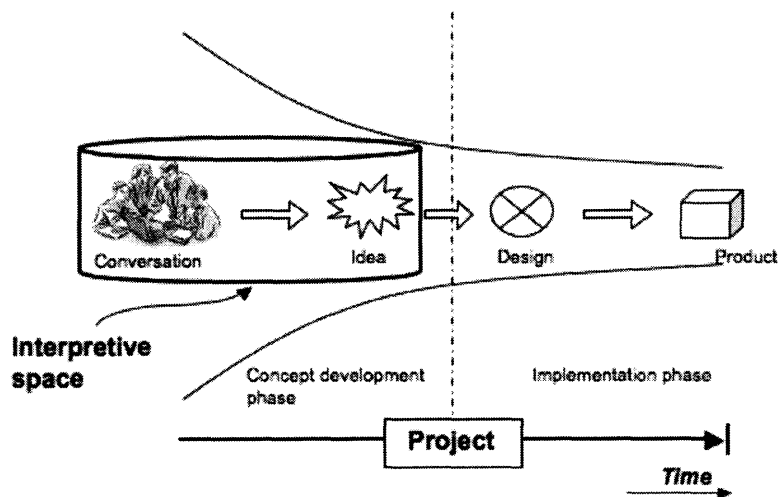
Figure 4-7. **Interpretive space.**

Some interpretive spaces come and go during the innovative life of a company as practitioners come together to explore new ideas. An engineer with a long career in Tampere's mechanical engineering industry, and at the time of this study the director of the Program for the Future of Mechanical Engineering of the Academy of Finland, gave a good example. As we discussed how Tampere's mechanical engineering industry had managed to reinvent itself and remain globally competitive, he expressed nostalgia for an *environment* in which people could find a *space* that was conducive to innovation:

> Earlier on many companies did a lot of R&D work, much not related to the product line of the time. It was not so controlled and not so tight and people who wanted to innovate could find a space to do it within the companies. If you were clever enough you could find a hole to do something. It is not anymore like that; it has become more competitive. But that environment created a lot of innovations carried out in small companies. Some of them became commercial and products succeeded. They began to develop on their own. (Policy)

These interpretive spaces created in practice reappeared repeatedly in the course of my conversations in Tampere. In September of 2003 I interviewed Arto Timperi, a senior engineer at MekaTree (the forest machinery company) during a forest industry show near Tampere. After observing one of the machines that he was instrumental in developing over the past few years, he recalled the early 1990s, when he was leading the development of the Total Machine Control (TMC) system that is now an integral part of MekaTree's forest harvesters. "Several revolutionary things were going on back then," he said. "It was quite a revolutionary thing to be thinking of controlling every single function of the machine with a Control Area Network." But this was no formalized development project. The TMC project started "secretly, without knowledge of company management; when they learned about it, it was already under way." Timperi's statement

echoed Hakalehto's words: TMC was developed in a "hole" within the company where the engineers could pursue this idea.

The second type of interpretive space is formalized as an organizational entity devoted to long-term research and development. IntelliTree, the research and development arm of MekaTree, is a good example. Although physically contiguous to MekaTree, it is a separate organization focused on projects for new technology development. During the first interview with the senior technology manager of the company back in March of 2003, near the end of our conversation I asked him: "So, how do you get new ideas?" He went on to tell us that new ideas come from different sources and that it was something hard to manage, but that "we try to create a positive attitude to the information that we get, and shelter the development process to support all ways to get the ideas and innovations for engineering." He said that there is a lot of internal resistance to new ideas, and that he is a "big believer in not trying to manage the innovation process; it is all about creating the environment with people with the right skill sets and competences together." I went on to ask him what he meant by "creating an environment" and he said: "For example IntelliTree. It is about having people who work with new ideas, without tight schedules and no short-term delivery work" (Company).

4.3.2 Envisioning future products and markets

When practitioners come together in interpretive space they imagine alternative uses or features of existing products, completely new products, and also alternative markets. Doing this requires that conversations in these spaces, even if they end up as commercial successes, be guided and sustained by a motivation that is not a direct response to market

needs. Taking distance from the market allows new ideas to be explored and think of new alternatives to emerge. What emerges from these spaces can anticipate needs and create market opportunities:

> At that time there was no customer acceptance for this technology [microprocessors in forest harvesting machinery] and competitors were using relay controls. A small customer need was measuring the log, and it was difficult to get accurate measures using relay controls, so we used a microcontroller. It is simple to calibrate and the software is simple. When we introduced it nobody in forestry and construction was using microcontrollers. Our business unit then was small and we were innovative, and from this it started to grow. We realized it, and the customers started to ask for more. (Company)

Coming together to think about new products and markets reflects a concern about the future. "You have to guess where the future might be going," the manager of IntelliTree said. An important motivation to talk about the future is a worry for the survival of the business. In Finland's crisis of the early 1990s, and in the mature industry of today, "it was key to understand that it was about survival and then we tried to do new things in projects," a manager said. The future is nothing more than an idea because it does not exist yet. "You need to have some business target in mind," the manager of IntelliTree commented. I asked him how he constructed the future.

> The way to do it is by analyzing the customer work process. We divide it into small pieces and then you can see where the opportunities are. If you change the process that can result in a change in the way the work is done. You need to monitor current work processes... If you split the process to microseconds you get a good picture of what is going on, and you can change it and have different harvesting systems. We are targeting to develop the work processes of customers. If we find bottlenecks, that's where we enter. (Company)

"Seeing" opportunities "monitoring" work processes getting "a good picture,"and "finding" bottlenecks. This language brings to mind an anthropologist who observes the customer's process in order to become very familiar with it and "get[s] a good picture" of

it. "You need to dive into the customer's process," he said. This is one way in which IntelliTree's manager said his company gets an idea of what the future might be. It is not some kind of otherworldly inspiration. Instead, it is about connecting the dots, about "seeing" the customer's process in ways that not even the customer can see them, and finding gaps where the company might "enter."

"Visions of the future also include the technology development trends," the manager of IntelliTree said. To be aware of these trends and to get these visions "it is good to have connections to the forest industry and have a total picture of the business where we operate." In addition to being aware of how the client works, caring about the future takes the form of perceived opportunities: beliefs and ideas that an existing or upcoming technology *will* be important. In MekAutomation, for example, "some people see that these new technologies will become important, and these people are influential and they can convince others," said a practitioner. I asked him to elaborate on what he meant by "seeing new technologies."

> It takes people that are interested about the future. Nowadays there is much information about the future. The problem is how to select the things, what to believe. The issue of selection is big. You put more effort on what the technologies could provide, what their future value might be. We have a more structured approach than 20 years ago. Now we have groups discussing important future technologies and then make decision about what we pursue. There might be some technologies of high penetration, and we need to figure out which type of technologies and for different application areas. If something becomes dominant then we use it more. (Company)

MekAutomation creates an understanding of what technological trends mean by "having groups discuss...important future technologies and make decisions about what to pursue." Conversations that lead to visions of the future are the first step towards

projects. For MekAutomation, as for MekaTree, the future is not some ethereal inspiration. It is about engaging in interpretive conversations to make connections between ideas and technologies, understanding what they mean, and creating a vision. "A lot of people talk about these big trends. You must understand what it really means to you,"

Visions give a sense of direction to practitioners working in projects. If there were no ideas about the future, no visions, there would be nothing to pursue. If the vision vanishes, the project breaks down. Having a space in which people could focus on long term visions has enabled MekaTree to be creative. What IntelliTree enabled MekaTree to do was to liberate itself from the constraints of the present and explore new ideas and new products. In other words, it enabled MekaTree to articulate and explore alternative futures.

4.3.3 Focusing on the long-term

To think about the future and envision alternative products and markets, it is necessary to have a long-term perspective. This was evident, for example, in an important distinction that our interviewees in MekaTree (and many others in Tampere) made between the "short-term" and "the long-term." The senior technology manager of MekaTree said, as quoted above, that in IntelliTree people work without "short-term delivery work." In the same interview he pointed out that while present product improvement is always focused on cost and process, on short-cycle improvements, "the daily activities often distract resources from long-term development, and that is why IntelliTree is separate from the rest of our product development." The senior technology manager of MekaTree thought

that short-term delivery placed constraints on creativity. When you focus on the short-term only, "you totally miss new ideas," he said. One way to think about the short-term is that people are working with little space, as if against a wall, focused on existing problems and existing products and on operating within cost constraints.

As a strategy to maintain capabilities for long-term innovation, short-term improvements, and problem solving, MekaTree explicitly separates product development into three separate levels, each with a different time horizon and level of risk. Present Product Improvement activities focus on reducing costs and making small improvements in existing products. In the Product Delivery Process the end result is always a product within a 2-year time frame, beginning from paper and going through several production prototypes, and is always 100% sure of delivering a product. The third level is long-term concept development and testing, which is carried out by IntelliTree.[18] In IntelliTree there is no certainty about the end result of projects. "In concept projects you are able to stop and no idea may move forward. There is a 50-50 chance that you will have some end result." A good example of long-term concept development is the walking forest machine, whose development went on for ten years. At the time of our conversation the machine was still a prototype.

Many times long-term projects fail. The thing doesn't work for two years, and you restart them later. The walking machine is a good example. The technology is ready for introduction, but stated 13-14 years ago, too early, on the short term you get spin-offs.

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[18] In the late 1980s IntelliTree was the Rauma-Repola Technology Center and operated as a small scale business, partly owned by management, selling advanced R&D services.

You learn, you learn a lot of different things and transfer smaller new things to current projects.

4.3.4 Managing and preserving ambiguity

In addition to a long-term perspective, interpretive conversations start without a clear goal in mind, and this lack of clarity is what unleashes their creative potential. If goals were clear prior to the start, there would be no room for exploration. The purpose of the conversations is precisely to create goals.

> You don't know exactly but you know it is the right technology to study, learn more and introduce to daily projects. You need to work in important parts, develop them further. Many times visions are made along the way, later on, after you start. If you ask Nokia cell phones, they are not now where they planned to be in the past (Company).

A practitioner warned against reaching conclusions too quickly. The most important thing at the "chaos" stage, or "quantum" stage as he called it, was to get a discussion going about different opportunities. At that stage, he said one had to "increase the chaos." I asked him what he meant by this and he said "have lots of discussions, have lots of opportunities, but not decisions yet." He added that "some people try to jump to decisions to quickly because they can't stand the uncertainty of the chaos." But he said that "it does take different kinds of inputs to open possibilities at the chaos stage; you need free information."

MekaTree's senior technology manager thought that managing interpretive spaces poses special challenges. He said that getting new ideas was "difficult to manage" and that he was "a believer in not trying to manage the innovation process." IntelliTree's director reflected on what these challenges were:

In this kind of small unit you have to put more flexibility into the work. We have no numbers at work, we have human beings. And the kinds of experts working here are like artists. You have to know what kind of people they are and give them freedom. The big thing is always the people. We do not have a big paper machine where you can adjust parameters. (Company)

I then asked him what he meant when he said that the people working in IntelliTree are like artists.

When new ideas or innovations are needed you cannot order people to do something. You have to organize the environment so that people can go on. If you are in the factory floor and you need to move something it is easy to do it. But if you are facing a problem without solution, then you cannot order. It is a very sensitive thing. This is not about management, it is about leadership, about creating the space for others. (Company)

Preserving the flexibility necessary in interpretive spaces requires sheltering these spaces from the constraints, performance measurements, and competitive behavior of the market. A senior executive said it clearly: "In Finland industry management and economic control has not been so tight [as in the United States]... If there are tight economic controls you are not doing these kinds of things. If you have loose management and there are visionaries and can convince people, with loose management it is possible." He particularly emphasized long-term projects that are focused on combining technologies in new ways by saying that "the economic part is no use because you cannot show the return soon enough." In a similar vein, an engineer, reflecting on the early sources of success in his company, said: "We didn't have anything to lose in the past. We made huge mistakes. We could always pay for the mistakes when the bill came back. When the money is big it is a different game."

At the time of this research there was uneasiness in the air about the acquisition of MekaTree by TreeGlobal would mean. IntelliTree's manager said that belonging to

TreeGlobal had many benefits, such as having more resources and the opportunity to cooperate with organizations in the U.S. But he worried that TreeGlobal might apply tight management criteria to IntelliTree. . "There is more bureaucracy and the decision making process is more difficult," IntelliTree's manager commented. He was concerned about the cultural differences between the organizations:

> As industries we are close, but the organizations have bigger differences. In US organizations it is important to have exact definitions for everything, clear processes, and that is not so important here. We have more flexibility in the organization. The bottom line is also important, but many other things are important too. Follow-up is getting also more important. If you can do the work getting results then it's ok. But in long term R&D you need something else. In this kind of small unit you have to have more flexibility in the work. (Company)

His uneasiness regarding these cultural differences was quite specific. IntelliTree had grown to be a space for innovation in MekaTree, sheltered from short-term pressures, in which engineers were free to be creative while pursuing risky, innovative ideas. Neither the senior technology manager of MekaTree nor the manager of IntelliTree felt comfortable with the idea of managing the innovation process. As managers, of course, they did manage the innovation process at MekaTree and IntelliTree, but they were conscious of the need to shelter that space so that creativity could blossom. When describing their management styles, they seemed to struggle to come up with terms to explain what they were doing. IntelliTree's manager said the people working there were like "artists" who needed "flexibility." Management provided visions, but these visions were fuzzy and ambiguous enough ideas to leave room and give basic direction for exploration. They were not constrained by hard-and-fast goals. . "The bottom line is also important here, but many other things are important too." They could not speak of results

in bottom-line terminology, but they had enough empirical proof that IntelliTree was good for MekaTrees' ability to innovate.

In all these risky pursuits there is no guarantee of success. Uncertainty is inherent. Deciding to pursue a new technology "it's some kind of feeling that you get," the managers said. "The thing is to continue to look and to continue testing."

4.3.5 Interdisciplinary integration: an interpretive process

This account of the innovation process is consistent with previous findings that have characterized the integration of different disciplines and technologies as a social process (Johnson, 2002; Johnson, 2003). In the duality of innovation framework, interdisciplinary integration is an interpretive process. Interdisciplinary integration requires individuals from different backgrounds to come together and initiate and sustain an interpretive conversation over time. Interpretive conversations and conversation-like interactions across organizational and disciplinary boundaries are the underlying social process that enables practitioners to integrate knowledge from different fields (Carlile, 2002; Bechky, 2003). These conversations include, as interlocutors, practitioners from different areas within the companies, as well as customers and experts from universities and, in some cases, other companies (Iansiti and Clark, 1994). Through these conversations practitioners engage in an interpretive process that gradually creates new meaning by merging the knowledge and understanding of the interlocutors and in that way arrive head towards a new, blended understanding that signals the emergence of a new idea or product concept (Malek, 2000; Lester and Piore, 2004).

These interpretive conversations occur in interpretive space. In Tampere, interpretive space appears in two forms. First, it is a space actively created by firms and formalized as an organizational entity, such as an R&D lab. Second, it can be a temporary space created during practice whenever two or more practitioners come together to discuss customers' needs, emerging technologies, or new ideas. The interpretive spaces examined by this case study suggest that they have two crucial functions. First, they are inherently integrative. When practitioners come together in interpretive space they temporarily step out of their organizational and professional boundaries. Through conversation they integrate their separate understandings into a coherent vision or concept for a new product. Second, interpretive space enables practitioners to imagine new products, product features, and new markets. Coming together in an interpretive space reflects a concern with the future, and conversations often result in a vision of what could be. If interpretive space orients towards the future, the projects that emerge from them are the bridges to reach the vision.

The most important factor that enables the creative and future-orienting functions of interpretive space is to nurture ambiguity. Doing so requires three conditions. First, there must be a long-term perspective that gives freedom of exploration. Second, people must come together with ambiguous or nonexistent goals. The purpose of the conversation is precisely to create goals. And third, one must avoid imposing on interpretive spaces tight deadlines, performance measurements, or organizational structures that could also restrict the conversation. The function of IntelliTree as an interpretive space is to provide an arena for play, exploration, and conversation. The

focus is on the development of long-term concepts and ideas, sheltered from the competitive and short-time pressures of the market. IntelliTree and organizational entities like it contribute to the life of the company by creating a space within the company in which these conditions, critical for the emergence of new ideas, exist. In the long term these ideas may lead to not new products.

When practitioners are in interpretive space, what do they look for when they reach out to universities and other supporting institutions? If the concept development phase of innovation is about the creation of meaning and orienting towards the future, what type of university-industry relationships and policies enhance the ability of companies to do this?
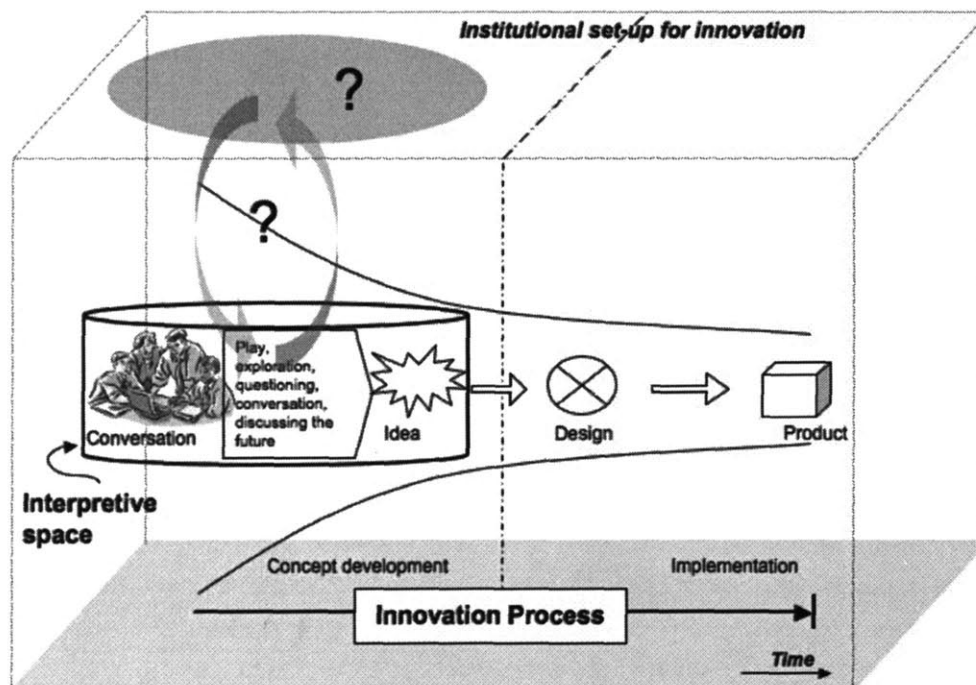
Figure 4-8 How do external interactions and organizations in the institutional set-up for innovation affect interdisciplinary integration?

4.4 Effects of the institutional set-up on the innovation process

In this section I examine how three organizations TUT, VTT and Tekes have affected the ability of the ability of Tampere's machinery companies to infuse new technology to their products.[19] The end goal of this study is to understand the role of TUT in facilitating the ability of local companies to integrate knowledge and technology from different fields. Placing the university's role in the broader set of organizations that affect the innovation process will help reach a more refined understanding of the university's role and the nature of interactions that contribute to the industry's integrative capabilities. An examination of VTT's, in particular, affords an opportunity to make a within-case comparison with an organization that has also played an important role in the reinvention of Tampere's machinery industry. Examining the role of Tekes will help to understand public policy effects on university–industry interactions.[20]

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[19] Previous research suggests that institutional factors play an important role in facilitating or constraining the ability of firms to integrate technology form different fields. The machine tools industry in the United States was not able to successfully compete with Japanese, German, and other European machine manufacturers in the 1980s. This failure was due, at least in part, to the inability of American manufacturers to integrate control systems, the most significant technological development in the machine tools industry between 1960 and 1990. This was also the case of the textile machinery industry. In both cases, institutional factors played a major role in the industry's demise (MIT, 1989). In the machine tools industry, institutional factors included inadequacies in engineering research and education at universities, a federal government policy biasing support towards research on large-scale complex engineering systems, a short-term economic logic on the corporate side, and an underestimation of the need to innovate on both producers and users (March, 1989). In the textile machinery case, besides low investment in R&D, firms maintained levels of secrecy that limited communication with the engineering professions. According to this study "the US lacked the regional institutions, supported jointly by government and industry, to provide training for industry personnel from machine operator to research engineer. Just as critical was a lack of broadly trained engineers working on process development and evaluation." (MIT, 1989)

[20] It is important to note that both Tekes and VTT are national organizations. This reflects the fact that the boundaries between Tampere's local innovation system and Finland's national innovation system are blurred. Local companies often reach out to other branches of VTT and national policies have an effect over their innovation activities. Both organizations' contributions to the innovation process have an important local dimension. VTT's branch in Tampere in the region is oriented towards the knowledge base at the heart of local industry and the design and management of Tekes' Technology Programs usually involves experts from both industry and academia in the technical areas they are meant to strengthen. The

4.4.1 The Tampere University of Technology

The Tampere University of Technology is a key organization in the local innovation system, with many firms and other support organizations having joint projects with it (Kautonen and Schienstock, 1998).[21] Tampere's mechanical engineering companies value TUT as an important partner in research, problem-solving, and as the source of engineers with the specific qualifications crucial to the competitiveness of the mechanical engineering industry. Departments and research groups in mechanical engineering and related fields are among the most prominent academic units of TUT and they have a tradition of close interaction with companies in the field. Examples include the Institute for Production Engineering, the Institute for Machine Design, and the Institute for Hydraulics and Automation (IHA).

The IHA is the academic unit that interviewees most often referred to as a key player. The IHA dates to 1972, when Tamrock, a leading supplier of mining machinery, reached out to a TUT professor, then a young researcher and today director of the IHA, to figure out how to integrate hydraulic power systems into mining machinery. The IHA has since then become a valued resource for many machinery companies in the region, and has acquired an international reputation in its field. The relationship between the IHA and local companies is representative of three critical functions that TUT performs in support

interactions of the local and national dimensions of technology policy in Finland are discussed by Sotarauta and Kautonen (Sotarauta and Kautonen, forthcoming). They describe it as a case of multi-level governance and a process of co-evolution.

[21] TUT was originally established in 1965 as a branch of the Helsinki University of Technology (HUT), but local efforts soon got underway to separate TUT from HUT, and in 1972 TUT began operations as an independent technical university. In addition to teaching and research activities, TUT has maintained close links with local industry even during the 1970s, when the Finnish government discouraged university-industry collaboration (Kostianen and Sotarauta, 2003).

of the industry's integrative capabilities: interdisciplinary research, interdisciplinary education, and creative interlocutor.

One of the most valued capabilities that machinery companies see in the university is its ability to perform interdisciplinary research. More specifically, industry leaders referred to the integration of hydraulics and automation systems. Previous research on interdisciplinary research in universities suggests that this process of integration is an inherently interpretive process. At the heart of this process is the emergence of a common language and an understanding that blends different fields at their boundaries (Becher, 1989; Martinez-Vela, 1998; Lattuca, 2001; Lester and Piore, 2004). One way to think about the IHA and other interdisciplinary academic units within TUT is as an interpretive space. Researchers from different fields converge in the context of projects, temporarily stepping over the boundaries of their academic units and disciplines to engage in an interpretive conversation that is at the heart of their ability to integrate knowledge from different disciplines.

Another integrative aspect of the engineering research agenda that stands out in the IHA is the bridging of theory and practice. At the time of this study, this agenda went from water hydraulics on the basic research side of the spectrum, to free piston engine technology, to hydraulic power systems for mobile machines, which is mostly applied. This portfolio, according to the IHA's director, allows the IHA to contribute to the industry along the spectrum from long-term concept development to short-term problem solving. In the latter type of engagement, the role of the IHA changes from a space for conversation across disciplinary boundaries problem-solving resource for companies.

The relationships, in this case, are very different from the interpretive conversations that support interdisciplinary integration. An engineer from a local for example, said that in this type of activity "engineers interact with the university usually with a goal in mind. Usually it is about improving or testing a machine" (Company).

An important observation is how the funding patterns and types of relationships and interlocutors involved with the IHA changed when moving from concept development to implementation. Funding transitioned from almost exclusively Academy of Finland (a NSF-like entity) funding for basic research, to Tekes funding in projects that transitioned from basic to applied, to almost pure corporate funding for mobile hydraulics. The IHA's director pointed out that project collaborators also changed from solely academic researchers, to projects in which industry engineers played a leading role. In the middle both were mixed. Another observation was that the mix of collaborators with the IHA changes from mostly universities and research institutes to mostly companies.

The second key contribution of TUT to the innovation process of the industry is the education of highly-qualified engineers. Tampere's engineers were a major factor that all companies repeatedly cited as the main reason why the region was a good place to be in. In addition to knowledge specific to company needs, practitioners in industry pointed out that one of the most important capabilities of TUT's engineers was the ability to integrate hydraulics and automation in their practice.

Previous research suggests that engineers acquire these integrative capabilities by engaging in practical activities and participating in interdisciplinary projects, where they work together with students and practitioners from different fields (Martinez-Vela, 1998).

These two features, practice and projects, are pervasive in the educational experience of engineers at TUT. This combination is central to the development of integrative capabilities in two ways. On the one hand, participation in projects exposes engineering students to interdisciplinary collaboration, inducing them to enact the same kind of interpretive conversations that are also characteristic of interdisciplinary research. On the other hand, participation in projects with a practical goal builds a bridge between classroom experience and hands-on experience (ibid.).

In Tampere, the bridge between theory and practice in engineering education is built through an apprenticeship system. Engineering students from TUT are constantly exposed to industry problems in academic units like the IHA. In addition, they complete their academic requirements by carrying out a project either closely related to or directly within the industry. One way to see this back-and-forth flow of students between the mechanical engineering industry and TUT is as an ongoing conversation that, over the years, continuously bridges the academic and industrial spheres and is part of the co-evolution of each side of the relationship. Further research in Tampere and other sites is needed to investigate whether this is a plausible interpretation and a possible unexplored role of apprenticeship systems.

A third important role of TUT, or rather, of its faculty members and researchers to support interdisciplinary integration, is to participate as interlocutors in interpretive conversations. This role of the university takes two forms. First, through the participation of members of TUT in interpretive conversations organized by firms, policy agencies. These conversations are meetings, joint development projects, seminars.

Several firms cited, as examples, meetings they had had with TUT researchers to explore

new ideas, or participated in joint projects with TUT academics (and from other Finnish

universities as well). The second way in which TUT's members act as interlocutors is by

initiating and sustaining interpretive conversations or conversation-like interactions

between specific academics and practitioners in companies. A good example of both

instances of this type of interaction comes from MiniMachine a local company:

> We gave a [machine] to the IHA so that they could show it to the students and make changes
> to it, and they came up with some ideas about how to develop the machine. The newest
> project came from their side. This project emerged after another machine that we gave them,
> that they modified and changed and added things and made it remote control, and we have the
> possibility of make it move by computer or through your mobile phone. This would have
> been unthinkable before but we now think it does have good market potential... We know
> them so well that one day Matti phoned me and told me about the idea, and that is how it
> started. This was a case where we said "yes" to an idea that came from the IHA, but in many
> other cases they come with ideas and we say no. In this case we put a man here responsible of
> the project, and then a team. We have meetings every now and then and our engineers often
> discuss issues with them. (Company)

4.4.2 VTT Technical Research Centre of Finland

Another important player in the industry's innovation process is the local branch of VTT.

[22] In contrast to TUT and other universities, VTT is more explicitly oriented to the needs

of industry. As one interviewee put it, "the university has more basic research, we [VTT]

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[22] VTT was founded in 1942, operating under the Ministry of Trade and Industry to perform military research and testing, evolved to focus on industry needs in the postwar years. It was an independent organization, but worked very closely with the Helsinki University of Technology. In its early days VTT was directed mainly to do research and testing for military and civil defense purposes, though testing was the primary activity during the early years. After the war, established testing and research units gradually redirected its focus towards the economy, with reconstruction being the primary goal. In the 1950s industry research needs started to grow, and in 1952 VTT redefined its mission to do general research that promoted the development of Finland's economy. In the 1960s VTT became Finland's biggest research institute, and as the economy internationalized technology development became more important. After 1980 VTT went through several major reorganizations, with the latest one, which took place after 2000, defining strategic technology themes aimed at current and future industry needs. Sources: Interviews and VTT website. See "The history of VTT" at http://www.vtt.fi/vtt/index.jsp. The Tampere branch was opened in 1974. In 1994 the VTT unit in Tampere became VTT Automation. In 2002 it was merged with VTT Manufacturing Technology to create VTT Industrial Systems.

do more applied research and companies focus on product development" (VTT). VTT research staff works in industry projects with clearer goals and deliverables, and in the majority of cases with a commercial application in mind.[23] An important outcome of VTT's research and development work is a portfolio of technologies that can be applied across industries.

MekAutomation values TUT as an educator of qualified engineers in the same way that MekaTree does, but interviewees said that VTT had been more important for the company's take up of new technology. "VTT," he argued, "has had a big role in bringing new technology in." Taking a look inside VTT reveals that the integrative capabilities of VTT come from its ability to create interpretive space. One of the interviewees in VTT said that their approach was to develop "generic technology that can be applied to new things that are often company or branch specific… We can transfer from pulp and paper to energy to rail transportation. We work as a hub. A company can interpret the message through its own frame; see how it fits its frame" (VTT). The account that follows illustrates how a conversation originated a recent innovation in MekAutomation:

> MekAutomation makes many field devices, and we worked in a project on valves that are used in big industrial plants… We wanted to have a project with BlueTooth, so it was more of a technology push. Industry was interested in it, and the idea emerged during one discussion that we had and we concluded that it was a real need. We were discussing with several companies, during a meeting of a very loose and informal group of people that came together to discuss wireless applications. It was us, the companies, and people from the university. It was us who send the invitations out. Initially there was wondering during the meeting, and we had several meetings like this and we kept discussing ideas back and forth. The first conversations didn't have a clear goal in mind, but by the end the idea emerged as a clear candidate for a new product. This kind of setting is not typical, but [the technology

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[23] A senior R&D manager in VTT mentioned, off the top of his head, that about 40% of the work is commercial, working in specific industry projects and problem-solving; 40% is applied research to develop new technologies and test and evaluate them with companies; and about 20% is basic research.

park] was promoting this kind of activity. We discussed this issue and ended up in a new project. (VTT)

This was not a transaction in the marketplace: This was an interpretive conversation, held in a temporary interpretive space (a meeting), that resulted in a new idea and that spun off a new project. The goals of the conversation were not clear a priori. Practitioners knew that they were looking for something but did not know what it was at the outset. There were no problems to solve; there were themes to talk about. Referring back to the value that MekaTree places on TUT's integrative capabilities –and on IHA in particular– TUT did for MekaTree something very similar to what VTT did for MekAutomation. Interpretive conversations were also at the heart of the IHA's ability to bring together hydraulics and automation and implement them in mechanical systems.

VTT also plays an important technology transfer role for local companies. Unlike the interpretive conversations just described, the technology transfer and problem solving roles of VTT involved a very different type of engagement. In this case interactions have clear goals a priori. The company is looking to buy some needed technology from VTT's portfolio or for an answer to a problem.

> More business-related R&D can be carried out in large companies. VTT is somewhere between basic and applied R&D, is used to project-type work with clearer objectives. Often universities are more relaxed about the way they work with companies. For us, VTT comes first, and then the universities. VTT sells R&D work, as a product. Some of its centers are ISO 9001 certified in professional knowledge management. Universities do not sell R&D as a product. Our policy, when we have a technical issue, is to check VTT first, because they often know the answer. (Company)

These accounts suggest that VTT played a dual role when it came to "bringing new technology in." On one hand, it had an interdisciplinary integration role. On the other

hand, it played a technology transfer and problem solving role, in which practitioners reached out to VTT with clear goals and needs in mind. One was an exploratory conversation to generate new ideas, while the other was a transactional interaction that involved the transfer of information and technology that already exists.

VTT is also the interface between the local and the national dimension of the support structure of Tampere's mechanical engineering industry. Interviewees in industry who referred to VTT as an important partner valued both the specificity of the local expertise, relevant to their innovation process, as well VTT's belonging to a national network of research institutes. Some companies go through the local VTT and then VTT reaches out to experts in other branches during projects, while other companies reach out themselves to other VTT units. A senior engineer said, for example, that when his company was first integrating microprocessors into control systems, the technology "was transferred from VTT Automation in Helsinki... They have also been sources in sensor technology, another area to which VTT is very committed" (Company).

4.4.3 Tekes

The third key player with an institutional effect on Tampere's mechanical engineering business sector is Tekes, the Finnish Funding Agency for Technology and Innovation.[24]

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[24] In Finland, technology policy is administratively separate from science policy, although closely articulated with it. Science policy is the responsibility of the Ministry of Education, which funds basic research through the Academy of Finland. The formulation, implementation, and government funding for R&D is the jurisdiction of the Ministry of Trade and Industry. Several agencies within the ministry are responsible for programs and policies aimed at the generation and diffusion of new technological knowledge in Finnish industry. Tekes is the most important. Tekes provides funding for high-risk R&D projects in companies registered in Finland as well at Finnish universities and research institutes. In addition, Tekes provides expert services and builds networks between universities, companies, and research institutes (Ylä-Anttila and Palmberg, 2005). In 2005 Tekes invested EUR 429 M, which accounts or 25%

The metal and mechanical industries were the largest recipient of Tekes R&D funding in 2005, with approximately EUR 65 million. Tekes repeatedly emerged during interviews not only with companies, but also with TUT and VTT. Tekes plays an important role in the ability of Tampere's machinery companies to detect technological opportunities and take up new technologies. Tekes implements technology policy and channels R&D funding through the Technology Programs. Technology Programs are technology-specific multi-year efforts to explore and develop new areas of technological expertise. Programs comprise research projects in industry, universities, and research institutes, as well as support for business operations through joint visioning, seminars, training, and internationalization support. A goal and effect of technology programs is to strengthen collaboration and build relationships between the actors involved (Tekes, 2005).[25] Our interviewees in Tampere suggest that the effects of Technology Programs go beyond providing an "input" –money– for the innovation process, and even beyond its stated goal of promoting "networking."

Fist, through Technology Programs Tekes catalyzes interpretive conversations across organizational and disciplinary boundaries, expanding the creative space of companies

of the Finnish government's expenditure on R&D. Of the total funding, EUR 250 million went to projects in companies and EUR 179 million to universities and research institutes. In 2005 Tekes paid out funding to 1,826 companies (Research.fi, Tekes Annual Report 2005, tekes.fi).). At the regional level, Tekes provides services through the Technology Development Departments of the Employment and Economic Development Centers, or T&E Centers. The T&E Center in the Tampere Region was founded in 1997 (Kautonen and Schienstock, 1998). However, all interviewees in companies, educational and research institutions in Tampere referred only to "Tekes" when discussing the role of the T&E Center in their innovation process.

[25] By the end of 2005 there were 25 programs under way, involving around 2000 companies and 500 research units, which received EUR 177 million in funding, or 41% of total Tekes funding. Technology programs have diversified from purely technical areas and industries into areas like industrial design and the creative industries.

beyond the boundaries of the firm. Technology Programs may be seen as a series of ongoing conversations, usually lasting between 3 and 5 years.

> I participate in stirring groups for Tekes Technology Programs, and there I get to meet people from other companies and can discuss and exchange ideas. Universities and VTT provide the basic know how, but participating in this is a good tool for networking and learning. (Company)

The current Technology Program most evidently related to Tampere's mechanical engineering industry is the MASINA 2002-2007 Mechanical Engineering Technology Program.[26] Of eleven members of the board of directors of the MASINA program, the only university representation comes from the IHA at TUT, the only VTT representative is from Tampere, and two of six industry members come from Tampere's machinery companies (Masina webpage). In Technology Programs practitioners explore emerging technologies with future potential. These ongoing conversations are organized as steering groups, seminars, trips to leading companies and research centers, and, most importantly, as a series of projects. Funding of Technology Programs usually requires collaboration between companies, universities, and VTT.

In addition to initiating and sustaining interpretive conversations through Technology Programs, Tekes motivates companies to undertake risky conversations on their own. In other words, Tekes funding is an incentive to carve out interpretive space. An example of this role comes from MekAutomation. As we were discussing risky, long-term

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[26] The stated goal of MASINA is "to boost the competitiveness and success potential of the Finnish mechanical engineering industry by developing new technologies and products and strengthening related design and research expertise." In 2005 MASINA projects received EUR 10.1 Million of Tekes funding, with 90 participating companies and 29 research units in universities and public research institutes (Tekes, 2005).

development projects, the interviewee said that "Tekes puts the risk money and pushed the research institutes and companies in projects, steering groups, discussing and developing a common language." The first point he made here is about risk. He said that Tekes makes it easier for people inside the company to establish new projects, because if Tekes is behind them, management is likely to support them too. In addition, Tekes puts in "risk money." In this way, "Tekes gives some kind of extra push to believe in new ideas," he said. Tekes has the indirect effect of carving or nurturing interpretive space within the company.

Finally, Tekes creates a safety net in the transition between concept development and implementation. Through its explicit emphasis on "moving" ideas from the concept development stage to implementation and commercial production, Tekes sets the sights of practitioners in academia and industry on implementation. Tekes does not fund the manufacturing or commercialization efforts of companies, but it does play a role in the transitional space between the concept development and implementation. By making funding available Tekes creates a buffer zone that makes companies willing to take the risk of jumping from good ideas to marketable products.

4.4.4 Other policy roles

The Academy of Finland, the Finnish equivalent to the National Science Foundation, plays an important role in funding basic research in universities. In the spectrum between concept development and implementation, the AoF acts during the early stages of innovation, indirectly supporting concept development and interdisciplinary integration by funding cutting-edge basic research in a variety of institutions. At the time of this

research the IHA was one of 26 centers supported by the Centers of Excellence program

of the AoF. The AoF was also funding the Research Program for the Future of

Mechanical Engineering (Tukeva).[27] The program director was Kalle Hakalehto, one of

the most experienced mechanical engineers in Tampere, who worked in Tampella and

moved into science policy.[28] Research Programs, implemented by the AoF, are for

science policy what Tekes' Technology Programs are for technology policy.

The second actor was the Centre of Expertise in Mechanical Engineering and

Automation, part of a national program on Centres of Expertise implemented by

Finland's Ministry of the Interior. Although its goals span the innovation process,

interviews in Tampere suggested that it was playing a role locally by promoting

interpretive conversations. The CoE expanded the interpretive space of companies

beyond their organizational boundaries and bringing together researchers from TUT,

VTT, and industry in seminars and loosely-organized working groups to discuss

emerging technologies, needs of industry and business opportunities. Some of these

conversations led local companies to initiate new projects, and in some cases to the

creation of support structure organizations to support fields of expertise required by

several companies. This is the case of the Foundry Institute, the Rubber Institute and the

FMS Training Centre. The CoE, in addition, is itself a forum, bringing 35 members from

industry, academia, and policymaking into its advisory board.

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[27] The goal of the Centers of Excellence Program is to raise the international standing of research in universities. In 2002-2007 the program received EUR 33.1 million in funding from the AoF. Tekes also participated with EUR 10.5 million. The Tukeva research program funded 13 research projects with EUR 3.4 million.

[28] Sources: Finnish Science and Technology Information Service (www.research.fi), Academy of Finland (www.aka.fi), and Final Report of Tukeva Program

The third policy actor that emerged a few times during the study is Hermia, the Tampere Technology Centre Ltd. Its intended role is comprehensive and includes business incubation and development in several fields. This study suggests that it also played a role in expanding the interpretive space of companies by promoting interpretive conversations. An example is the conversation that led to the project to integrate BlueTooth technology into MekAutomation valves, cited above.

4.4.5 Informal institutions

Interviews with company managers and engineers, policymakers, and academics, showed that three informal institutions are critical to make possible collaboration and conversations across organizational boundaries.

Shared professional identity

Most of the industry, policy and academic interviewees in Tampere were educated at the Tampere University of Technology, and many of them are mechanical engineers. A senior R&D manager said, for example, that "if you have not graduated from the university they do not relate to you, and you do not understand each other" (Company). For the most senior interviewees, knowing each other from previous posts in other companies was also important. This shared academic and professional identity, which blurs organizational boundaries, has enabled them to easily interact and communicate when they needed to find something about something. As an interviewee put it: "It has been easier to understand that we had to go somewhere to get knowledge when necessary. When my boss asked something, I could not say I didn't know. He encouraged me to call anybody who knows more than you and in 3-4 calls you find who knows

everything" (Company). In addition, this shared identity facilitates a frank, open conversation {find quotation}.

Shared knowledge base without competition

"In Tampere competition is not very strong between companies. All are aimed at different markets, yet they face similar challenges. One thing they have in common is that many of them are about 'heavy mobile machinery'. Cooperation has a long tradition and this is possible because competition between companies is not bloody. They all draw from the same pool of knowledge and have similar targets" (Policy). This account summarizes the effects of this background condition. Mechanical engineering companies in Tampere, and machinery companies in particular, although operating in different markets, work within the field of mechanical engineering and subfields related to machine building. They share a core set of technological platforms that take different forms depending on the domain of application. Hydraulic power systems are applied, for example in machines destined for the forestry, mining, or container handling niches. In addition, these companies do not compete in the market because they sell to radically different industries and niches. Interviews suggest that this combination helps collaboration during the innovation process.

Awareness of the integrative nature of the innovation process

Several interviewees commented on the significance of combining mechanical engineering with information technology to the region's competitive advantage. According to one senior policymaker, "[T]he reason why the mechanical engineering industry is strong in Tampere is the use of high level information technology in

mechanical engineering products. Information technology is embedded in them" (Policy). This awareness is in itself an incentive to collaborate across disciplinary boundaries, both in academic collaborations and also to collaboration between mechanical engineering and information technology companies. Interviews with academics, practitioners in industry, and policy makers frequently referred to instances of conversations that included mechanical engineers, information technology specialists, as well as software companies and machinery companies, which then led to the start of new projects.

4.5 Understanding the university's role

A more detailed analysis that places TUT's role in the context of the other functions identified above, will advance our understanding of the contribution that a university can make to an industry which, like many others today, requires interdisciplinary integration to innovate. Because this was a qualitative and interview-based study of a small subset of companies and their relationships with three organizations within a single innovation system, it cannot provide definitive evidence. A more comprehensive sample of companies within the region, in-depth historical and ethnographic studies of the innovation process within them, and a comparison with processes in other innovation systems would have to be undertaken to produce a higher level of abstraction and generalizability. However, this study is suggestive of a pattern in the contributions that TUT, joined in some instances by other support structure organizations, makes to interdisciplinary integration capabilities in a mechanical engineering industry. Examining the patterns that emerge from the previous discussion helps us understand how findings from this case might apply to other settings.

The support that TUT lends to interdisciplinary integration is interpretive. More specifically, the innovation-enhancing role of TUT hinges upon its ability to provide, enhance, and expand interpretive space. First, it provides interpretive space to local mechanical engineering companies by creating and sustaining interdisciplinary research groups inside the university, such as the Institute for Hydraulics and Automation, in which there is an ongoing interpretive conversation across disciplinary boundaries. Second, it expands the interpretive spaces of local companies by participating in interpretive conversations or research projects across organizational boundaries. And third, it enhances interpretive spaces by supplying creative interlocutors to meetings and seminars, as well as to policy initiatives that bring together academics and industry practitioners. In the two latter roles, TUT becomes part of the interpretive space of companies through its interlocutors, who serve as conduits or bridges between companies in the business sector and the interpretive conversations inside the university. When the university provides or expands interpretive space it enhances the integrative capabilities of local companies and the ability of practitioners to imagine alternative products, product features, and markets.

The university-industry interactions involved in providing, expanding, and enhancing interpretive space are interpretive conversations or conversation-like interactions. The value of these relationships for companies comes from their exploratory and ambiguous nature, not from the transfer of specific technologies or bits of information. Practitioners reach out to academic units and individual researchers to engage in an exploration that does not necessarily have clear goals in mind and is open to the unexpected. These

relationships escape traditional characterizations of problem-solving, consulting, or technology transfer, which are market-like transactions in which both parties know what they want and knowledge is codified.

TUT's role in providing, expanding and enhancing interpretive space is supported by public policies. Tekes Technology Programs, as well as local organizations like the Centre of Expertise or the Technology Centre, make university researchers active interlocutors in interpretive conversations with practitioners, both in informal and temporary settings, and through formalized joint development projects and policy initiatives. A senior policymaker reflected on the role of the Centre of Expertise Program:

> There was one project where a TUT Lab was doing major work. One company in the area thought it was good and was not willing to cooperate. During this program they arranged a one-day meeting. People from companies presented what they were doing and talked about a new generation of products. This was supposed to be one morning. At the end of the morning university people shared the state of the art and discussed current trends in the industry. Before lunch the R&D manager of the company suggested that the meeting go on and that they should continue in the afternoon and keep discussing what was happening. This happened, and after that, the company changed its plans and they totally started from the beginning, and the director said that this saved them. That decision allowed them to maintain their technological innovation leadership. (Policy)

These policies for enhancing interpretation are very different from the usual approach to promote the university's role in economic development through intellectual property, technology transfer, and business incubation. While policies for this purpose are also in place, the interpretation-enhancing role of public policies like the Technology Programs stood out during this research and offer important lessons for the design of a more comprehensive university-industry partnership policy.

While the interpretive role of the university is critical for interdisciplinary integration, another important aspect of the relationship between university and industry emerges when thinking about the integration of theory and practice. Seen through the duality of innovation and its relationship to the product lifecycle (see Section 3.3), doing research and educating engineers who integrate theory and practice means having research and educational activities that bridge interpretive conversations and analytic problem-solving. In research, the Institute for Hydraulics and Automation is a good illustration of how operating in a continuum from basic to applied research enables the IHA to engage companies in both research and problem-solving roles. Educating engineers capable of moving between theory and practice, of solving application-specific problems but also engaging in the interpretive conversations necessary for interdisciplinary integration is a central contribution of the university to the industry. This capability is developed through the apprenticeship system that is a keystone of the university-industry relationship in mechanical engineering.

History and tradition facilitate a close university-industry relationship between Tampere's machinery companies and TUT. First, there is a tradition of engagement between TUT and local mechanical engineering industry. This tradition is rooted in the history of the university, which was founded by local business and civic leaders to assist local industrial development and educate engineers. Even during the 1970s, when Finnish law severely restricted university-industry relationships, TUT and local industry remained engaged. It was in that period, for instance, when the Institute of Hydraulics and Automation emerged and started to become a key player in the industry's innovation

process. There has been an ongoing conversation between industry and the university for decades, and as such the relationship is taken for granted by both the university and the industry. University-industry engagement has been sustained through joint research projects, problem-solving for industry, and through the back-and-forth flow of students between TUT and local companies. There is mutual recognition of the value of being engaged with each other.

Informal institutions, which also come from a shared historical trajectory of organizations and individuals in the region, facilitate open engagement. As argued before, informal institutions affect the permeability of organizational boundaries. When practitioners know each other, share a common language, and have a common professional background, and in addition do not compete in the marketplace, the boundaries are permeable. "In Tampere", a practitioner said, "it is rather easy to discuss and there is an open attitude." In Tampere, without these informal institutions, it is less likely that any of the policies that exist to promote conversation across boundaries would work. Steps would be needed first to build the confidence among potential conversation partners. In Tampere, the common background of many senior managers, coupled with the role of TUT in educating the majority of engineers in the industry for several decades, both creates and renews social networks, fertilizing the ground for collaboration across boundaries. Without a common background, and if they did not know each other, it is unlikely that practitioners in industry would be willing to talk to each other openly and interact in the spirit of trust and openness and disclosure that characterize a fruitful interpretive conversation.

Beyond a shared history and the informal institutions that facilitate a close university-industry partnership, accounts from both academics and practitioners suggest that the innovation process in the industry and the knowledge base, educational and research process in the university are *compatible.* Several aspects of university-industry compatibility emerge from this study.

First, there is an evident match between the knowledge base of the industry and the research and educational areas of TUT. The match exists on a disciplinary basis, such as the specific capability of TUT to do research and educate engineers in mobile hydraulics and automation. The lack of a match between the university and MekAutomation was one of the reasons why MekAutomation looked for support elsewhere. An emerging match in control theory with the university's expertise was cited by MekAutomation's executive as opening possibilities for further engagement. There is also a match along the engineering continuum. Local companies are engaged in the full spectrum of activities from concept development to implementation, hence enabling a relationship with the university across the full spectrum. It they were doing only problem-solving or optimization of existing products, it is unlikely that the relationship would be of interest to the university or satisfy the requirements of a comprehensive engineering education. This issue will be discussed in the next chapter.

Accounts from practitioners and academics suggest that nurturing interpretive spaces and university-industry interpretive conversations require the same conditions that enable companies themselves to do so: flexible or open-ended goals and a desire to explore, a long-term time horizon, and being mindful and inspired by but not restricted by existing

products or market needs. I suggest that a key to a functional university-industry relationship in this specific case study is a match in expectations and awareness in both industry and TUT (but particularly on the part of some senior industry practitioners) that university-industry relationships are most creative and valuable under these conditions.

A final, key enabling condition for university-industry interactions is compatibility between the collaborative culture of local industry and the public nature of the university. The university is an inherently *public* space. What this means is that a research unit inside the university can have relationships with multiple companies at the same time. The interpretive conversations and problem-solving interactions taking place inside a research unit (and the university as a whole) are public. Their creative and problem-solving potential is enriched through the ability of academics and students to talk to each other in an environment of openness and collaboration. Because companies in the industry share a common knowledge base but operate in different market niches appropriability concerns during the very early stages of innovation are reduced. If companies were too worried about preserving their ideas, they would be unlikely to engage the university as intensely as they do, whether it is to explore new ideas or to solve specific problems, because they would be worried that their secrets would leak through the university.

4.6 Discussion

This case suggests that a fundamental contribution that TUT makes to local machinery companies, interdisciplinary integration, hinges upon its ability to engage in conversations across disciplinary and organizational boundaries in a spirit of openness

and collaboration. It also hinges upon its ability to be an interlocutor in interpretive conversations with many industry practitioners. Furthermore, it suggests that the integrative abilities of engineers educated in TUT hinges upon its participation in activities along the spectrum from concept development to implementation.

The most important challenge that TUT faces in its relationships with industry is to manage both interpretive conversations and problem-solving interactions. Doing this calls on TUT to manage the conflicting demands associated with work in the duality of innovation. It is important for TUT to protect interpretive spaces. A warning sign in this respect came from one research unit at the university. In discussing how this unit engaged companies that are competitors in the marketplace, it turned out that limits were set among researchers and students on what they could talk about. The research group created separate project teams who, in the words of the interviewee, "were only allowed to talk about the weather" to each other. This does not mean that TUT should not have clear mechanisms to manage university-industry partnerships that require attentiveness to the disclosure of sensitive information. But if interpretive conversations are enriched by the openness of interlocutors, one can imagine the consequences of more pervasive barriers to conversation.

The second challenge for TUT is to balance its mission-orientation towards local industry with the ambiguity, open-endedness, and long-term perspective that makes it a creative agent not just for the mechanical engineering industry, but for the local economy as a whole. The IHA is an example of how having a research portfolio ranging from basic to applied is a way to manage this tension. But in this case, even long-term

oriented research is mindful of market needs and of existing products. This is necessary to enhance innovation in a mature industry like machinery. The question is whether too much focus on market needs would enable the creation of completely new product architectures. The challenge is thus to balance proximity to industry needs with being far enough from the market to enable the university to make its contributions as an agent that enhances the ability of companies to envision alternative products, product architectures and even new markets. This is a usual focus of science-based fields such as biotechnology. How to do it for a mature industry is an open question. The point is not to do one or the other thing exclusively. TUT's continued contributions to the machinery industry come form its ability to operate across the spectrum.

Senior executives, policymakers and engineers in Tampere's machinery industry under study saw the university as a space for innovation accessible and compatible yet separate and distinct. They appreciated the closeness between the research agenda and the content of engineering education at TUT and the needs of local companies. However, some industry executives pointed out that the university had distinct capabilities –by virtue of being a university– that made the university a valuable partner in their innovation process.

> It is important that there are differences between the culture of the university and the company. Universities need to focus on doing R&D and not product development for the companies. Companies are paying for applied R&D, but they need to invest more in basic R&D too. Technology development cannot happen without it, you have to go all the way from basic R&D to applied R&D to product development. All the levels are needed. (Company)

Practitioners emphasized the ability of the university to focus on the long term and how this contributs to their own ability to maintain a long-term perspective. "If you focus only on short-term product development most likely you cannot go on for very long. You totally miss new ideas. So this difference between companies and universities is good." (Company). Similarly, they were aware that most engagements with the university whose purpose is not to solve problems or acquire technology, but rather to come up with new ideas, were open-ended and often take them to unexpected places. "In the cases when you do not get to where you thought you would get, you might get something else. In the long run failed projects may lead to something else. Many great innovations have appeared when the target has been something else, and that should be the role of universities" (Company).

The final reflection on university-industry partnerships relates to the effects of Tekes Technology Programs (TTPs). Seen from the duality of innovation perspective, TTPs are a vivid example of an innovation policy instrument that enhances interpretive capabilities. TTPs do this through financial incentives that motivate practitioners and researchers to create interpretive space and by promoting a series of ongoing conversations about emerging technologies. A great deal can be learned from this effect of Technology Programs for the design of innovation policies in other settings.

TTPs, however, might also have two subtle and non-quantifiable undesirable effects. First, TTPs highlight *specific* themes for conversation and product development. While participating academics and practitioners are free to formulate a myriad of possible projects within a TTP umbrella, they start out with a specific technological orientation, as

broad as it might be. As diverse, varied and temporary as they are, do TTPs thematic conversations reduce the ambiguity that is required for radical innovation? The second undesirable effect comes from the allocation of TTP funds to projects of limited duration. The focus on funding projects is also a valuable lesson from Tekes for other policy settings. In the specific case of Tampere, the reinvention of the mechanical engineering industry as a whole may be seen as the cumulative effect of a stream of successful projects. Funding projects is clearly important to motivate innovation and make the jump from concept development to implementation. However, does a focus on projects as the main organizing unit for innovation to which TTPs allocate money promote a shorter-term orientation than that which is required to preserve the ambiguity necessary for radical innovation?

These two questions merit further reflection, if not a radical reexamination of Technology Programs as a policy instrument. Tekes, as a funding agency whose goal is to translate technological innovation into competitiveness and economic prosperity, is admired in policymaking circles for its pragmatic approach to innovation policy. These two questions suggest, however, that it is important to examine other aspects of Finland's institutional set-up for innovation to ensure that the application-oriented approach of Tekes is complemented with enough funding for basic research from the Academy of Finland. In the words of a business executive from Tampere: "Technology development cannot happen without it; you have to go all the way from basic R&D to applied R&D to product development. All the levels are needed."

5 Speed Matters: Innovation in the NASCAR Motorsports Industry

5.1 Introduction

If you live in the United States and turn on the TV on Saturday night or Sunday afternoon between February and November it is very likely that you will run into the NASCAR racing series. Colorful cars covered with corporate logos race neck-and-neck around racetracks ("speedways") in major locations around the country. The cars compete for several hours covering distances totaling as much as 600 miles at speeds that top 180 miles per hour. NASCAR, the National Association of Stock-Car Auto Racing, is the sanctioning and organizing body of the NASCAR racing series.[1] Today the NASCAR series is the second most popular spectator sport in the United States after football and the fastest growing in terms of attendance and television audience.[2] What started as a hobby in the American Southeast has become a multi-billion dollar industry of national reach at the intersection of entertainment, sports, and automotive technology. As an industrial activity, NASCAR racing belongs in the broad category of automotive motorsports.[3] Motorsports is the practice of running motor vehicles against each other in a race with the goal of winning.[4]

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[1] NASCAR was established in 1948 by Bill France, and has since then been headquartered in Daytona Beach, Florida. Before NASCAR, aficionados raced their cars against each other in informal and loosely organized races. NASCAR created an institutional identity, a brand name, a standard set of rules and a level playing field where interested teams could participate as long as they followed the rules and had the resources to enter the competition.

[2] According to data compiled by Richmond Gage from Rowan Cabarrus Community College in Concord, NC, TV audience of the Daytona 500, the most popular race of the NASCAR Series, increased from 8.25 million in 1997 to 12.5 million in 2006.

[3] In auto racing, other motorsports include Formula One, the Indy Racing League, the A1 Grand Prix, Drag Racing, and others. Each of these racing series is regulated and promoted by a different sanctioning body. Motorcycle and motorboat racing are also modalities of motorsports. The automotive motorsports industry started to develop in Germany, Italy, and Britain after WWI. In the United States, with the exception of the

NASCAR motorsports is an innovation-intensive industry. NASCAR places tight constraints on the technological avenues that teams can explore. Examples of these constraints include a prohibition on the use of electronic devices and a mandate to use carburetor, not fuel-injection engines. But within the rules, incremental innovation has dramatically improved component and overall car performance. Changes might only be in the details, but change is quick and continuous. The following account from a practitioner captures this well:

> It's a constant evolution. We are very technology driven, like computer companies we have added more processing power, more storage space. We have added more RPMs and increased the durability of engines. You see other things evolve and what we do can change very quickly. There is very little that remains the same from year to year. Some parts of the engine involve a heavy investment to change, and you can be sure that 6 months from now things will be different. (Team)

This continuous search and discovery yields a stream of modifications that, added together over time, make a significant difference in performance. Teams rely on better engines, cylinders, materials, tire compounds, brakes, and so on. Since the early 90s, understanding and improving aerodynamic performance has become a critical element of their competitive strategy. Top speeds have increased from around 140mph in 1960 to

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Indianapolis 500, the motorsports industry did not begin to develop until around 1950. During the 20th century motorsports clusters around the country were anchored by racetracks. Proximity to racetracks allowed competitors to quickly test new developments in conditions close to an actual race. Four auto racing clusters emerged in the United States: sports car road racing in New England, open wheel oval track racing in the Midwest, drag racing in Southern California, and stock car oval track racing in the Southeast. During the 20th century these clusters were anchored by race tracks: drag strips in Southern California, road race courses in New England, the Indianapolis Motor Speedway in the Midwest , and stock-car oval tracks near Spartanburg SC and Charlotte NC (Williams, 2003).

[4] While some observers debate whether motorsports is actually a sport, NASCAR teams are in many respects analogous to a team in other sports like football and baseball. All practitioners inside the industry refer to it as a sport, but the fact is that some aspects of stock-car racing look more like a sport than others. Drivers and their pit crews at the top of the series are professionally trained athletes. The organization of stock-car racing in various leagues ranging from amateur to professional resembles the hierarchical organization of other sports in leagues and divisions.

around 200 mph today, and they would be higher were it not for the restrictions on innovation placed by NASCAR. From its roots in the original Chevy Small-Block Engine, which had an output of 162hp, after successive generations and gradual improvements, engine output today has reached approximately 800hp, with some reports saying it is as high as 900 hp. In the 1980s engines operated in the 7000 rpm range. Today they operate as high as 9200 rpm.

The driver of innovation in the industry is competition. Every team has virtually the same technology and the cars race against each other every Sunday for 36 weeks a year in what teams call a "leveled-playing field." In an attempt to be better at innovation and become more competitive, the nature of the industry has changed enormously over the past two decades. The three major changes are specialization, the reliance on engineering, and the adoption of advanced simulation, testing, and manufacturing technologies. Specialization is manifest in a more fine-grained division of labor inside NASCAR teams that mirrors virtually every car component or critical performance area (like engines, shock absorbers, and aerodynamics) with specialized individuals and functional units. The reliance on engineering has transformed the employee mix, the relevant knowledge base and the innovation process of NASCAR teams. NASCAR motorsports used to be populated by craftsmen whose knowledge and skills were primarily learned through experience. Experience and craftsmanship remain critical to the sport, but since the early 1990s engineers with college and graduate degrees have

been hired and play increasingly important roles within NASCAR teams.[5] Unlike

Formula 1 racing in Europe, where cars are infused with sophisticated electronics, data

acquisition and control systems, NASCAR rules preclude teams from using these

technologies in the race itself. But these and other sophisticated tools have become

critical to the innovation process. The combined effect of engineering, IT, and advanced

manufacturing technologies has enabled teams to open up more avenues for change and

experimentation, to solve problems more systematically, and to implement changes as

fast as possible.

The NASCAR motorsports industry is geographically concentrated in the region

around Charlotte, North Carolina.[6] To all effects Charlotte is a motorsports industrial

district or industry cluster. The region has been recently called "NASCAR Valley."[7]

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[5] In addition, the teams' increased use of more technically sophisticated tools and methods has prompted the creation and arrival of new businesses. Engineering-based suppliers and service providers like wind tunnels, prototyping, manufacturing, simulation and data acquisition systems have sprung up.

[6] In its early years stock-car racing developed as a distinctively Southern endeavor. According to popular accounts, stock-car racing was born when 'moonshiners' trafficking liquor drove from place to place in the Southeast. To outrun the police, IRS agents, and sheriffs, the moonshiners would "soup up" their cars – modify the engines in order to go faster, and especially faster than law enforcement officers (see Gabbard, 2000). The role of illegal liquor trafficking in the growth stock-car racing has been disputed on the grounds that in the American Southeast auto racing began to be actively promoted early in the 20th century, well before the moonshining period (Hall, 2002). In the early days the races took place on dirt roads not built especially for racing, but racetracks later started to appear throughout the Southeast. Stock-car racing grew around oval tracks near Spartanburg, SC and later the Charlotte Motor Speedway (Williams, 2003). Charlotte, North Carolina, has been the hub of stock-car racing since the early days of the sport. The first racetrack in Charlotte, located off Route 26 in Pineville (10 miles South of center city), staged its first race on October 25, 1924. It was a 1.25 mile oval constructed of green pinewood, situated adjacent to the railroad. The speedway deteriorated and never reopened after 1927 (Fielden, 2000). On June 19, 1949, Charlotte hosted the first NASCAR race in what was then called the Strictly Stock Division (antecedent of today's NEXTEL Cup Series), bringing together 33 drivers to compete in the dirt track on Wilkinson Boulevard (Singer and Sumner, 2003).

[7] The stage for the formal growth of the sport in the region was set with the construction and opening of the Charlotte Motor Speedway in 1960, known today as the Lowe's Motor Speedway (LMS) (Fielden, 2000). H.M. "Humpy" Wheeler and Bruton Smith, founders of the LMS are prominent examples of how individual entrepreneurial energy and vision have been instrumental throughout the history of the sport. Several teams and suppliers set up shop near the Speedway facilities, partly because of the convenience of

What Hollywood is to the movies, Charlotte is to NASCAR. The industry is anchored by

a high concentration of professional motorsports racing teams, which are organizations

"primarily engaged in the research and development, design, manufacture, repair,

maintenance, and operation of motor vehicles used in live motorsports racing events

before a paying audience."[8] Approximately 90% of professional NASCAR teams are

located within a 50 mile radius of the Charlotte region. In addition to the teams, there is a

highly diversified amalgam of businesses, with firms accounted for in 40 different

NAICS codes (Connaughton, Madsen et al., 2004).[9] In the Charlotte region alone, there

were approximately 450 motorsports related businesses in 2004 (Charlotte Regional

Partnership, 2004).[10] The highest concentration is in the towns of Mooresville in Iredell

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being close for testing purposes. Suppliers located there because they were near the teams. Before NASCAR motorsports had national reach, most races took place in racetracks that were within a 2 to 3 hour drive of Charlotte, and this convenience is often cited by practitioners as an incentive for teams to locate there in the early days of the sport. Today, however, with the national scope of the business, logistics is no longer a reason for teams to be there. Charlotte is no longer the geographical center of the sport. NEXTEL cup races are held as far away as Sonoma, California and Loudon, New Hampshire.

[8] As defined by the General Assembly of North Carolina in House Bill 2170. Ratified on July 26, 2006. Source: North Carolina General Assembly.

[9] Entrepreneurship has been an important driver for growth, with many businesses created by individuals who have left previous jobs in the industry, often with teams, to start their own businesses. As the industry has expanded, it has also attracted national and international suppliers of parts and services to the region. Examples include Goodridge, a UK-based producer of specialized hose and fittings that came to Mooresville "strictly to be close to the motorsports teams", in the words of its manager. A similar case is PI Research, a UK-based data acquisition systems provider specializing in motorsports. Several marketing firms have recently opened local offices to cater to the motorsports industry.

[10] Teams rely on a localized network of specialized suppliers that range from small shops to large distributors and manufacturers of automotive and racing equipment. Technical service providers have also sprung up around the teams, such as wind tunnel operators and specialized engineering and training services. Commercial services providers include for example sports marketing. Some of the teams outsource the management of their marketing and sponsorship programs to specialized marketing firms. The entertainment side of the business includes both infrastructure and media. The main players on the infrastructure side are the speedways. The region is home not only to the Lowe's Motor Speedway, but also to its parent company Speedway Motorsports, which owns and operates six speedways around the country. On the media side the region is the home of specialized publications, magazines, radio programming and production and television production and broadcasting. SMI owns the Performance Racing Network, which produces and sells syndicated motorsports programming around the country. The Speed Channel, a cable network specialized in motor sports is also based in Charlotte.

County ("Race City, USA") and Concord in Cabarrus County ("the Center of American

Motorsports"). [11] According to Connaughton and Madsen (2006), the economic impact

of the motorsports industry on the economy of North Carolina in 2005 was $5.9 billion,

up from $5.1 billion in 2003. Within the Charlotte Regional Partnership economic

development region, the total economic impact was $4.5 billion, or 77 percent of the total

impact on the state economy.[12] Statewide, the industry generated approximately 27,200

jobs in 2005, up from 24,400 in 2003. 19,800 or 73 percent of motorsports' total

employment in North Carolina is within the Charlotte Regional Partnership region

(Connaughton and Madsen, 2006).

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[11]The industry is heavily agglomerated in the counties of Cabarrus and Iredell, respectively to the Northeast and North of Charlotte. In Cabarrus County, whose motto is "The Center of American Motorsports", the concentration in the town of Concord developed around the Lowe's Motor Speedway, which continues to be a focal point for the industry and its economic impact. More recently the Concord Regional Airport has become a transportation hub for teams and several have moved nearby. Although the cars and equipment are shipped by truck to each race, some personnel fly to each race location week by week. Mooresville, nicknamed "Race City, USA" is home to several dozen suppliers and race teams. The town had no significant relationship to motorsports until the late 1980s. According to 2003 data supplied by the local Chamber of Commerce, there were approximately 60 stock-car teams and 100 racing related suppliers. (Mooresville Chamber of Commerce, 2003). The economic impact for Mooresville and Concord is substantial. In 2002 approximately 385,000 fans attended three Winston (NEXTEL today) Cup races in the Loews Motor Speedway. It has been estimated that the speedway and the race events generate around 275 million USD annually in Cabarrus, Iredell and Mecklenburg counties. About 75% of this was spent by fans in local businesses. Nicknamed "Race City, USA", Mooresville is located to the South of Iredell County and about 20 miles North of Charlotte city center along Interstate 77.

[12] North Carolina is divided into seven economic development regions designated by the North Carolina Department of Commerce. The Charlotte Regional Partnership includes 12 counties, including Cabarrus, Iredell, Rowan, and Mecklenburg, where the majority of motorsports companies are located.

Figure 5-1 Dots show the location (2002) of professional NASCAR teams competing in the NEXTEL Cup (previously Winston Cup) and Busch Cup Series. Some teams have relocated since then but stayed within the Charlotte Region. Source: The Charlotte Observer, October 10, 2002.

For decades the NASCAR motorsports industry flourished in Charlotte under the eyes of civic, business, and government leaders who were either not aware of the industry or looked down on it. The uptake of engineering knowledge and technology by the industry in the last two decades occurred without research and educational support from local universities, community colleges, public research institutions, or policy agencies and until very recently without supportive public policies to support business development and innovation. The industry was offered none of the tax incentives for research and technology development, university-industry technology transfer incentives, targeted

public investment in research, and the like. Such supports for business development and innovation are common in other industries.

More recently this has begun to change. The Charlotte region has become conscious of the industry and its importance to the local economy and the local government and business communities have become increasingly active in trying to support the industry.[13] Two types of initiatives have started to emerge: economic incentives and institutional support for innovation. Progress has been made in providing economic incentives in the form of tax concessions.[14] When it comes to institutional support for innovation, efforts have included the popular measures among local policy makers, business, and higher education leaders to enhance the region's capabilities for technology-based economic development by building closer linkages between higher education and the industry,

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[13] In the last two or three years recognition of the industry has developed very rapidly. A key catalyst in this process was the North Carolina Motorsports Association (NCMA), founded in 2001. Following a study of the American motorsports marketplace done by the UK Motorsports Industry Association (see MIA, 2002), the NCMA commissioned economic development and industry cluster studies (see Connaughton, Madsen et al., 2004; Sanford Holshouser, 2004) whose results brought widespread media and policy attention. The founding of the NCMA and government recognition was catalyzed by NASCAR's threat of moving one or two major racing events away from the Lowe's Motor Speedway. The efforts of state and local governments in Virginia and South Carolina to attract motorsports businesses were also a warning to local business, government, and industry leaders. Today the Charlotte Regional Partnership (a public-private organization promoting business development in the region), the Charlotte Chamber of Commerce, the North Carolina Department of Commerce, and the North Carolina General Assembly recognize motorsports and have specialists or working groups focused on the industry. A visible example of the region's embrace of the industry unfolded in 2005. In that year Charlotte competed against five other cities to host the NASCAR Hall of Fame. With the motto "Racing was built here, racing belongs here" and citing Charlotte's strengths as "NASCAR Valley" (the Silicon Valley of American motorsports), a coalition of civic, government, and business leaders pushed forward Charlotte's successful bid, which included close to USD 150 million of public funds. The NASCAR Hall of Fame, which will be owned by the City of Charlotte and is scheduled to open in 2009, will be located in center city (known as Uptown to the locals). In a symbolic development, an industry that flourished in the outskirts of Charlotte is now prominently represented side-by-side with the city's vibrant banking industry Uptown.

[14] Local governments in Mooresville and Concord started early to provide tax advantages for new or growing motorsports businesses since the mid 90s, before the industry gained widespread recognition. The North Carolina General Assembly recently passed several bills providing tax incentives and credits specific of motorsports businesses and NASCAR teams and enabling the use of public funds for the NASCAR Fall of Fame.

focusing on professional NASCAR teams. Since the mid 1990s, the University of North Carolina at Charlotte (UNCC) and some of the community colleges have built up research and educational programs in motorsports technology and management. In the process they have tried to establish closer linkages with the industry on their own initiative. In 2004 an initiative of civic, government, and even motorsports industry leaders was to create the NC Motorsports Testing and Research Complex ("test track"), a grand vision to support and retain the industry by building a USD 50 million research and testing complex. A key element in this initiative, which was to be managed by UNCC once in operation, was to make UNCC an active and involved player in supporting of the industry's innovation process and retain it in the region.

These initiatives to bring the university and the NASCAR motorsports industry closer together have not worked.[15] They have not been harmful to the industry, but nor have they had any substantive impact on the industry's innovative capacity or its ability to take up new knowledge and technology. UNCC's own efforts to build research and educational ties with the industry, which started in 1998, are valued by the industry but continue to be small in scale and scope. In the case of the test track, a feasibility study that got underway in the second half of 2004 concluded in February of 2006 that a research and testing complex was not what NASCAR teams needed or wanted.

Compared to the prominent role that the Tampere University of Technology has historically played in enhancing the innovative capacity of the machinery industry in

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[15] Section 5.5 will discuss the underlying reasons for the struggles to build a close university-industry interaction.

Tampere, Finland (see Chapter 4), the prosperity of Charlotte's NASCAR motorsports industry cluster appears puzzling for at least two reasons. First, the industry has become more innovative and absorbed new technology despite the absence of a local university's support, which is often associated –at least in theory– with the growth and prosperity of an innovation-intensive industry cluster. And second, efforts to build a close relationship between NASCAR teams and the most important research university in the region, UNCC, have either not taken off in any substantive way and, as in the case of the test track, have failed outright. The goal of this chapter is to shed light on these puzzles by presenting the results of an inductive and empirically grounded case study of the innovation process in the NASCAR industry located near Charlotte, NC. This study considered three research questions:

- How do NASCAR teams innovate?

- Which external organizations affect the innovation process in NASCAR teams, what is the nature of the interactions, and what effects do they have on the process?

- Why have NASCAR teams and UNCC struggled to build a university-industry relationship?

The unit of analysis of this study is the innovation process in professional NASCAR NEXTEL Cup teams, the top of the league and the most professionalized and sophisticated racing organizations in the industry. The core empirical data for this study consists of 60 semi-structured interviews conducted during three rounds of fieldwork in February, April, and November 2003, and an additional round of telephone interviews

conducted towards the end of this research during July and August 2006.[16] The final data

collection for this study took place on September 17, 2006, and involved close

observation of the work of NASCAR NEXTEL Cup teams at the New Hampshire

International Speedway in Loudon, NH. I spent three full days immersed in the garages

and at the pits during races, observing preparations and practice sessions on Friday and

Saturday, and the race, activities in the pit stops, the post-race inspection and wrap-up of

activities at the end of the day on Sunday.

Following the logic of the previous chapter, I approach this investigation by first

providing an overview of the technology of stock-car racing and opening up the black

box of the innovation process in NASCAR motorsports. I then explore how a supporting

set of organizations specific to the industry affects the ability of NASCAR teams to

innovate by enhancing their innovation processes. After examining into the nature of the

innovation process and the type of innovation support that NASCAR teams receive from

other organizations, I then examine how the nature of the innovation process in the

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[16] The first round of fieldwork consisted of exploratory interviews, mainly with university faculty and administrators and local civic leaders, and was organized with the support of the Office of the Chancellor of UNCC. This round led to the selection of the NASCAR motor sports industry as the focus of the study. The second round of fieldwork focused on developing a grounded understanding of the industry and of cluster-level innovation processes, including an exploration of the role of UNCC and local community colleges. Interviews included practitioners in several NASCAR teams, suppliers, local economic development officials, as well as academics from the university. The third round of interviews focused on developing an understanding of firm-level innovation processes. 20 of the early interviews were conducted together with Kimmo Viljamaa, a researcher from the University of Tampere, in Finland. Interview data has been validated via triangulation and complemented by the rich popular press and aficionado accounts of NASCAR, which capture in great detail much that goes on in the industry, from gossip about drivers to the latest advances in engine technology. Brochures, publications, and other documents collected during the fieldwork were also valuable sources. In addition, the Charlotte Observer (major local newspaper) and the Charlotte Business Journal, through their online access, were also important sources of insights to keep abreast on industry developments between 2003 and 2006.

industry makes the university-industry relationship problematic in this case and, at least in the way the industry works today, perhaps even unnecessary.

5.2　Overview of technology and organization

The term "stock-car" dates back to the early stages of NASCAR racing. It referred to cars that had not been modified for racing and whose owners also used them for regular transportation. While stock-cars look similar to street cars, they are radically different. Other than the name, stock-cars have little resemblance to street models.[17] A stock-car has no door, so drivers climb through the window opening to get in. The windshield is in three sections and is made of a shatterproof plastic. The lights and headlights are not real; they are decals. Inside there is just one seat, and the gauges and systems have nothing to do with regular cars. Unlike commercial vehicles, for example, stock-cars use carburetor engines.[18]

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[17] NASCAR Nextel Cup and Busch Series teams run Dodge Charger, Chevrolet Montecarlo, Ford Fusion, and beginning in 2007, Toyota Camry. Crafstman Series run Chevrolet Silverado, Dodge Ram, Ford F-150, and Toyota Tundra. NASCAR has to give approval to an OEM's "submission" of a model to compete in the sport.
[18] The main difference among racing series from a technical standpoint is the type of vehicle. Formula One and CART, among others, use *open wheel cars*, in which the wheels are exposed and located outside of the car's body. The vehicles in NASCAR are *stock-cars*.

Figure 5-2 The front of a stock-car. Shown Dale Earnhardt's Jr., #8. Author's Photograph. September 15, 2006. Loudon International Speedway, Loudon, NH.

Figure 5-3 Side view of Dale Earnhardt Jr.'s Car #8. Author's Photograph. September 15, 2006. Loudon International Speedway, Loudon, NH.

Stock-cars are not mass-produced like regular cars in an assembly line. NASCAR teams manufacture and maintain stock-cars in race shops, which are the facilities where all the equipment necessary for the manufacturing and testing of the car and its diverse

components is located. They Building a stock-car starts with the chassis, which is assembled on a "jig." After a team buys or builds the chassis, the body goes on. The body consists of pieces of metal carefully cut and shaped. The pieces are "hung" – riveted and welded – onto the chassis by hand. In the body shop the surface of the car is smoothed out, checked for gaps and holes, degreased, painted, "baked" several times, and thoroughly checked for integrity. The sponsorship and number decals are then added by hand. With the chassis and the body complete, the teams begin mounting suspension components and the drive train, and equip the cockpit with the seat, the gauges and safety equipment (Burt, 2002). Finally, the engine and the transmission are installed. Building a car takes about five weeks, or approximately 1,000 work hours (Team).

Each car-team prepares between 12 and 15 stock-cars to run per season. Stock-cars are different depending on whether they are running in the NEXTEL Cup or the Busch Series, and are also customized according to the type of racetrack and specific race conditions. Cars have a different "setup" depending on whether they will be used in a super speedway (more than two miles long), an intermediate track (one to two miles long) or a short track (less than one mile long).[19] Each of these tracks places different demands on the car, and hence the different setup. Before each race a car team will "dial in" setup adjustments to achieve optimum performance. During a race the driver is in

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[19] The set-up is "the combination of engine power, handling ability, braking ability and aerodynamic qualities of the car" (Burt, 2002, p. 49). Teams arrive at the racetrack with an initial setup, but this may be adjusted during pit stops based on driver input about how the car is behaving. A set-up includes, to name a few adjustments to specific parameters, changes to shock absorbers and springs, tire pressure, brakes (short-tracks place higher demands on the brakes), and body and spoiler adjustments to alter aerodynamic flow (Martin, 2000; Burt, 2002). The engine is "tuned" before the race starts, also according to known and predicted race conditions.

constant radio communication with his crew, and his feedback on the car's behavior is used to make minor adjustments during pit stops.
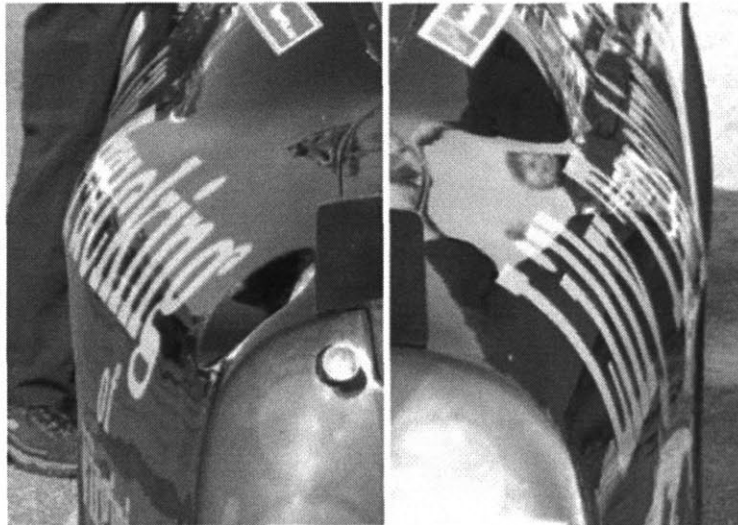
Figure 5-4 Teams use slightly different cars for different racetracks. Variations in the car's "set-up" include body shape. Notice the difference between the left and right sides of the rear of this car. As part of the aerodynamic setup of for this race, there is a "bump" on the left side of the car. Author's photographs. 9/16/2006. Loudon International Speedway, Loudon, NH.

The heart of a stock-car is the engine. Most teams build their own engines, but some teams buy them or lease them from other teams or specialized manufacturers. For the NEXTEL Cup, the engines are limited to 358 cubic inches. They run around 16 to 1 compression with an output of up to 900 hp at up to 9000 rpm. The four main blocks are manufactured by the race divisions of manufacturers, while many other components of the engine, such as the cylinder, are manufactured by NASCAR teams in their own facilities or by specialized racecar engine manufacturers. According to one practitioner, it takes approximately 160 hours to put a new engine together from scratch.

The basis of most stock-car racing engines is the Chevrolet Small-Block (SB) Engine. The basic engine architecture of the SB was introduced in 1955. The original engine had an output of 162 hp. The production engine topped 375 hp. GM made its first major revision of the SB engine when in 1998 it introduced the Small-Block, Second Generation Engine (SB2), designed specifically for NASCAR. In the 80s, Winston Cup (predecessor of today's NEXTEL Cup) engines ran somewhere in the mid 7,000 rpm range. With continued development, that has risen to around 9,000 rpm on super speedways. The engines of Robert Yates, one of the most famous engine builders in the industry, have been reported to run at up to 9,200 rpm (Martin, 2006). Output reaches 900 hp, building on the same basic architecture (Fasola, 2006; Lemasters Jr., 2006).

As an example of the size of engine operations in major teams, consider Hendrick Motorsports (HMS). HMS builds or rebuilds 700 engines per year with an engine-department staff of 82. During 2005 HMS rebuilt 12 to 15 engines a week. The Hendrick Engine Department consists of 20 engineers and 100 engine-shop employees.[20] It takes about 120 hours to build a new engine and 40 hours to perform routine maintenance and cleaning. Iron engine blocks and aluminum cylinder heads are supplied by General Motors. The approximate cost of a new open engine is $45,000 and $65,000 for a restrictor plate engine.[21] Rebuilding costs about $28,000 per engine. Teams take

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[20] Sources: http://www.hendrickmotorsports.com/, Interviews
[21] Open engines are those in which the air intake is not restricted. Restrictor plate engines have the air intake limited with a *restrictor plate* in order to limit power output and speed. Restrictor plates were introduced for use in super speedways for safety reasons. Prior to introduction of restrictor plates stock-cars in superspeedways would reach speeds around 200 mph. After several major accidents, NASCAR decided on the restrictor plate as a way to limit how fast cars could go. NEXTEL Cup races at the Talladega Superspeedway (Talladega, Alabama) and Daytona International Speedway (Daytona Beach, Florida) are restrictor plate races. Open engines are used in all others.

three engines to the track each weekend: one in the primary car, one in the backup car, and one engine as a spare (Lorincz, 2006)

Since the early 1990s engineering has transformed NASCAR motorsports and the ability of NASCAR teams to innovate. Several practitioners suggested that this transformation was catalyzed by the success of Alan Kulwicki, who made history as the first engineer to become a successful driver. Having entered the sport in 1985, he was Rookie of the Year in 1986 and won the Winston Cup in 1992. He is credited in the industry for having "won by brains, not by strength" and for bringing a more systematic way of thinking to the design and manufacturing of the cars and the organization of stock-car racing teams. Today's major teams have created specialized engineering and R&D departments. In addition, the teams' increased use of more technically sophisticated tools and methods has prompted the creation and arrival of new businesses to the region. Engineering-based suppliers and service providers like wind tunnels, prototyping, manufacturing, simulation and data acquisition systems have sprung up.

Unlike Formula 1, where cars are infused with sophisticated electronics, data acquisition and control systems, NASCAR rules preclude teams from using these technologies in stock-cars. However, all of these tools can be used during design, manufacturing, and testing. Engine performance and aerodynamics are among the most heavily impacted areas. Information technology plays prominent roles in data acquisition, analysis, and access; knowledge management, product life cycle management, and simulation and modeling. Closely tied with information technology is the adoption of testing and metrology equipment, such as wind tunnels, dynamometers

and coordinate measuring machines. Advanced manufacturing technologies, such as rapid prototyping and CNC machining, enable teams to rapidly transform new designs into prototypes and actual parts.

5.2.1 Motorsports: technical and deeply human

Although NASCAR motorsports has become increasingly technology- and engineering-intensive, NASCAR racing (and all forms or racing for that matter) is a social endeavor. Motorsports is a team sport. While the driver (and sometimes the crew chief) receives most of the media and fan attention, behind him and his racecar there is a large team involved in the manufacturing, preparation, and fine-tuning, and technical support during the race.[22] Second, as important as engineering science has become in the sport, interviewees insisted that, given that every team runs virtually the same technology, what makes a difference in performance is "the human element." The ability of the individuals to adapt, work as a team and communicate well was cited numerous times as a critical variable affecting performance outcomes. In addition, despite increasing use of information technologies, "the driver is the only data acquisition system," an engineer said, since telemetry and data acquisition systems are forbidden at the track. The driver's ability to translate into words how the car "feels" and communicate that information via radio to the garage and pit crews is fundamental.

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[22] In the raceshop there are the managers, engineers, fabricators, mechanics, and multiple other craftsmen and specialists involved in manufacturing, testing, and tuning the car for each race. At the racetrack the pit crew plays a critical role in team performance, both through technical support for the car and through their ability to carry work as fast as possible. During my attendance to the Sylvania 300 race in Loudon NH on September 17, 2006, an engineer from a multi-car teams that runs four cars in each NEXTEL Cup race said that has to bring back approximately 80 people to the team's home base in Charlotte.

Figure 5-5 NASCAR motorsports is a deeply social endeavor. Above, Jeff Gordon's #24 Dupont team in pit lane right before the start of the Sylvania 300 race at the Loudon International Speedway in new Hampshire. Author's photograph. 9/17/06

The relevance of experience and the continuing importance of craftsmanship, two additional pillars of the human element in NASCAR motorsports, are discussed in Section 5.3.3.

The second, deeply social dimension of NASCAR motorsports is its entertainment side. All motorsports are at the intersection of sports, engineering, and entertainment. To describe these multiple faces of racing, Post, in his treatise about the technology and culture of drag racing (Post, 2001), chooses the word performance. "All of drag racing is saturated in the language of mechanical of mechanical technology, naturally, but slightly more so than with the imagery of the theater. The race cars come out in pairs, then they stage and prepare to perform. The very word *performance* has a delicious ambiguity...

Some conceive of performance in the context of engineering; for others the crucial referent is entertainment. The show can be as scrubby as a small-time carnival, or it can be the stuff of high drama; call it "legitimate" theater, perhaps, but it is still theater." This description might as well be used to describe stock-car racing. The car-driver duo, in a symbiosis that blurs the boundaries between human and artifact, is the main performer.

"Everything about drag racing was a human invention of one kind or another, technological or cultural. Nothing ever "evolved." (Post, 2001, p. 14). The same is true for NASCAR. Motorsports is about racing technological artifacts against each other. Engineering science, information, technology, and advanced manufacturing are critical to improve racecars. Motorsports is a team sport in which interaction, experience and craftsmanship are always be critical. The innovation process in NASCAR motorsports is deeply social. It is constrained by laws of physics and by the rules of the game. On this last point, Post's description of drag racing applies also to stock-car racing: "even though racers always grumbled about legislation as if there were no choices left, deep down they knew their choices remained "literally innumerable"." (ibid., p. 321). Human creativity, ingenuity, and a passion for both racing and winning drive the continuous improvement of racecars.

5.3 The innovation process

Innovation in NASCAR is an ongoing process. A NASCAR team's ability to innovate involves the continuous search, discovery, and implementation of ways to gain a competitive edge. The innovation process in NASCAR motorsports is driven by a single

and immutable goal: to win races. "It drives the thinking as you are testing things," a

practitioner said. This goal gives a great deal of focus to the innovation process.

> We are all here for the same purpose, whether it is myself, the team manager, the mechanic, or the driver: we are all here to try to win. Everyone wants nothing more than to win. We understand it. I need the mechanics to help, I need their help in order to win, and they understand they need their help in order to win. So whether or not we have differences, we all have that same commitment to pursue whether it's race wins or championship. In this organization that's what keeps everybody going. (Team)

The innovation process focuses even more as the race weekend approaches.

> Between now and Thursday, when we leave for the race, we can do anything. But after we leave, everything focuses on one single thing: on the race. And that is the interesting part of this job: that you get to do a lot of things for a while but then you need to completely focus on one thing. This diversity-focus matters. (Team)

This focus on a single immutable goal contrasts greatly with the previous case study,

in which innovation at the intersection of mechanical engineering and IT is catalyzed

when practitioners can imagine alternative products and markets. The stock-cars, which

are the products of NASCAR teams, are not "sold" to a market. Teams might get

sponsorship from corporations but what these corporations are buying is advertising and

market exposure, not cars. There is no market for stock-cars but the racetrack is stock-

car racing's marketplace. As an engineer put it succinctly: "Our marketplace is the race

track, and these tools allow us to get there quicker and beat the competition from a

performance and reliability stand point."[23] This proximity to their "market" during race

season creates an extreme competitive environment that drives the innovation process.

Thinking of racetracks as a marketplace means that every Sunday, for 36 weeks a year,

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[23] Brian Whitesell, in an interview for Industrial Laser Solutions, July 2004. Accessed online at ils.pennnet.com. 6/5/06.

NASCAR teams are putting out products in the marketplace and competing to see who has the best product.[24]

There, is, however, one fundamental difference between the racetrack and the market of most industries: the lack of ambiguity. Unlike the Tampere case study (and unlike most other industries), in NASCAR motorsports teams have no flexibility to think about new uses of their product or new markets for it. The focusing effects of the goal–the finishing line– drive the innovation process, directs creativity towards a single goal, and restricts (and discourages) talking about or doing anything that does not contribute to the goal. Winning races gives teams a well-defined problem to solve. Seen through the duality of innovation lens, the innovation process in NASCAR motorsports is distinctively –and extremely– analytic. It consists of solving problems, with clear goals and well defined means to achieve them.

5.3.1 Optimizing

This well-defined problem may be understood as a problem of optimization. The innovation process in NASCAR motorsports consists in the continuous optimization of an existing product, the racecar. Seen through the duality of innovation, NASCAR teams operate in the implementation phase of innovation in a process that is for the most part a problem-solving activity.

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[24] Since teams use different types of cars for each type of racetrack, having weekly races does not mean that the same car is run every week.
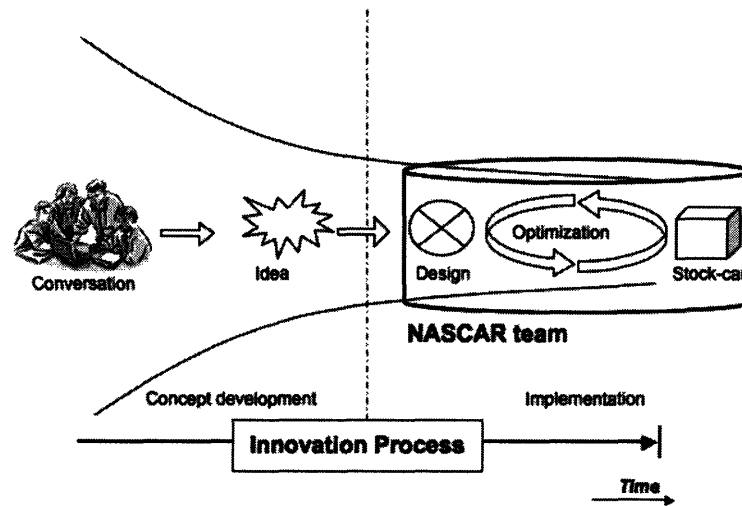
Figure 5-6 NASCAR teams operate in the implementation phase of the innovation process and have an extremely analytic innovation process, focused on solving problems

Optimization problems have three fundamental elements: an objective function, a collection of variables, and a set of constraints.[25] First, there is an objective function to be maximized or minimized. The objective function for NASCAR teams is to increase the speed and reliability of stock-cars during races. An industry executive said, echoing comments from other practitioners in the industry: "The object in racing is to beat the other cars, and therefore to beat the other cars you run faster, and the evolvement of technology has caused those cars to run faster" (Team). The second element of an optimization problem is a collection of variables whose values can be manipulated to optimize the objective. In NASCAR motorsports, these variables span every single component of the stock-car, with engine output and aerodynamics being two prominent

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[25] I use the term optimization not to talk about innovation in NASCAR using mathematical terms. Instead, the basic elements of an optimization problem offer an extremely useful set of analogies to discuss how NASCAR teams innovate. This simple characterization of optimization comes from the Encyclopaedia Britannica. optimization. (2006). In Encyclopædia Britannica. Retrieved October 3, 2006, from Encyclopædia Britannica Online: http://www.search.eb.com/eb/article-9108643

examples to increase speed, and better materials and systemic coordination among components to increase reliability. Another set of variables relate to organization, such as minimizing the time of a pit stop –a variable that became key to competitive advantage since the mid 1990s.[26] Finally, production speed is also central, such as minimizing the time it takes to modify and manufacture a component, like an engine cylinder.

The third element of an optimization problem is a set of constraints. There are two important constraints in the innovation process of NASCAR motorsports: speed, and the rules of the game set by NASCAR.

The most important constraint and key variable that affects the competitive performance of teams is speed. The business is speed and everything is going on at high speed. "In this particular sport," an industry executive said, "in order to be successful you got to be able to react quickly and that includes everything we do, whether it is building vehicles, or repairing them, or getting additional help, or hiring workers on a temporary basis, etc." (Team). Product development, testing, manufacturing, pit stops, dealing with failures, moving on to the next race are among the activities that teams constantly strive to do not only better, but faster. In the terminology developed by Fine (1998), NASCAR teams operate at an extremely high clock-speed.

The second constraint is the rules of NASCAR. The rules of the game constrain and direct the avenues of exploration and problem solving that teams can follow during the

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[26] The Wood Brothers team, the oldest team still in the competition, with Cale Yarborough its driver was able to change two tires in 21.922 seconds. In the last year of the competition, Bill Elliott's pit crew changed four tires in 16.725 seconds. Today teams look for less than 14 or 13 second pit stops. Source: The New York Times, August 15, 2006.

optimization process. "The rules limit our work... we have to operate within them but how we get better is only a matter of skill and imagination." Throughout design, manufacturing, and testing, stock-cars are subject to the performance and design parameters set by NASCAR. "In this industry it is always a balancing act between technology, regulation, and production" (Team).

During race weekend NASCAR does a pre-race inspection, which as of September 17, 2006 involved 147 inspection points of all cars before certifying them for competition. 33 "templates" are used to ensure the body of the car meets regulations. Cars are inspected before qualifying, after qualifying, before the race, and the top performing cars are also inspected after the race. Inspections begin in some specific areas of the garages, where teams haul their cars for measurement and other aspects. The final inspection happens right before the cars enter the track, to be parked in the pit lane before the race itself begins. That inspection focused on the body and the tires, primarily. Team members carry with them some tools in case they have to make changes at that point to meet the regulations. I observed, for example, how a NASCAR inspector found something suspicious with the body of one car, necessitating that one of the crew members had to hammer the body surface until it met the requirements. NASCAR also does a post-race inspection and engine teardown of top performing cars and engines. In that way, NASCAR can find out what teams are doing differently every week and either change or create a new rule.

Figure 5-7 NASCAR officials using one of the 33 templates (as of 9/15/06) to make sure that each racecar's body meets the specifications set by the rules. Author's photograph. Loudon International Speedway, NH. 9/15/06.

I overheard a conversation at the racetrack between a team member and a NASCAR inspector in which the team member said: "So, what new rules do you have for us this week?" While major rule changes are rare during racing season, an effect of rule changes from season to season is to create new problems and to force teams to look for new solutions and avenues of exploration. As a practitioner put it: "Now that NASCAR is coming up with a rule to have only one engine, not two (one for qualifying and one for the race), we will redirect resources from building two good engines to different purposes and figure out how to do the same thing with one single engine, only do it better." (Team).

5.3.2 Experimenting

The method that NASCAR teams use to optimize racecar performance may be seen as a process of successive approximations. In numerical analysis, successive approximation involves the iterative search for a solution that begins with a guess of what the solution might be. In this context, successive approximations take the form of an iterative process of intensive and fast-paced experimentation.

Unlike the process of interdisciplinary integration described in the previous chapter, which thrived in an open-ended interpretive conversation that gradually reached a goal that was not known a priori, in this case the search for solutions involves the use of well-defined means and is targeted towards specific ends. Through an iterative and systematic trial and error process, a solution to a given problem is found or approached. This is a good way to understand how NASCAR teams innovate. Practitioners are constantly oscillating between coming up with new ideas, figuring out what a problem might be, testing, and implementation in the car and its components. The guesses practitioners make are not random. They are informed by experience and accumulated knowledge.

A crucial activity of NASCAR teams in this process is testing. Through testing practitioners try out ideas or solutions, select among alternatives, refine these alternatives, and gradually approximate the desired performance and reliability level, whether of components or of the car as a whole. NASCAR teams perform testing in every critical aspect of the stock -car by using specialized equipment, such as engine dynamometers and wind tunnels. Because NASCAR limits the number of on-track tests that teams can

perform, they have adopted simulation technologies to test ideas and component changes using computers.

The iterative process of optimization extends to race weekend. During practice sessions, the driver goes out onto the racetrack. While he is doing a few laps, he is constantly relaying information about specific problems that he feels in the car via radio back to the garage. Then, he comes back to the garage and the mechanics get to work to fine tune the problem areas that the driver identified. The driver goes again, does another few laps, and returns to the garage several times during the practice session. Even in pit stops during the race some small changes are made to the car to improve performance. The ultimate test is the race. "Performance is measured every 7 days during the race... You get to the bottom line real quick here," a practitioner said.

The process of technological change and the ability of teams to improve car and team performance is the cumulative effect of the small improvements that teams make from season to season, and sometimes from race to race, through this process of testing and successive approximations. Conversations with practitioners suggest that this is crucial to learning. A senior engineer suggested that "the problem with off-time is that you do not have that constant measuring. Some things are measurable on the track, some others are not" (Team). What seem to be short-term improvements and problem solutions, added over time, have yielded significant performance improvements and add to the stock of knowledge of the teams.
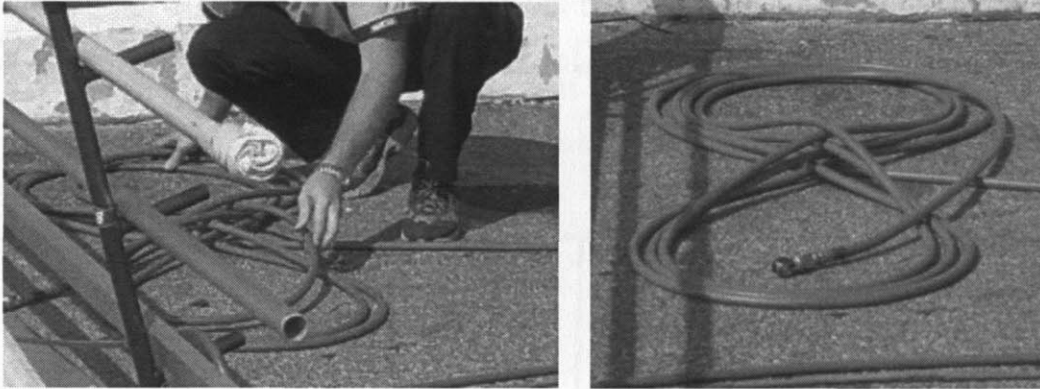
Figure 5-8 In NASCAR motorsports, the need to react as fast as possible goes to extremes. Right before the race, this crew member was arranging the hose to ensure that it would not tangle when during a pit stop, which would slow down the process. Author's photograph. New Hampshire International Speedway. Sepbember 17, 2006.

5.3.3 Transforming innovation

With time being such a critical variable for the competitiveness of teams, optimization and problem-solving needs to happen as fast as possible. To speed up the innovation process teams strive to reduce ambiguity in the generation of ideas, search for solutions, and problem solving in general. This contrasts sharply with Tampere's machinery industry, whose creativity thrives in ambiguous communication. In NASCAR motorsports effective and efficient problem solving thrives on clarity and precision: ambiguity is an enemy because it slows down innovation and problem solving.

In NASCAR teams the reduction of ambiguity involves (1) narrowing down the search space, which goes hand in hand with procuring as much information as possible during the problem solving process, (2) standardization and codification and (3) doing a more targeted and efficient search. Ideally, it would involve the instantaneous transmission of solutions so that searching would not even be necessary hence reducing

the time even further. The second strategy is, simply put, to do more iterations in less time. The three most important organizational and technological changes in the industry since the 1980s –specialization, the infusion of engineering, and the adoption of testing and advanced manufacturing technologies– have served to reduce ambiguity and speed up the innovation process.

5.3.3.1 Specializing

NASCAR teams divide their organizations into functions that mirror the car architecture and its components. Specialization deepens, targets and makes more efficient the search for improvement in different components and performance areas of racecars. The division of labor is more refined, with groups of tasks that were carried out by a single individual in the past being subdivided today among specialists. As a team executive said when I asked him how the people working within his team has changed:

> Drastically. Years ago we used to race a team with 10-20 people. Together in a 3-car team here we have 137 employees. This time a year ago we had 105 employees, so we are 32 more now than this time a year go. And because that is, number one because the technology has increased. We have 9 engineers on our staff here, where 10 years ago we had none. And not only that, you have specialists, people that all they deal with is shock absorbers, or gearboxes, or transmissions. People that all they deal with is tires, or the rear end of the car, in a particular car. (Team).

With specialization comes a problem of coordination. "Racing exploits the weakest link. We can't work around the weakest link, and that affects our day in a negative way," a practitioner said (Team). A change in one aspect of the car might have a systemic effect and teams need to ensure that the pieces fit together and meet regulations. Coordination spans both the technical and the human element of NASCAR motorsports, but the human element is key:

When you have all these elements that come together, there are these human elements that you cannot distil out. The "hard" part so to speak is the mechanical, but once that is right, as long as the motor stays together, it's ok. But with the human element everybody matters and has to work together. (Team)

It comes down to one thing that makes the difference: the people. The people that perform together better as a team win. And it is the same in football, baseball, basketball or racing. The teams that work together and perform together and work as a team, as a unit, prevail. (Team).

I inquired how the process of integration and coordination is managed. Several interviewees suggested that in this industry having a single, immutable goal helps people work together.

The one thing that you have to learn once you walk in this door whether you are a fabricator or an engine man; the first thing that they want to do is what? They all want to win. So therefore it's just a natural adaptation that they work together. Because there is one goal, and that's to win. And the only way you can do that is work together as a team. (Team)

In addition, the competition itself seems to have a coordinating effect as practitioners move towards the goal of winning a race, especially during the racing season when working transparently across boundaries is critical for the speed of the innovation process.

Competition manages it to a great extent. You cannot be managing too closely during the season. Winter is perhaps the worst time around here, when everybody is here. What makes it work is the competition. The problem with off-time is that you do not have that constant measuring. Some things are measurable on the track, some others are not (Team)

Practitioners in NASCAR teams coordinate work and technological change through ongoing, back-and-forth communication across functional, and in some cases organizational, boundaries. A practitioner whose work involved serving as an interface

between the engine group and other functional groups within a major NASCAR team described his ongoing interactions:

> I am the main liaison between the race team and the engine department. A lot of what I do here and what I deal with, are the loose ends before the engine is in the car optimized. It involves interacting with the driver, the crew chief, and the tuner. It is a two-way interaction all the time, asking questions and many things need to be communicated back and forth. Communication matters greatly. Today I do not have people calling all the time but that is how it usually is: phone calls from mechanics, crew chief, etc. (Team)

This form of communication is very different from the interpretive conversations across boundaries observed in Tampere's interdisciplinary integration process. In this case, the purpose of communication is not to blend separate disciplines. The purpose of communication is to transmit information to bring together the pieces of a puzzle. These pieces, whatever they are, are already "out there." This communication process is also iterative, but it is not an interpretive conversation. The purpose of this communication is to (1) to coordinate change across boundaries and (2) to iterate towards an optimal solution when there is a problem. Unlike an interpretive conversation, in which the goal is not known, in this case communication has a purpose and an expected end point.

To facilitate coordination across boundaries, developing a shared understanding and a clear code of communication is important for NASCAR teams. In the words of a practitioner: "if you touch this table and I touch it too, we need to feel the same temperature. If that does not happen, it doesn't work. Things need to be understood and shared and viewed with the same result in mind" (Team). An important challenge in this respect is to bring together the culture of engineering with the culture of craftsmanship, which, as I argued above, is important to the performance of teams. When I asked an

engineer from another team how to bring together the two cultures he also said that "you have to respect and understand their job, how and what they do and how your job impacts theirs from the engineering standpoint" (Team).

A senior executive, echoing other interviews, insisted on how important it is for engineers to be able communicate ideas in a way that is understandable to others and to be able to interpret what more practice-oriented individuals have to say. "You can have the best engineer in the world, if he cannot communicate that to the people setting it up in the car, what he wants, then it doesn't work" (Team). Communication is not transparent, though.

> You have to be able to "tune in" your discussion to their understanding level. They have to do the same with you. You know we are trying to develop a manual that will almost contain a language of what we talk about here so that everybody speaks on the same terms. That way an engineer doesn't call a piece one thing when in the floor is called in another, so you can all develop the same communication (Team).

5.3.3.2 Engineering

The arrival of engineers into NASCAR motorsports in the last fifteen years has transformed the innovation process in two ways. The first and most obvious one is by bringing new knowledge into the industry, expanding in that way the range of ideas and tools available for the innovation process. Engineering has been instrumental, for example, in the use of aerodynamic testing and modeling techniques, failure analysis, and sophisticated optimization and simulation techniques. But the impact of engineering goes beyond the expansion in the knowledge base available for problem solving. Equally important is what a practitioner called "the engineering mindset." Engineers have enhanced the problem solving capabilities by bringing a systematic approach to problem

solving that contributes to a more efficient and targeted search for solutions. Engineers

brought a different way of thinking and of doing things.

> Think in terms of the engineering coming in not only from the physical attributes. It's the thought process that comes in from the engineering mentality: repeatability, reliability, quality control. That's what's inbred in every engineer. Why did this test if I run it 10 different times I want it to always come back the same. If not something is wrong. The engineering process is what's coming into the sport. So think in terms not only of the physical attributes. (Supplier)

The systematic approach to problem solving has gone hand in hand with the

codification of previously tacit or uncodified knowledge. A senior engineer in a major

team said that engineering allows teams to understand and fix failures better, to do

reverse engineering, build models of things that only existed in drawings, and improve

performance in areas not clearly defined by the rules (Interviews, 2003). With engineers,

came a new language. I asked a senior executive from a major team about what

difference it made to have a car-team in which the driver is an engineer and he replied:

> I think the ability to communicate with the engineers on a one-on-one basis in an engineering vernacular discussing the problems of the racetrack like a physics problem, that's his advantage. He wants to resolve it using logic. (Team)

The systematic approach is seen in the industry as contributing to overall

competitiveness by reducing ambiguity and increasing speed across a wide range of

areas. Take, for instance, the following account about how to make pit crews work

better:

> Their body has basically to become a machine... Robots is what we want. We really do want robots that go out and do exactly the same way every time. Consistency gives you the speed. Plus good athletic ability. They have to be mentally capable to block out and to focus on the task at hand. (Supplier)

5.3.3.3 Speeding up

Another important change in the sport closely linked with the infusion of engineering science is the adoption of computer-based data acquisition, analysis, modeling, and simulation tools. These techniques have had three innovation-enhancing effects. First, they create a wealth of information and data points that inform and enhance problem solving in ways that experience could never do. They bring a fine-grained, unambiguous, quantitative understanding of performance parameters and give direction to the optimization process. Using laptops and wireless connections, teams use information technology enables teams to access data sets during races and models gathered during design and testing. Second, they enable teams may carry out virtual tests outside of the racetrack. The number of tests that teams can perform on track before a race is set by NASCAR. Teams, however, are engaged in an ongoing and intensive computer-assisted testing and modification process using modeling and simulation software. And third, they enable teams to carry out more tests in the same amount of time. I asked an engineer what he meant when he said that he "believed in simulation" and he said:

> I believe in [simulation] because I think you, because I have seen the power of it. I have seen guys rely 100% on simulation to improve their race cars and even given initial starting setups that require very little fine-tuning. I've seen guys use it during races. It speeds up the development process, it identifies, it can more quickly identify where you are weak at, and it can quickly identify where you can put your resources in, where you are gonna get the most bang for your buck. It allows you to significantly speed up the cycle and to become more efficient. In a typical race weekend you can't make many changes. You get 2 hours of practice before qualifying, and 1.5 hours of practice before the race. For qualifying you might make 6 changes, for the race, you can make, to say something 6 changes and you got to get your car perfect. Simulation allows you to more efficiently tune your car engine. It can also help you if you are lost, which happens every now and then.

Advanced manufacturing technologies (AMTs), such as rapid prototyping and CNC machining, enable teams to rapidly transform new designs into prototypes and actual parts. An example is piston manufacturing, a critical component of the engine that teams are constantly seeking to improve. It used to take months to design a piston, produce a forging, manufacture the tooling, and machine the part. With CNC machining and CAD programs, the time has been cut to weeks and even to days for prototyping (Fasola, 2006). Taken together, information technology and advanced manufacturing technology have further increased the clock-speed of the industry.

5.3.4 Blending craft and science

As important as engineering has become for the industry, however, experience continues to be key to the competitiveness of NASCAR teams.

> It is like knowing the playing field and that the terrain is not what it looks at first sight in a photo or in an image. There are things that you can only know by experience, you have to go out there. The simplest things. Nothing is really easy in the sport and experience counts greatly. There is people who know every race track, who know how to, let's say, find an exit if the door is shut. This is people who have relationships and are very important. You can use a lot of technical stuff but what really matters is what the crew chief can see and what the driver can communicate. (Team)

The systematic approach that engineers have brought into the industry enhances problem solving, but there are other situations that are ambiguous and uncertain which seem to draw on knowledge acquired through experience. "The engineers often do not have common sense... You cannot look only at numbers. Racing is very practical (Team)

Bringing together engineering with craftsmanship and experience is not trivial. One

of the most important trade magazines of stock-car racing captured this cultural divide in

the cover of its August 2003 issue with the headline "Old School vs. New School." At

the heart of the divide is a conflict between two ways of thinking, talking, and learning.

Those belonging to the old school have a practical mind, speak in terms of empirical

reality, and learn through practice. Those belonging to the new school have an analytical

and theoretically-oriented mind, speak in terms of engineering, physics, and mathematics,

and learn through abstraction. One practitioner, reflecting on this difference, gave an

extreme example as he said:

> Think of manufacturing a new part. You have a design [done by an engineer], give it to
> someone doing the patterns, and then it goes to a foundry with a guy that works with metal,
> that may not know how to read but has his own way to talking. (Team)

In an industry that has little time to do anything other than win races, there is little

time for training. For the craftsmen that dominate the industry it has been a challenge to

adapt.

> I didn't know how to turn the computer on, much less what to do with it. But now I can go in
> and do whatever I need to do with it, writing programs, deals, or setup sheets, pull-down tabs,
> put the set up sheet, etc. So I really worked hard to keep up with the industry and the changes
> and the technology and that's something. I feel I can do a lot of things that engineer can do,
> but I don't have the degree. (Team).

The challenge of blending and coordinating the work of engineers and craftsmen is

double sided. On the one hand, it is necessary for engineers to acquire and value

experience, and on the other to get the craftsmen to acquire some of the engineering

rationale. A team engineer put it succinctly in a personal communication on the subject

when I asked him whether the biggest educational challenge was to upgrade the skills of

the craftsmen, and he did not fully agree:

> I don't know if I would totally agree that we are trying to upgrade the skills of the craftsmen, as much as trying to combine the best of the old and new methods. Engineering won't totally change the way that this industry operates, and there aren't any engineers who have the 20+ years of experience that some of the craftsmen have. There is quite a bit of value in experience, and the people that have been building and racing these cars for years and years bring quite a bit to the table to improve performance. We have to get the craftsmen to accept some new and better ways of testing ideas, and we have to get the engineers to realize that they aren't the only ones with ideas on how to improve performance, and be open to people who have "been there, done that" before. One of the biggest challenges with new engineers is getting them to work with the guys building the cars and accepting that they often have better ideas than they do (Team).

From the engineering side, this study made it clear that other than having the

technical skills, engineers ought to have experience to working in the industry; what a

senior executive called "the racing background."

I would suggest that this is a sign that, as in the previous case study, practical

experience bridges the duality of innovation. Experience, I suggest, also has an

ambiguity-reducing effect in the problem-solving process, but of a different kind from the

one brought in by engineers. Drawing from the wealth of knowledge that comes through

years of involvement in the sport, many times tacitly, experienced individuals can rapidly

come up with a solution or a suggestion to confront an ambiguous situation and "know

the playing field." Through experience, practitioners know where to look, and what to

look for, hence do a more targeted and efficient search. Perhaps they cannot say what

they do or how they do it, but they know it and that is what matters.

From the craftsmanship side, a possible opportunity to improve coordination is to

assist the craftsmen who work with engineers to develop a common understanding. Both

sides are equally important: finite element methods and aerodynamics enhance analysis, but the body of the car is built and shaped by hand. The situations during races, as much as teams strive to reduce ambiguity, are uncertain and ambiguous and often escape systematization. The key is to keep the ability to bring together experience and engineering to coordinate across boundaries as transparently as possible. It seems important, however, to avoid turning the craftsmen and experienced individuals in the industry into systematic problem-solvers. The point is to work together, not to become like one another.

5.3.5 Coming together

One of the major organizational innovations in NASCAR motorsports is the multi-car team. Until the mid 1980s competing teams in NASCAR races were organized around a single car. These were stand-alone businesses. Since the mid 1980s a consolidation process started in the industry. Since the 1990s the multi-car teams have predominated in the competition, and today the largest and most successful and competitive teams are multi-car teams.

One way to understand NASCAR teams is as an organizational solution to the optimization problem that NASCAR teams face during the innovation process. They enhance coordination among specialized functional units, they enable the sharing of engineering, testing and other problem-solving resources, they bring under the same umbrella the engineers and craftsmen that make the industry work, and they bring all of these resources together enhancing successive approximations.

I suggest that the most important advantage provided by multi-car teams is to speed up the problem solving process that drives innovation. As such, they are better spaces for experimentation, which, I have argued, is the fundamental way in which practitioners in this industry learn and drive technological change. By speeding up the innovation process multi-car teams arrive at solutions faster than competitors. In addition, they are able to do more iterations that result in a racecar that is better optimized in the same amount of time. This acceleration comes from two effects that enhance communication by (1) increasing the amount of information available when solving a problem and (2) making communication more transparent due to lack of competition and the familiarity with team members.

By sheltering from competition, multi-car teams enable what would otherwise be extremely secretive individuals to openly share problem-solving resources, knowledge, and information. As a practitioner put it: "another phase that I have experienced in the sport is the multi-car team. People wondered how to do it. How can you do it if you have competition out there? Then everybody realized that when you got two cars you have twice as much engineering and information" (Team). I asked an engine specialist about whether there was any information sharing with other teams and he said:

> With 8 teams we get a lot of information about our engines, so we really do not need to be out there talking to others. I at least do not do it or feel the need to do it. We do visually look at what the competition is doing -every Sunday- Our advantage is that we deal with so much. (Team)

This advantage permeates what teams do throughout the innovation process, including what goes on during races:

And then you got multi-car teams where you really got a lot of people you can feed off for information, so when you got to a race, maybe one of the other [car-teams]is having problems, it really don't hurt your performance any. (Team)

Amplifying the innovation-enhancing effect of openly shared information and problem-solving resources is the creation of a tightly knit community whose members consider each other trustworthy and reliable. A practitioner made an analogy of multi-car teams with brothers: "You see brothers successful and that is partly because of the sharing of experience and information that happens between drivers, crew members, etc. It is hard to get that with competitors. That is precisely one of the advantages of multi-car teams" (Team). By knowing and trusting each other, being aware exactly of what other team members have to offer, practitioners know where to look first when they need an idea or a solution to a problem, and they do not have to waste time reaching out, writing contracts, or getting to know each other. They do not waste time wondering and finding out who can do the job.

5.4 External interactions and effects

NASCAR teams do not innovate in isolation. I asked an engineer where he looked for new ideas when he had a problem, and more specifically whether he looked for ideas and solutions inside the team or beyond its boundaries. His answer was:

> We usually start inside the team. Depends a little bit on the problem. We usually start inside team, and usually not just inside the engineering group. If it's a mechanical problem we go to the mechanics. We have some suppliers also when something we think our suppliers can help us with we often go to them. We go to the [Indy Racing League] team in Indianapolis. There are even times when we would go to competitors. A lot of us have relationships with different people on different teams, whether it's crew chiefs, mechanics, or engineers, and there is a bit of data trade and information transfer that way (Team).

Different teams do slightly different things. This one, for example, benefits by belonging to a larger organization that participates in other racing leagues. But NASCAR teams do not innovate in isolation. I characterized the innovation process as the optimization of an existing product. This process involved the solution of a constant stream of problems as fast as possible. How do interactions that cross the organizational boundaries of the teams affect the teams' ability to innovate?
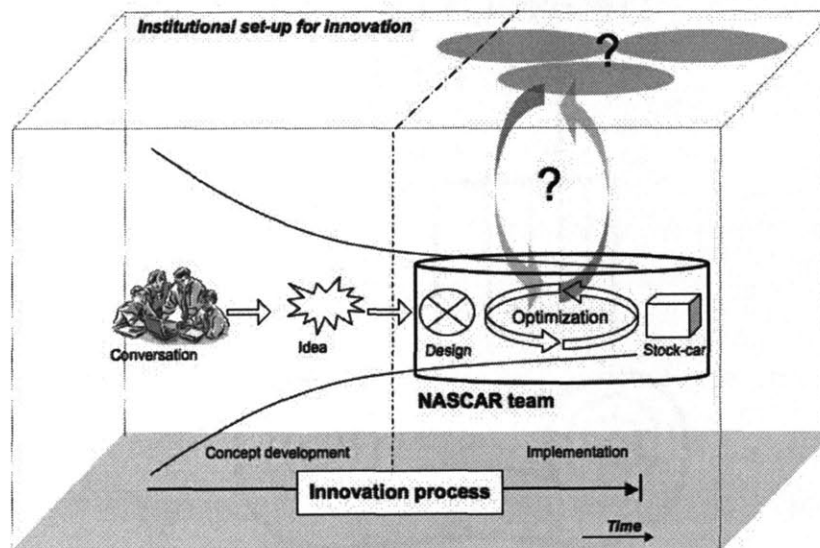
Figure 5-9 What organizations affect the innovation process in NASCAR teams? What is the nature of the interactions?

This case study provides additional evidence that the duality of innovation is translated into a duality of interactions across boundaries. It provides further evidence that the functions of these relationships in the innovation process follow a similar pattern: analytic interactions are related to a set of analytic functions, and interpretive interactions to a set of interpretive functions. In contrast to the previous case study, in which the most important interactions and functions enhancing the innovation process were interpretive,

in this case the most important innovation-enhancing effects are analytic. Some of the functions that I have identified here, although carried out by different organizations, are equivalent to roles identified in Tampere.

5.4.1 Analytic interactions and functions

In this industry, analytic interactions are the most important to enhance the innovation process of NASCAR teams. They are analytic because interactions are motivated by the need to solve specific problems, with goals that are known a priori. They might involve an iterative interaction, but unlike an interpretive conversation, the goal is to reach an optimal solution to the problem. Their most important effects are to disseminate information, to create new problems to solve, and to assist in the problem-solving resources for NASCAR teams.

5.4.1.1 Analytic public space

During an interview with a practitioner he said that when something out of the ordinary happens – in the sense that a team does something that gives it an advantage – pretty soon everyone is doing the same thing. I asked him which were the arenas or forums through which they learned about what the others are doing and he said: "The racetrack is very important. The cars are physically next to each other and you can see things... Direct observation of what the others are doing is very important." (Team)

One way to understand the role of the racetrack is as a public space. But in contrast to the interpretive spaces that were critical to the innovation process in Tampere, in this case the racetrack is an *analytic* public space. What makes it analytic is the type of

communication that takes place among teams. Unlike conversations in interpretive space, in the racetrack there are *flows of existing information*. Information might be new for a team, but there is no new knowledge generated through these flows and no ambiguity in the communication.

A common saying in the industry is "monkey see, monkey do." There are two crucial moments in which this happens: The garage and the post-race engine teardown. At the garage, with cars parked extremely close to each other, practitioners overhear what other teams are saying and, most importantly, learn what others are doing through direct observation. The specialists working at the garages can detect the smallest changes in, for example, the body of the neighboring racecar. NASCAR dictates how cars are positioned at the garages, according to point standing, in descending order.

In the post-race teardown NASCAR plays a role in making information public during the post-race engine tear down and inspection. "It is a fairly private industry with each team doing things different. But at the end of the week what we've done is out for public display" said a practitioner (Team). Another senior executive called NASCAR "the great equalizer" as he said that:

> That's the kind of technology that every team gets a little bit of an edge, and then the great equalizer, called NASCAR, will tear down your engine in front of other people. So you spend millions of dollars developing this technology and the other guys are sitting there watching saying "Oh, that's what they did." Next week, they are doing the same thing. That's part of the show. We understand it. But will you maintain forever a competitive advantage? No. (Supplier)

Figure 5-10 In the post-race engine teardown, which I observed during my visit to the track, NASCAR makes the top 3 winning teams plus the pole-setter take out the engines of their cars. The engines are placed within 12-15 feet of each other, and the engine specialists of each team tear them down. NASCAR inspectors take the parts, inspect them, and put some of them on tables that are so close to each other that they end up in public display. Anything out of the ordinary is made public. Author's photograph. Loudon International Speedway, NH. 9/17/06. Taken with permission of NASCAR inspector.

5.4.1.2 Regulation as problem-setting

As the sanctioning body of the sport, NASCAR plays a role analogous to a regulatory agency. Innovation is regulated to ensure that teams run races with cars that are technologically identical. The goal is to maintain a competitive 'level playing field' that is deemed important to keep the lure of the sport as an entertainment business, and to make sure that the skill of the driver remains relevant. The rules also restrict the advancement of technology, thereby avoiding an arms-race of technological innovation among the teams that would lead to ever-increasing costs.

The NASCAR rulebook, which is not available only to participating teams, sets the rules of the game. Regulations restrict what teams can do with the stock-cars from a technological point of view to improve performance. The rules are constantly changing as NASCAR deems necessary. Rule changes are usually geared towards tightening the possibilities for innovation and ensuring safety. In the case of safety, NASCAR creates rules to limit the speed of the cars or to require the use of certain materials that create safer operating conditions, both during races and in case of accidents. An example of a technological change that was prompted by safety concerns but affected how teams innovate is the restrictor plate, which is used in super speedways to restrict the intake of air to the engine at the carburetor, thus reducing the horsepower output of the engine by about 150 hp, limiting the speed of the car.

Seen through the duality of innovation, the rules of NASCAR play two closely related analytic functions: information dissemination and problem-setting. At the racetrack, through observation and most importantly through the ongoing inspection process, NASCAR gains a great deal of insight into what each team is doing. When it detects something out of the ordinary that might give an unfair advantage, it creates a new rule. The effect of this rule is dual. What was a secret is made public in a rule and wipes out a competitive edge, intensifying the competition by leveling the field again. And second, a new rule gives practitioners new problems to solve. In this way NASCAR redirects the flow of problem-solving within the teams, who are forced to explore or improve performance within new areas to push the technological frontier a little further.

This aspect of NASCAR's regulatory process is analytic because there is no ambiguity in the rules. Teams are told exactly what to do or not to do. Teams might be "be creative" with them, that is, interpret rules in ways that enable them to be more creative. But the rules themselves are unambiguous.

5.4.1.3   Problem solving resources and technology transfer

The two most important partners in problem solving and technology transfer resources for NASCAR teams are the auto manufacturers and the suppliers.

The teams affiliated with each major auto manufacturer have access to the personnel, equipment, and in general to the expertise of the latter racing divisions of GM, Ford, Dodge, and Toyota. There is an ongoing flow of information and technology between NASCAR teams and auto manufacturers, with representatives from each of them often visiting teams in Charlotte. There are some examples of former personnel from the racing divisions of these teams who have moved to work in NASCAR teams. In addition, auto manufacturers provide some critical engine parts to the teams. A practitioner described well the role that manufacturers play for NASCAR teams:

> There is no doubt that the teams benefit much more from a close manufacturer relationship than the other way around. There are a few things that have transferred from our team to the manufacturers (testing methods, sensor development), but for the most part a manufacturer provides resources that we wouldn't have access to otherwise (Team).

In the case of suppliers, teams establish close relationships with suppliers of equipment, parts, and technical services. Practitioners within teams reach out to suppliers to solve problems related to specific parts or to acquire new technology. In some cases they establish an ongoing interaction, as in the case of some major teams' relationships

with providers of CNC machine tools and other advanced manufacturing technology. A few interviews suggested other technology transfer relationships. A few major teams, for example, have relationships with specialized companies in the UK's Motorsports Valley. Another team transferred heat-protecting technology from the Space Shuttle program to NASCAR teams. This technology was made available to all teams through a local supplier.

An additional effect of these relationships is to create another flow of information across team boundaries. In the case of suppliers, even though relationships are bounded by trust and extreme confidentiality, when suppliers are shared they learn from interactions with different teams and apply those lessons to improve their own products and components. In the case of auto manufacturers, they are a semi-public arena in which the teams affiliated with them share the same problem solving resources and in some cases come together with the manufacturer to solve common problems.

5.4.1.4   Testing

I have argued that NASCAR teams optimize racecars through a process of successive approximations. This means that they are engaged in an intensive and sophisticated trial and error process by means of which they gradually reach an optimal, or close to optimal, performance level of parts or of the car as a whole.

Although they have acquired internal capabilities for computer-based modeling and simulation, having access to external testing facilities like wind tunnels and engineering simulation services has become critical for NASCAR teams. Teams go as far as Ottawa,

Canada, to have access to wind tunnel testing facilities. Others use the GM wind tunnel in Detroit, or the NASA wind tunnel in Langley, Virginia. More recently Aerodyn, a local venture in Mooresville, NC, has been very successful by creating a wind tunnel for local teams that is in high demand. The owner of HASS automation, a major American machine tools manufacturer, which is involved in NASCAR both through team ownership and by providing equipment to several teams, has recently announced plans to create a major full-scale wind tunnel in the region. Wind tunnel testing allows teams both to test the aerodynamic performance of racecars and to gather vast amounts of data that is fed back into the optimization process.

NASCAR places limitations on the number of tests that can be done at racetracks, and that is partly why testing facilities have become so important for teams. But the racetracks are the final ground for testing and optimization. While teams arrive at the track with highly optimized cars, the final fine tuning happens during practice sessions and even during the race itself.

5.4.2 Interpretive interactions and functions

Interpretive relationships and functions appeared during this research, but play a very limited role in the industry's innovation process, which is primarily problem-solving oriented. The ambiguous nature of interpretive conversations and relationships is incompatible with the need for clarity and swift problem-solving and responsiveness required by the industry. Nevertheless, I discuss two instances of interpretive roles, played by NASCAR and auto manufacturers. This illustrates that when the innovation process moves towards concept development, which in the duality of innovation I

characterized as interpretive, innovation-enhancing external relationships are also interpretive.

5.4.2.1 Interpretive space

When major technical changes are going to take place, NASCAR itself promotes interpretive conversations among the teams and manufacturers to set new standards. In this case, the innovation process shifts towards the concept development side of the spectrum and become more interpretive and long-term oriented, even if there is an end point in mind at the start of the conversation. A current example is the Car of Tomorrow (CoT), whose launch will begin gradually during 2007. The CoT has been in development for more than three years, and represents a substantial design change for the stock-cars. Developing the CoT has involved an ongoing conversation between NASCAR, teams, and auto manufacturers that has spanned already over two years. A NASAR inspector at the racetrack described how NASCAR has relied on the teams own insights as never before to come up with the new standards. Major teams have created dedicated development teams focusing on the Car of Tomorrow. The process resembles the interactions between a standard setting body in which companies that compete in the marketplace talk with each other to design and adopt the new standards. The inspector also said that at some point the rules will be frozen, there will be a new rulebook, and teams will then be forced to push the frontiers forward within those rules.

5.4.2.2 Research and development

Major NASCAR teams have little time to focus on long-term issues, and are indeed

discouraged to devote any energy to long-term improvements because whatever

advantage they gain through them might be quickly wiped out through a change of rules.

As a practitioner put it:

> "Long-term" is a little different in racing than in other organizations, I think no matter what the series. Due to rules changes, we cannot look too far ahead, as the next rule change could easily eliminate the current development projects we are working on. (Team)

Nevertheless, some of the teams have research units in house focused on developing

better tools to optimize car performance. When it comes to external research partners,

the most important are auto manufacturers. Teams rely on those teams as research units.

> In traditional terms, there is no research function within our team looking two or three years out and developing new materials or things of that nature. But the trial and error method of experimentation is also starting to go by the wayside as engineering gets implemented more and more into the fold. There is quite a bit of focus on alternative methods to develop cars using simulations, computational fluid dynamics, and other methods that are significantly different than the traditional methods, mainly because the sanctioning bodies are severely limiting track testing opportunities to learn by the traditional method. The real substitute for an internal research function is the manufacturers, as they provide help with those kind of projects as well.

5.5 Understanding the absence of the university

UNCC is the largest campus in the UNC System, and considers itself a research-intensive

university with an explicit regional economic development mission.[27] But despite the fact

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[27] The history of higher education in the Charlotte region is relatively recent. The antecedent of the University of North Carolina at Charlotte (UNCC) was founded in 1946 as one of 14 college centers opened across the state by the State of North Carolina in response to increased demand for tertiary education in the immediate postwar period. Driven by local business initiatives, the Charlotte Center would later become the Charlotte College, and move to its current location on land acquired by local leaders and donated to the state. In 1965 the University of North Carolina at Charlotte was established by the NC State Legislature. UNCC started programs leading to doctoral degrees in 1992 and today it is the

that the university has coexisted with NASCAR motorsports for more than 30 years, the

two only found each other relatively recently.   The university started a motorsports and

automotive engineering program, with research and education initiatives in 1998. There

is a well-established motorsports engineering concentration for mechanical engineering

majors, but research collaborations are few and very small in scale and scope.[28] There is

virtually no industry funding for research in motorsports at UNCC.

In 2004 there was a prominent attempt to bring the motorsports industry and UNCC

closer together.[29] The idea was to create the NC Motorsports Testing and Research

Complex ("test track").   This was a grand vision of civic, government, and even

motorsports industry leaders to support and retain the industry by building a USD 50

million research and testing complex.[30] UNCC was the key factor in the equation. UNCC

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fourth largest UNC campus and the largest higher education institution in the Charlotte region. On a 100 acre site across from the present UNCC campus, several new buildings to house all applied research in engineering, science, and technology are under construction. The idea behind it is similar to the Centennial Campus of NCSU in Raleigh, in which university research and companies are co-located to foster technology transfer and university-industry interactions. Interviews with academic practitioners reflect a commitment to applied interdisciplinary research responsive to industry needs and many faculty members have had some kind of industry experience. The university operates one of the oldest research parks in North Carolina. The former chancellor, Jim Woodward, was a strong advocate of increasing the engagement of UNCC with local industry, and the university and its individual faculty members do have close ties with local industry.

[28] Today, there are 23 faculty members affiliated with the program. All of them are specialized in other fields (such as metrology or subfields of mechanical engineering) with motorsports being an important focus for approximately four out of the 23 faculty. On the educational side, the motorsports concentration is available to students majoring in mechanical engineering.   According to estimates from a faculty member in the program, there are between 50-60 mechanical engineering undergraduates involved in the motorsports concentration every year, with 15 to 20 graduates per year. Of these, only a small fraction ends up working with a NASCAR team.

[29] This effort follows a larger regional trend in which established civic and government institutions have looked towards UNCC as an active player in strengthening the region's economy. Following a 1999 study on the future of the regional economy, in 2001 Duke Energy, a major utility headquartered in Charlotte, donated 10 million USD to UNCC towards an endowment for an envisioned Charlotte Institute for Technological Innovation, now called the Charlotte Research Institute (CRI).

[30] This idea responded to a major need of most of the teams, who due to NASCAR regulations can make only a limited number of tests, and have limited access to racetracks in which sanctioned races take place.

was not an interlocutor in the early conversations about the test track, but was later

approached by one of the initiators of the project.[31]   Members of the university

administration were initially reluctant to get involved because the test track was more of a

"day-to-day business venture" than research and development, and "universities are not

good at managing businesses."   NASCAR motorsports were perceived to be "too

volatile" and also to be doing well on their own.   But the initiative continued to gain

political momentum and backing from some business leaders and UNCC became an

active part of the conversation to realize the test complex.

Concerns remained in the university about whether a test track was a good idea at all.

As the project got underway, a task force was convened by UNCC's chancellor to look

more carefully at the initiative.   A feasibility study got underway in the second half of

2004, consulting more than 110 teams and other motorsports business interests within

and outside the region.   The conclusion, released in February of 2006, was that the test

track was not what NASCAR teams needed or wanted.   Having shelved the test complex

idea, attention has now shifted towards workforce development which is the main need

identified by the taskforce.   For research, problem solving and testing support, according

to one interviewee, teams generally preferred "to let the market decide and respond to

their needs as they evolved."   While the test complex idea is off the table, UNCC's

automotive and motorsports engineering program, now called the NC Motorsports and

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Teams would spend hundreds of thousands of dollars a year taking cars to racetracks where they could test. The idea of a racetrack seemed initially to make sense, both in terms of helping the teams and as a way to demonstrate the commitment of the region to the industry. It was also assumed that, if teams accepted the idea, they would pay fees to make the venture financially self-sustaining.

[31] A consortium to build support and momentum for the initiative was also created, involving the Charlotte Regional Partnership, the Charlotte Chamber of Commerce, the North Carolina Motorsports Association, UNCC, Hendrick Motorsports and the NC Department of Commerce.

Automotive Research Center, moved into a new, larger research and educational facility in late 2005. The relationship continues to develop slowly.

Why was UNCC hesitant and why were teams resistant to building a relationship through the testing complex? A simple answer to this question is that the industry is doing well on its own. However, NASCAR teams do not innovate in isolation. As the previous section shows NASCAR teams' innovation process is enhanced not just by intense competition, but also with resources, technology, and information funneled into the innovation process by other organizations. Some of the functions of these organizations, like the auto manufacturers and suppliers, include research, problem-solving, testing and technology transfer. These are innovation support functions that universities play for many other industries. Why not in this one?

In the previous case study, there were two important enabling conditions for the university-industry relationship associated with history and tradition. Since its creation, the Tampere University of Technology (TUT) has had a mission and tradition of engagement with the local mechanical engineering industry. Having educated engineers and managers for the industry for years, TUT has also been responsible for creating and renewing a closely knit community of engineers. TUT academics part of what Tampere's one senior engineer called "the tribe." Once employed by these companies, it is natural for them to reach back to TUT. Over time, this back and forth interaction has also had the effect of making the knowledge bases of the industry and the university co-evolve.

UNCC was also created with an economic development mission at around the same time that TUT was created in Tampere. But at the time of UNCC's creation the

NASCAR motorsports industry was very different from what it has become. It was an industry dominated by self-taught craftsmen, not by engineers. The professionalization and increased technical sophistication of the industry is very recent and the idea of research is very new for NASCAR teams. As one practitioner inside one of the major teams put it:

> You have to recognize that 30 years ago this sport was not what it is today, and the university could do basically nothing for it. It was a very crude activity. In a way we have failed to recognize each other, and the university has failed to recognize the growth of the industry in every sense. (Team)

With the infusion and relevance of engineering into the industry, the possibility for engagement now exists. However, UNCC and NASCAR teams do not have a tradition of engagement and the university has not played any role in educating many of the current managers and engineers of the industry. For an industry that is an insider's business, in which being a well-known business partner or a trusted member of the ol'boys network is a precondition for any form of engagement, engaging a university that has never been an important part of the network and who previously had nothing to contribute, does not come naturally. This should not be taken to mean that developing a relationship between UNCC, NASCAR teams and other industry players is impossible. Rather, it is a matter of time and it will take careful reflection on the nature of relationships that work. I propose some avenues for building this relationship in Section 5.5.

5.5.1 Innovation process incompatibility

In addition to these two barriers to entry, I propose that there is an inherent incompatibility between the forms of institutional support that the university can provide and key aspects of the innovation process in NASCAR motorsports.

5.5.1.1 Research vs. problem–solving

First, as an academic pointed out during an interview, "you have to understand that what NASCAR teams mean by research is different from what we mean by research." Practitioners in NASCAR teams learn and innovate through experimentation and problem-solving. These two activities are also part of an academic engineer's activities, but in academia there is an emphasis on research and engaging the industry only in a problem-solving fashion is not very interesting. This is not to say that problem-solving is not done by academics or undesirable to them. The problem comes when it is the *exclusive* focus of a university-industry partnership. For an academic, if there are no research results to publish associated with the interactions there is less incentive to engage. "You would not get tenure doing that if you are an assistant professor," an academic argued. This contrasts with the relationships in Tampere's mechanical engineering industry, in which the university-industry interactions did have an important problem-solving activity activity, but included collaboration across the continuum from concept development to implementation.

5.5.1.2 Exploration vs. instrumental goal orientation

The focus on implementation and problem-solving means that practitioners in NASCAR teams engage outside partners when they have a clear sense of what they want, a problem

to solve, or an experiment to carry out. The exploratory, open-ended conversations that are so important for university research and characterize university-industry relationships during concept development (such as those between Tampere's machinery companies and TUT as illustrated in the previous chapter) are thus incompatible with the instrumental goal orientation of NASCAR teams, which strive to reduce ambiguity and save time. On top of this, the space for exploration in NASCAR teams is tightly constrained by the rules. Practitioners in NASCAR teams are not used to engaging outsiders if they do not have a more or less clear sense of what they will get from the interaction. When they engage with others, they engage only within the space afforded by the rules. In other words, open-ended exploration is not only uncommon; there is little room to explore. For an academic, having no room for exploration is not very interesting. For NASCAR teams, exploration is a waste of time.

5.5.1.3 Public space vs. proprietary knowledge

The exploratory conversations that universities contribute to the concept development phase of a company, are generally public. This means that a research group in the university can have an ongoing relationship with companies that are competitors in the marketplace. Even if there are agreed limits on dissemination, research results are generally public knowledge. This contrasts sharply with the culture of NASCAR teams, which are greatly concerned with confidentiality and the potential disclosure of information to other teams. This concern was stated by several practitioners in the industry and clearly reflected in the two following academic accounts:

We are trying to cooperate but they are scared to death about having their secrets revealed. Most of them do in-house engine development and have little secrets that they would not share. Robert Yates is like the CIA. You will simply not get in. They all accuse each other of cheating. Teams accuse other teams of everything. (University)

They are a very paranoid business. They like to keep all their ideas in house and keep everyone on close looks so sending work to the university generally makes them very nervous. It is my observation and experience... They are very proprietary, they don't like any outsiders getting any of their ideas and taking them into another team. So it's kind of a tight close shop. (University)

Concerns about secrets leaking to other teams through the university were also mentioned by practitioners when thinking of engaging the university in problem-solving, testing, and simulation. In this case, teams expressed concerns about sharing their data sets or models with the university due to fear that they would leak to other teams. Universities can certainly do problem solving, testing and evaluation for industry.

5.5.1.4 Long-term vs. short-term

Perhaps the most important barrier to the participation of the university as a partner for NASCAR teams is a different time horizon. NASCAR teams are inherently short-term oriented. Their main source of competitive advantage is to do things as fast as possible. Universities on the other hand, are inherently oriented towards the long-term. One practitioner stated this very clearly:

This is usually the problem with universities. Our environment is very fast paced, and by the time they get to it, when we have a problem, those problems have got to be fixed in a day and a half. Because let's see we have a problem at a race this week. We get home on Monday, get to the car, analyze the problem, figure out a solution, and we have to implement that on Tuesday, because cars on Wednesday are out to the racetrack again. So that turn around time doesn't correlate to the university schedule very well. (Team)

During the 16 weeks of the off-season they are preparing for the racing season. And during the 36 weeks of racing season, they are focused on weekly race preparation, a

process that requires swift implementation and rapid solution of problems. Practitioners in NASCAR teams suggest that the short-term orientation is amplified by the need to be constantly procuring sponsorship money, and by the continuous change in the rules. NASCAR teams are aware that whatever efforts they make to become more competitive can be wiped out with a change of rules. This sense of urgency in solving problems and the constraints placed on long-term thinking by the nature of the sport and NASCAR rules contrasts sharply with what academics do.

5.5.2 The duality of innovation, UNCC, and NASCAR teams

NASCAR teams, by the nature of their business, are like a natural laboratory that brings into broad relief differences between universities and industry that are often discussed, but seldom clearly articulated, when building university-industry relationships. The problem-solving emphasis of NASCAR teams and their need for knowledge on demand contrasts with the exploratory conversations that academics and practitioners from industry engage in when trying to expand their repertoire of ideas in preparation for what could be and play an active role in creating products and markets that do not exist yet. The secretive, hypercompetitive way of operating of NASCAR teams highlights the conflicts with the public space function of the university. Their short-term orientation contrasts with the mission of research universities to articulate what the future might be about and explore areas that industry, because of its short-term focus and emphasis on the bottom line, has little incentive –and time– to explore.

The duality of innovation, I suggest, offers one way to understand the struggles of UNCC and NASCAR teams to relate to each other. Most of the innovation support that

NASCAR teams require is purely analytic: improve problem solving and procure information and technology. This contrasts with the previous case study, in which interactions between TUT and local machinery companies have an important interpretive component. I suggest that in NASCAR, the exclusive focus of NASCAR teams on building analytic relationships in which there is no interpretive flexibility (ambiguity, as I said, is an enemy in this industry) was a problem with the university. NASCAR teams interact with external organizations that can meet their terms of engagement.
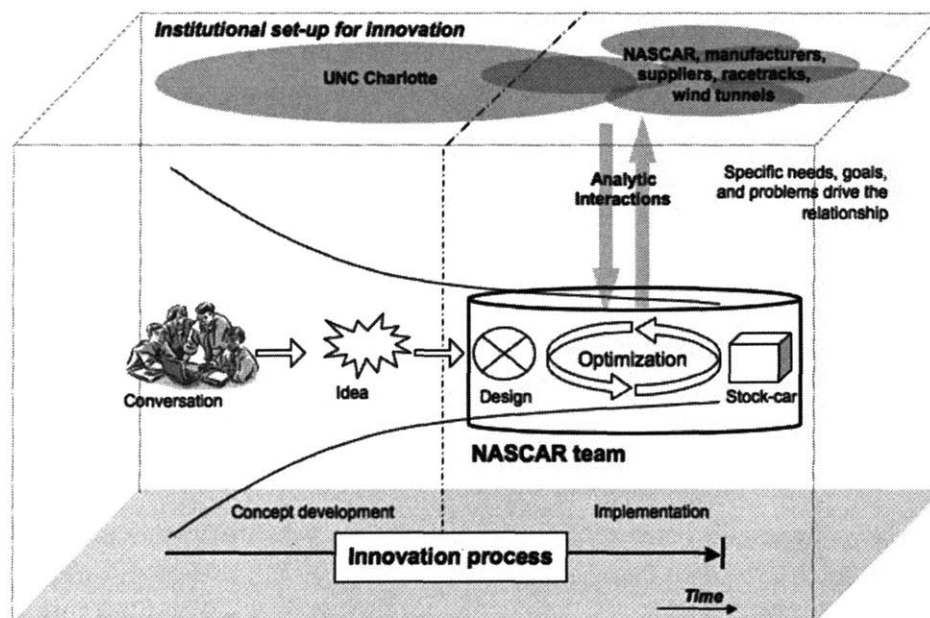
Figure 5-11 The struggle to build a relationship between UNCC and NASCAR teams, I suggest, has two explanations. First, NASCAR teams have all their innovation support covered. There is no space for the university. Second, the exclusive focus on analytic relationships was a problem for the university.

Incompatibility between NASCAR and UNCC reaches the normative sphere. In this particular case there is a clear conflict of values between what research is and the solution of immediate problems, between what is public and private knowledge, and between a short-term goal orientation and a long-term perspective. This is not to say that one side is right and the other is wrong. What must be recognized is that life in NASCAR teams and life in UNCC are guided by different goals and values.

5.6 Discussion

Having acknowledged these differences, where might the relationship go from here? Whether thinking of building research or education collaborations, the question is whether common ground can be found. The first step is to get to know each other better so that UNCC can become part of the "family" and NASCAR teams see what a university-industry relationship can do for them.[32] Then, there is the need to bridge compatibility issues such as the short-term, experimentation and problem-solving orientation of NASCAR teams and the long-term research, development and general engineering education of the university. Another important question is how to address the concern of public vs. proprietary knowledge. An academic suggested that practitioners are not familiar with the academic practice of signing academic or non-disclosure agreements with companies. The university, however, ought to carefully

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[32] According to a faculty member from UNCC, a dialogue is beginning through the new facilities of UNCC's Motorsports and Automotive Research Center. A specialized supplier for the motorsports industry donated a piece of equipment to the university so that practitioners from NASCAR teams could learn how to use it. Now, the "NASCAR flow" often comes to UNCC's facilities to use the equipment. According to the academic, this has enabled practitioners to discover what UNCC has to offer, and academics to start building relationships with individuals beyond the management ranks of NASCAR teams. It remains to be seen whether UNCC and practitioners from the teams will start tapping into this relationship in the future and for what purpose.

evaluate to what degree to enter into confidentiality agreements, because the advancement of knowledge in academia depends upon exploring and sharing knowledge without walls. NASCAR teams should become aware that the most value they can get out of the university comes from open conversations oriented towards the long-term. It will be up to the university to clearly articulate why the greatest mutual benefits come from keeping the relationship as non-exclusive as possible.

5.6.1 Building research collaborations

For UNCC it will be important to choose carefully the subjects for collaboration. When it comes to short-term problem solving, teams have already figured it out and have a set of external interactions to assist them in the process. As one academic said, the NASCAR motorsports industry is very volatile. A great deal of the knowledge is application-specific and areas of emphasis today can change rapidly with a change of rules. More promising would be to focus on issues that do not pose competitive worries to the teams, are of common interest to all of them and to the university, or are longer-term oriented. The domains of collaboration that would be most valuable to the university would be in subfields that can could also be applied to industries other than motorsports, such as machinery, automotive, aerospace, materials, and others. A potential area for engagement is advanced technologies for data acquisition, modeling, simulation, experimentation, all crucial for speeding up the innovation process in NASCAR teams. Perhaps UNCC should work to become a world-class *high-performance engineering research and education center*, with motorsports and automotive engineering as a subset of a wider field. Motorsports is an industry of extremes. Why not try to develop a

specialization in carrying out engineering science and design in extreme environments? Through research and development collaborations with NASCAR teams, UNCC could potentially build up capabilities in these fields while benefiting other industries.

Although it is beyond the scope of this study, potential for mutually beneficial collaboration exists on the non-technical sides of the industry. UNCC, community colleges, and the industry are already working on the educational side of this, and this might as well be extended to research.

5.6.2 Building educational collaborations

Deeper engagement with the industry on education confronts several obstacles. First of all, jobs in the industry are few. Second, those that are available tend to be reserved for individuals with a racing background. Third, teams already have well-established hiring practices that recruit the most qualified wherever they can find them. Fourth, the industry's historical roots as a territory of craftsmen and self-taught mechanics still places obstacles for engineers.

Teams suggest that having internship programs with UNCC (and community colleges) would be fundamental for their ability to hire students out of college. But conversations with academics and practitioners suggest that university-industry compatibility issues also play out. The focus of NASCAR teams on implementation, on learning by doing, and on short-term problem solving would be an incomplete educational experience for an engineer. I also inquired whether it would be possible for engineering students to work on longer term issues by doing, for example, a master's

thesis. But at least two practitioners were worried that if a student works on a master's thesis for one of the teams, whatever he or she learned would end up with another team. In addition, the short-term problem solving orientation becomes a barrier when thinking of master's engineering students doing a thesis that takes one year to complete. The need of teams to solve problems and absorb knowledge as fast as possible is not compatible with the timescales of a master's thesis.

This study suggests that, from an educational content standpoint, the most important educational and training challenge (in the industry as a whole and NASCAR teams in particular) is to reconcile the tradition of craftsmanship and trial and error with the systematic and IT-intensive approach to problem-solving characteristic of engineers. Practice and project-based education with exposure to the industry is the most important bridging mechanism between the two sides. This, however, means something different to an engineer and to a craftsman; it will also be viewed differently by UNCC, on the one hand, and the community colleges on the other.

For undergraduates, the university has already figured out what it needs to do to educate students to work in the industry by having not only specialized subjects, but also having them participate in student racing leagues that expose them to the inner workings of racing. For the craftsmen the educational challenge has two sides. First, to upgrade the skills of the existing workforce, and this can be addressed through continuing education or short courses. These programs could involve close collaboration between UNCC to bring an emphasis on engineering science and community colleges to bring an emphasis on technical craftsmanship. Such take place during the off-season. The second

challenge is to educate the future workforce of the industry. This is the domain of community colleges. CC's would need to educate technicians whose skills are applicable to industries other than motorsports, bringing in the application-specificity through internship programs. UNCC could also collaborate with community colleges to design programs that blend engineering science with technical craftsmanship. A practitioner in Tampere described how he had worked with a vocational school to educate "mechatronics artisans." The task here is to educate high-performance engineering artisans.

5.6.3 Collaborating with NASCAR and suppliers

Thus far the discussion on university-industry collaborations in NASCAR motorsports has focused on NASCAR teams and UNCC. Two other potential university-industry partnerships to explore include NASCAR itself, as the sanctioning and regulatory body of the sport, and suppliers. An opportunity for collaboration with NASCAR in which UNCC could have been a more active partner is the Car of Tomorrow, a concept development process that has spanned several years, and in which teams and manufacturers are participating together. A collaboration with NASCAR would also be more compatible because, in a sense, NASCAR is a public space: it deals with all teams, designs rules for all of them, and disseminates information across their boundaries. This would assure that there are interesting and valuable research areas for faculty and students to engage in.

The other opportunity for collaboration is with suppliers. The innovation process of NASCAR teams demands ever more refined parts, better materials, more sophisticated

data acquisition and testing technologies, and faster responsiveness and coordination between them and the supplier network. According to several parts distributors, many of the suppliers of specialized parts are (or were) small craft shops started by former racing employees, focusing on a single part of the car. For NASCAR teams to continue to be engaged with them, these suppliers would have to be able to meet the speed and reliability requirements crucial for their competitiveness. This suggests that a potential, very important area for university engagement is in upgrading the knowledge and management capabilities of the supplier base. As a side effect, this would keep NASCAR teams from bringing in house manufacturing on parts that suppliers cannot longer provide with the speed and reliability required, thus enhancing the survival ability of a group of businesses that have substantial economic impact in terms of revenues and employment.

5.6.4 Preparing for the future

From the perspective of policymakers one incentive to bring UNCC closer to the motorsports industry was the real or perceived possibility that an important industry for the regional economy might leave. The test complex initiative suggests that a Silicon-Valley model was in the mind of civic, business and government leaders who overlooked the fact that NASCAR motorsports is different from IT, UNCC is different from Stanford, and Charlotte from Palo Alto. Keeping in mind university-industry compatibility, what could the university do –if anything– to contribute to anchoring the industry in the region?

The relevant question for UNCC (and also for community colleges) is: From a knowledge and innovation point of view, what could prompt the industry to relocate? In the event that UNCC and community colleges are considered part of the equation to keep the industry there and nurture it, what are they to do? There is no simple answer to these questions, but the temptation ought to be avoided of blindly jumping on the bandwagon of established recipes and fashions that are not empirically substantiated; not contingent upon the local context, history, and culture; and not adapted to how the industry works.

Some inspiration might come from the British Motor Sport Valley, whose emergence and importance as the center of European motorsports and Formula One racing has been investigated by Steven Pinch and Nick Henry (Henry, Pinch et al., 1996; Pinch and Henry, 1999; Henry and Pinch, 2000; Henry and Pinch, 2001). Before motorsports took a strong hold in Southeastern England after 1960, the former center of European motorsports was Northern Italy. Contesting the idea that the industry agglomerated in Southeastern England due to a series of coincidences, Pinch and Henry argue that an emerging group of small racing teams and companies in Southeastern England in the late 1960s had access to a knowledge base that would become central to the competition. At that time, technological advantage in racing started to come increasingly from lightweight aluminum motors, composite materials, and aerodynamics. All these fields were derived from aerospace rather than mass-produced cars. With governmental support for manufacture and research in aerospace during and after WWII, Britain had grown research centers, and supported aeronautical departments in universities, resulting in a concentration of expertise and a large talent pool in aerospace by the 1950s. When the

sources of advantage in racing started to shift towards aerospace-related areas, Italy did

not have the same amount of knowledge in the field. Building on an established and

growing base of racing companies that had already started to apply aviation technology to

racing, British manufacturers had an advantage at the right time and the industry shifted

very rapidly from northern Italy to Southern Britain (Pinch and Henry, 1999, p. 822).

Recognizing that when it comes to any social process –and technological change is a

social process– we can only make well informed guesses about the future, the lesson of

Britain's takeover of the motorsports industry from Italy is clear. If UNCC and the state

and local governments want to improve the likelihood that NASCAR motorsports will

flourish and stay in the Charlotte region, they need to invest to prepare the regional

knowledge infrastructure and talent base for where the future of the industry might be.

The way the industry works today, radical technological changes are very unlikely. But

what would happen if NASCAR decided tomorrow that within five years steel is out and

only composite materials will be allowed in stock-cars? What would happen if NASCAR

decided that in eight years only zero-emission electric powered vehicles capable of

reaching 180 miles an hour for 4 hours will be allowed?

Charlotte would have to worry if another city with an emerging motorsports industry

had the best research centers and talent pool in the fields needed for this type of

technological transition, but it would have to worry less if, when the time comes, it has

knowledge and expertise of its own. The task is to figure out, in a dialogue with

NASCAR teams and NASCAR itself, where the future of the industry might be, do

excellent research and educate excellent engineers in fields that matter not only for the

problems of today, but in fields that prepare for the future. In the event of this future becoming real, UNCC would have made a valuable contribution. If it does not, there would still be benefits. UNCC would have been faithful in working towards its mission and long-term goal of becoming a top-tier research university, NASCAR teams would have been continuously exposed and have an institutional partner in a creative exploration that takes them beyond their extremely narrow set of topics that they know and prepares them better prepared for radical technological shifts, and Charlotte would be left with a world-class concentration of high-performance engineering and high performance craftsmanship expertise. A great deal can be done with that: create a new industry, lure other industries that demand high-performance engineering, or infuse existing industries with new technology.

5.7 Conclusion

To conclude this case, I address two important questions that emerge from the previous analysis. First, if there is no local organization that anchors the teams in the region, if they reach out as far as necessary to access knowledge and technology, and if there is already a support structure that enhances every aspect of the innovation process, what advantage do NASCAR teams, and the industry as a whole, get by being close to each other? And second, if the industry works well as it is, what would justify any type of public support, financial or institutional?

5.7.1 Why cluster?

The first answer to this question is common to all industry clusters: NASCAR teams have an abundance of resources, individuals, and specialized suppliers to support them. In addition to resources, this research is suggestive of explanations related to the innovation process that shed light on why NASCAR teams and all their supporting businesses are in the Charlotte region together.[33] The first reason is knowledge, skills and technology, embodied in highly qualified individuals and embedded in suppliers. The second reason is to be swimming amidst a formal and informal flow of ideas through interactions between practitioners, suppliers, and the rapid movement of people across the industry.

> [You] have that knowledge that you can share back and forth. Even in something as simple as going to lunch, you are bound to run into people from different race teams, who know each other, who talk you know; and it just helps gain information that you can either use to help yourself or help others, just to further your cause... Just the fact that they can communicate with others within the same industry so close helps the industry as well (Supplier).

This is a flow of self-renewal, and not being there would mean not having access to new knowledge and being excluded from the interactions that bring new ideas into being and are at the heart of innovation. "We would not have a path to all the information if we

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[33] There are remarkable similarities between the way proximity enhances interactions in NASCAR teams and the findings of previous research done in the UK's Motorsports Valley (Henry, Pinch et al., 1996; Henry and Pinch, 2000; Henry and Pinch, 2001), the world's manufacturing and research center for Formula 1. The way in which extremely secretive organizations share knowledge across boundaries are virtually the same: rapid turnover of staff, information leakage through links with suppliers, new firm formation by insiders, informal collaboration, gossip, rumour, personal contact network and observation in the pit lane during races are all identified as of primary importance in Formula 1. Henry and Pinch (2000) argue that: "In effect, the region constitutes a knowledge'pool' whose internal configuration is continually changing but a pool which, overall, is on a constant learning trajectory. To leave the region is to risk your position within the 'knowledge loop' and it is clear that whilst many British engineers/designers sell their knowledge overseas, very few leave the Valley for any great length of time" (ibid. p. 206). This case study of NASCAR motorsports suggests a similar lesson. That is perhaps why one of the oldest teams, the Wood Brothers, recently relocated to the region from Virginia. A newspaper report said that "the Woods knew it was a difficult yet necessary move if they hoped to achieve their quest for the Nextel Cup. Their re-location to Mooresville, NC allowed them more resources and greater access to personnel and technology in the hub of NASCAR racing."

were isolated. So that's why we moved here... You end up behind the game without internalizing of information. That's why we moved" (Team). The third reason is coordination. Stock-cars are always in the making, parts are always changing and need to be put back together. Proximity enables the back-and-forth interactions needed to coordinate change, put the pieces together, and reach optimal solutions.

> The fact that any of the race teams can come directly to us and get not only their questions answered, but any modifications that need to be done [or] adjustments, they can be done right here on the spot. We can also provide product testing as well... They are driving up and down here this road. All the teams are here, they can just give us a call and we will swing over, or drop by and pick up their parts. They don't have to go out of their way (Supplier).

The concentration of people who can do the job, belonging to the family, flows of information, and improved coordination all boil down to the most important competitive advantage of teams: speed.

> [Speed is] very important. [NASCAR teams] will start building their cars, they need something right away, or [need to] make changes to a car, or testing. Everything seems to be last minute and everything seems to be right now. And that makes a big difference. We are very quick response... it has to be immediate response. If they can't get it from you right away they would go somewhere else. In order to keep the business you have to meet their demand (Supplier).

The source of competitive advantage in this industry is to do everything as fast as possible, either to take less time doing the same thing or to make more iterations in the same amount of time thus reaching a better optimization. What being so close to each other ultimately affords the whole industry is to increase the clockspeed. In this industry –and probably in every industry– the elimination of ambiguity is *the* most important variable to increase clockspeed. In the ol' boys network, everybody knows everybody. They know what they know and how good they are at what they do. Everyone shares the

same knowledge and skill base. They share the racing background. Practitioners can reach out to clarify or solve problems quickly without ambiguity. They can hire someone who they know can do the job. For NASCAR motorsports, Charlotte has become a tremendously unambiguous, information-rich space for innovation and competition.

5.7.2 Does public investment in the motorsports industry make sense?

After recognizing the relevance of the industry for the regional economy, local and state agencies have started to provide support for the industry, particularly for NASCAR teams through tax breaks for the teams, tax incentives for relocation to the area, and more recently through public money for the NASCAR Hall of Fame. Knowing what they are worth for the regional economy, teams have also started to expect the state and local governments to absorb some of their costs. Two questions come to mind. Will any of these incentives do anything to keep NASCAR teams, the anchors of the industry, from relocating? Is public investment in NASCAR motorsports justified?

In regard to the first question, the answer is probably yes, because every company likes to reduce costs. Incentives will be especially helpful to keep existing suppliers from moving elsewhere and to attract other support businesses critical to the industry. In the case of NASCAR teams, as much money as they might save with tax incentives, this research suggests that with or without incentives teams –and the industry as a whole– is well served by staying together. Proximity, I have argued, speeds up the innovation *process*. NASCAR teams might replicate the resources and problem-solving capabilities elsewhere. But replicating the innovation-enhancing effects afforded by being in Charlotte would be difficult and most likely take a very long time. From a learning,

innovation, and competitiveness perspective, NASCAR teams and supporting businesses are well served by staying together.

But the fact is that NASCAR teams will do anything it takes to win and that includes moving. Leaving aside tradition, strong family ties, quality of life, and in the hypothetical absence of a commitment to the region for their own good and for the region's well-being, it is unlikely that NASCAR teams will hesitate to leave, with or without tax incentives, if moving elsewhere is what it takes to win. That is their ethos – and reasonably so because their viability as organizations and businesses depends on winning races. If teams move it is likely that suppliers will move with them to replicate the processes discussed above, so crucial to innovation. Perhaps harder to move are people, but in an industry full of passionately committed individuals it is not unthinkable that they will move too. Many of them moved to the region to race, and there is no reason why they would not move again to keep racing.

If the industry works well as it is, if teams and their suppliers get a competitive advantage just by being close to each other, and if they are likely to leave if that is what it takes to win, why invest public money and institutional effort in motorsports? The deeper question is about the place of motorsports in the landscape of American industry.

In the early stages of this research in April of 2003, after coming back from my second round of fieldwork in Charlotte, I was impressed by the creative energy that I sensed during my conversations with practitioners in the motorsports industry. Shortly after my return from the field, I was discussing some preliminary ideas with a close friend and colleague and my stories of innovation in NASCAR teams reminded her of

biotechnology firms. We wondered whether motorsports was or could be to innovation in the automotive industry what biotech is to the pharmaceutical industry: a hotbed of innovation and a space for exploration of radically new ideas.

Three and a half years into this research I remain fascinated and impressed by motorsports and the creative energy of its people. But it is now clear that the motorsports industry, whose roots and identity have traditionally been linked to the automotive industry, has a technological life of its own. While some advances in automotive technology have come from motorsports, such possibilities have diminished as the technological trajectories of cars and racecars diverge.

> There is no doubt that the teams benefit much more from a close manufacturer relationship than the other way around. There are a few things that have transferred from our team to the manufacturers (testing methods, sensor development), but for the most part a manufacturer provides resources that we wouldn't have access to otherwise. As race cars diverge more and more from productions cars, there is less and less technology that gets transferred to production vehicles. I think the main way that manufacturers use racing now is people development, taking their high achievers and putting them in racing for a few years to accelerate their learning curve (Team).

As Herb Fishel, former head of GM's racing division has argued, while engineering is still an important part of the argument for auto manufacturers to get involved in motorsports, marketing has become far more important. The more expensive racing gets and the more unclear it becomes how much knowledge and technology makes its way from teams to manufacturers, perhaps major league auto racing is itself at risk.

Motorsports' place as a creative space and hotbed of innovation for the automotive industry could only be assured by bringing the technological profile of both industries closer together. As it is today, NASCAR rules and the rule-setting process promote

innovation in areas that are only relevant to making for a safer and more exciting show. To bring motorsports and automotive technologies closer together, NASCAR and other sanctioning bodies would have to assume a role beyond sports sanctioning bodies and marketing machines. They would need to bring technological innovation to the forefront of their agenda, but not just to reduce costs or keep a level playing field. NASCAR could start setting rules that would force the teams to focus on radical technological areas that could ultimately benefit both their competitive ability *and* the auto industry's ability to innovate. Imagine if NASCAR became a space in which auto manufacturers discuss common technological platforms to make the industry more competitive and a better corporate citizen. Imagine if motorsports teams were to become the radical innovators of the auto industry, channeling some of their creative energy to technologies that made their way into auto manufacturers, improving the quality of consumer products and the competitiveness of the auto industry.

Motorsports is an industry, but it is also a game. Why invest in a game? Because games and game-like activities are inherently playful, open-ended, and experimental endeavors that unleash the creative potential of human beings. Motorsports, as a game with thousands of people at play, is an industry full of creative energy. Imagine if it were the playground of the auto industry and that creative energy were harnessed for the betterment of technologies that have an impact in the present and future quality of our daily lives. If, while remaining a game and a show, motorsports were also about the advancement of knowledge and long-term technological innovation would have a

stronger justification to remain involved and universities more interest in building closer

ties with the motorsports industry.

6 Conclusion

This dissertation started with the goal of better understanding the role of the university in industrial upgrading. To advance this understanding I examine the role of two universities in two local innovation systems: The machinery industry located in Tampere, Finland and the NASCAR motorsports industry located in Charlotte, North Carolina. In each case study I investigate the role of the university from the ground up, analyzing the innovation process with a social constructivist view of technological change. To move beyond the limitations of the linear and interactive models of innovation that implicitly inform the majority of research and policymaking about the university's role in economic development, I examine the innovation process using a conceptual framework that shows that innovation has a dual nature: analytic and interpretive. From an analytic perspective, innovation is a problem solving activity. From an interpretive perspective, it is an ongoing conversation. I refer to this conceptual framework as the duality of innovation. In the Tampere case study I find that industrial upgrading consists on interdisciplinary integration, a process that, seen through the duality of innovation lens, is primarily interpretive. In the Charlotte case I find that industrial upgrading consists on the optimization of an existing product, a process that is quintessentially analytic.

After analyzing the innovation process in each case, I proceed to examine the role of the university. I find that the Tampere University of Technology (TUT) has played a major role in industrial upgrading. In contrast, Charlotte's NASCAR motorsports industry has upgraded without the support of the University of North Carolina at Charlotte (UNCC). In reference to the duality of innovation, two observations stand out.

In the Tampere case, whose core innovation process is interpretive, the university plays a crucial role. This role, however, is nothing like technology transfer. TUT's contributions to interdisciplinary integration consist in creating interpretive space and interacting with companies via interpretive conversations. In Charlotte, where the innovation process is mostly analytic, the university plays essentially no role. Technology transfer interactions are important for the industry's upgrading, but the NASCAR teams rely on trusted business partners, not the university. Taken together, the case findings question the empirical validity of the technology transfer model that informs a great deal of research, policymaking, and university efforts to embrace the third mission of economic development.

The case study findings raise three important questions. How do variations in the nature of the innovation process help to explain the presence of the university in one case and its absence in the other? What are the implications of the duality of innovation for our understanding of the role of the university in economic development? Why is the technology transfer model absent from the university–industry interactions in the case studies, and what does this absence tell us about the university's third mission? Searching for an answer to these puzzles will help us to take a step towards a better understanding of the role of the university in economic development.

As the first step in answering these questions, I revisit the concept of interpretive flexibility introduced in Chapter 3 (see Section 3.1.1). Interpretive flexibility exists when an artifact is open to interpretation. This means that designers and users can attribute multiple meanings to an artifact. An artifact that is interpretively flexible in use means

that the user can attribute more than one meaning and hence make more than one use of it. In this study I use the concept of interpretive flexibility to examine not just artifacts, but the innovation process that brings them into being. For product designers interpretive flexibility implies the possibility to imagine multiple ways to design a product and to imagine alternative uses and markets for it.

Interpretive flexibility is a key difference between the innovation process in each case study. The interpretive conversations at the heart of interdisciplinary integration in Tampere evoke an image of playfulness, flexibility, and freedom of exploration. In contrast, the goal-oriented problem-solving work involved in the optimization of stock-cars in NASCAR teams evokes an image of constrained expediency and instrumentality. The innovation process in Tampere's machinery companies is interpretively flexible. Practitioners come together in interpretive conversations to create new ideas without *a priori* clarity of the outcome. In these conversations practitioners have a freedom to imagine new products and new roles for the machines in the market. By integrating information technology into machinery, for example, MekaTree has expanded its business model from selling only machines to process management and logistics. In NASCAR motorsports, on the other hand, interpretive flexibility is very low. There is no ambiguity about what the stock-car is, what it can do, how to make it go faster, or what its "market" is. Practitioners are engaged in an ongoing problem solving process focused on the next race, with clear goals and the means to achieve them.

In addition to interpretive flexibility, four variables emerge in sharp contrast when comparing the innovation process in Tampere and Charlotte: openness, freedom of exploration, time horizon, and goal ambiguity.

Table 6-1 Interpretive flexibility and differences in the innovation process of Tampere's machinery industry and Charlotte's NASCAR motorsports industry.

	Tampere Machinery	Charlotte Motorsports
Nature of the innovation process	Interpretive	Analytic
Interpretive flexibility	High	Low
Openness	Multiple interlocutors converse in an environment of trust and disclosure	Exclusivity is preferred. Strong confidentiality concerns create secrecy and distrust
Freedom of exploration	Existing and necessary	Little room for open-ended exploration
Time horizon	Long-term	Short-term
Goal ambiguity	Ambiguity at the start of the conversation	Goals are usually clear

I propose that these variables affect the interpretive flexibility of the innovation process in the two case studies in the following way. An innovation process characterized by openness enhances interpretive flexibility because it allows for interactions in an inclusive environment of trust and disclosure without confidentiality, appropriation or exclusivity concerns. An innovation process in which there is freedom of exploration is interpretively flexible because interlocutors can take the conversation into new and sometimes unexpected paths, leading to the discovery of something new. Goal ambiguity and time horizon affect interpretive flexibility through their effect on freedom of exploration. Goal ambiguity refers, literally, to how ambiguous goals are at the start of an interaction. When goals are clear there is little room for exploration and

hence less interpretive flexibility. Time horizon refers to where interlocutors experience

their work in a spectrum between the short term and the long term.[1] Time horizon is

proportional to interpretive flexibility. The closer goals are in time, there is less room to

explore and less interpretive flexibility. Figure 6-1 shows the relationship between the

four variables and interpretive flexibility.

Time
horizon

Goal
ambiguity

Freedom of
exploration

Interpretive
Flexibility
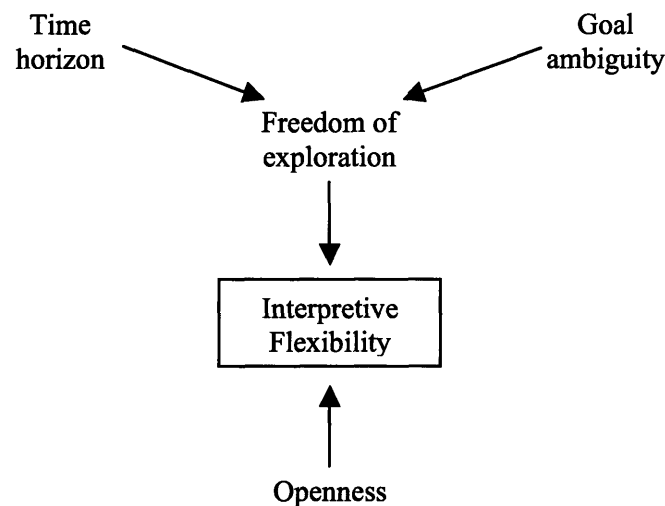
Openness

Figure 6-1 Interpretive flexibility, freedom of exploration,
and openness.

In addition to bringing into broad relief the differences between the innovation

processes in the two case studies, interpretive flexibility helps to explain differences in

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[1] What engineers, managers, and policymakers consider long-term and short-term depends on the context. Against an absolute measure of time, what in an industry is short-term in another might be long-term. Here, time horizon is taken to be an experience, not an absolute measure. In the context of innovation systems, Lundvall et al. (2002) have suggested that the distinction between the short-term and the long-term is an important dimension that defines the operation of institutional set-up for innovation in different countries and the types of technologies developed. "The distinction between short-termism as characterizing corporate governance in Anglo-Saxon countries and long-termism in for instance Japanese investment decisions is one important example of how institutional differences have a decisive influence on the conduct and performance at the national level. It is quite obvious that this distinction is important not only for the allocation of finance but also for other aspects of technological innovation. Certain technologies will only be developed by agents who operate with a long-term perspective while others might be easier to exploit with a short-term horizon" (ibid., p. 220).

the nature of interactions between Tampere's machinery companies and TUT, and

between NASCAR teams and the organizations that affect the innovation process.

Interactions between TUT and machinery companies are interpretively flexible: they are

exploratory, with a long-term time horizon and ambiguous goals. In some instances

interlocutors from multiple firms and non-firm organizations come together in an

environment of openness and trust. Interactions between NASCAR teams and other

business partners whose goal is to enhance optimization and problem-solving are

interpretively inflexible. They are discreet exchanges of bits of information or

technology, with clear goals in mind, aimed at solving immediate needs as fast as

possible, and often marked by exclusivity and confidentiality. In the Tampere case,

interactions between machinery companies and TUT (and other organizations as well)

that enhance interdisciplinary integration, an interpretive process, may be also be seen as

interpretive. In contrast, interactions that enhance optimization and problem solving in

Charlotte's NASCAR teams, an analytic process, may be considered analytic. In other

words, the case studies suggest that firms reflect in interactions with other organizations

the interpretive flexibility of the innovation process.[2]

The duality of innovation and the concept of interpretive flexibility help to explain

the variations in the role of the university in the Tampere and Charlotte cases. In the

Tampere case study, where the university has played a key role in the industrial

upgrading of the local machinery industry, none of the interactions that contribute to the

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[2] See section 3.3 for a discussion on how the duality of innovation and interpretive flexibility relate to the product lifecycle. From this point of view, the nature of interactions with other organizations changes from interpretive to analytic as the innovation process moves from concept development to implementation.

process of interdisciplinary integration resemble a transaction of patents or existing technology. In the early stages of innovation, when the process of interdisciplinary integration begins, there is no clear definition of what either party expects to obtain. There are no problems to solve. Ideas, goals, and problems emerge during an ongoing conversation. In Tampere's machinery companies, the most important contributions of the university to industrial innovation hinge on its ability to create interpretive space and participate in interpretive conversations. Building on this insight from the Tampere case, I will refer to the university's ability to create interpretive space and participate in interpretive conversations as interpretive capabilities.

The Tampere case suggests that the interpretive capabilities of the university depend on two variables. First, they depends on considering knowledge a public good. This facilitates the free flow of ideas inside the university and across its organizational boundaries, as well as the participation of multiple interlocutors in the conversation. Second, interpretive capabilities depend on the exploratory nature of the relationships. A long time horizon and goal ambiguity (or no initial goals at all) provide the room for exploration necessary for interpretive conversations. In Charlotte, neither of these two conditions exists. NASCAR teams view knowledge as a private good and harbor extreme confidentiality concerns to protect their competitive advantage. In addition, exploration and goal ambiguity are incompatible with the need for clarity and precision that NASCAR teams require in order to innovate as fast as possible. They are always oriented towards solving the specific problems that help them reach the goal of winning races. The conditions that make an innovation process interpretively flexible, which are

also the conditions that characterize TUT's interpretive contribution to the innovation process, are consistent with what is often associated with the university's distinctive contributions to the innovation process of any industry. Research universities, in particular, are characterized by being public spaces engaged in an ongoing, long-term oriented process of exploration whose guiding vision is the ambiguous goal of advancing the frontiers of knowledge. This insight leads to the following proposition:

> **Proposition 1.** The university has a distinctive ability to make interpretive contributions to industrial innovation through interpretive capabilities. These capabilities involve the provision of interpretive space and the participation of individual academic interlocutors and academic units in interpretive conversations with firms.

Previous research suggests that an important contribution of the university to industrial innovation, other than education, is to enhance interpretive processes (Lester and Piore, 2004). In its interpretive role the university, companies and entrepreneurs engage in an open-ended exploration in which goals or outcomes are not necessarily known with precision when the exploration begins. One of the purposes might be to create a vision of what the future might look like. After some period of exploring and talking to each other a new idea or product concept jells and both parties might chart a more precise course of action towards design and implementation. But the value of the university-industry relationship is in the exploration itself, and for industry, in the exposure to ideas that it cannot explore itself due to its inherently narrow focus and short-term orientation. The contribution of a university to this relationship comes from its own

ability to create and maintain interpretive space – that is, from its institutional ability to enable open-ended conversations and communication to take place, future-oriented and sheltered from market forces and proprietary concerns. Inside the university, these conversations take the form of research. When industry is involved, research groups often engage with companies working in the same field, learn from all of them, and publish the results. These conversations depend the university's public and neutral nature that grants it legitimacy to convene conversations among interlocutors that would normally not talk to each other. By highlighting the interpretive contributions of the university to industrial innovation, a clearer picture emerges about where the technology transfer model fits in the university's contributions to industrial innovation. Seen through the duality of innovation lens, the logic behind the technology transfer model implicitly assumes that innovation is analytic, and thus misses the interpretive side of innovation. Under the technology transfer model interactions between university and industry –and the economy as a whole– are distinctively analytic and interpretively inflexible. These interactions involve the transmission or exchange of knowledge that already exists and is "out there" as information, codified in the form of patents or products. The goals of the interaction are clear at the start of the interaction, so there is no emergence of new knowledge.

The analytic external relationships of NASCAR teams with their business partners is an extreme illustration of how these relationships look in practice. NASCAR teams relate to suppliers and auto manufacturers seeking a solution to very specific problems, to acquire a component, or to transfer technology to improve the innovation process. In

addition, NASCAR teams relate to other organizations having great concerns about confidentiality. To address these concerns, they either seek exclusive relationships or relate to organizations that can address their need for secrecy. These terms of engagement contrast sharply with the terms that make interpretively flexible relationships possible. This insight leads to a second proposition:

Proposition 2. Too much emphasis on practices commonly emphasized by the technology transfer model, such as patenting and commercialization, may put at risk the university's interpretive capabilities and hence its most distinctive contribution to industrial innovation.

The technology transfer rationale may put at risk the interpretive capabilities of the university by undermining both its public and exploratory nature.[3] First, it risks compromising the exploratory nature of the university because it requires the codification of knowledge, perhaps stifling the emergence of new knowledge in interpretive

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[3] At the heart of this compromise is what Slaughter and Rhodes call a change in the "knowledge/learning regime" of the university. In their analysis of commercial and market-oriented activities in higher education in the new economy, Slaughter and Rhodes (2004) argue that universities have traditionally been characterized by a "public good knowledge/learning regime" in which there is a clear separation between the public and private sectors. In this regime knowledge flows freely among scholars and between scholars and the public and is valued as a public good to which society at large has claims. Basic science leads to discovery of new knowledge and serendipitously to public benefits. In contrast, technology transfer implies the entry of an "academic capitalist knowledge/learning regime" into higher education. This regime "values knowledge privatization and profit taking in which institutions, inventor faculty, and corporations have claims that come before those of the public... Knowledge is construed as a private good, valued for creating streams of high-technology products that generate profit as they flow through global markets... Discovery is valued because it leads to high-technology products for a knowledge economy" (Slaughter and Rhoades, 2004, p. 29). In this regime the boundaries between the public and private sectors are redrawn, making them more permeable. This introduces market and market-like behaviors into universities and faculty behavior, including competition for external money, for-profit activity and the sale of products and services (Slaughter and Leslie, 1997). These insights suggest that the technology transfer rationale implies a transition from a knowledge/learning regime that is favorable to interpretation to one that is favorable to analysis, emphasizing the university's role in economic development as a goal-oriented and problem-solving activity.

interactions. It may also put freedom of exploration at risk by bringing the university closer to the market, directing and focusing attention to market needs. This would reduce or eliminate the ambiguity of goals necessary to have freedom of exploration. If a specific use or a specific market is in mind a priori, it is less likely that a new product, a new use or a new market will emerge. Second, the technology transfer model may risk the public nature of the university in two ways. On the one hand, it creates incentives to privatize knowledge through intellectual property arrangements, thus impeding its free flow and free access from the public at large, orienting it instead to specific individuals and enterprises with vested ownership or commercial interests. On the other hand, the technology transfer model introduces market-like behaviors into the university, perhaps reducing the willingness to share knowledge freely, undermining the richness of conversations or shutting them down altogether.

6.1 Terms of engagement

This analysis is a critique, not a condemnation, of technology transfer. By making this critique I am not advocating rejection of translating research results into commercializable outcomes, nor am I arguing that the university should shun its role in economic development through industrial innovation or that it should disengage from industry altogether. But I share the view put forward by Rosenberg and Nelson's in their widely cited analysis of the university's role in the technical advance of American industry (Rosenberg and Nelson, 1994). As the Tampere case shows, universities do have a contribution to make to industrial innovation, competitiveness, and economic

development. Both industry and the university can benefit from this engagement. But it needs to be done in the right way. This way, in the view of Rosenberg and Nelson, is:

> ...to respect the division of labor between universities and industry that has grown up with the development of the engineering disciplines and applied sciences, rather than one that attempts to draw universities deeply into a world in which decisions need to be made with respect to commercial criteria. There is no reason to believe that universities will function well in such an environment, and good reason to believe that such an environment will do damage to the legitimate functions of universities. On the other hand, binding university research closer to industry, while respecting the condition that research be 'basic' in the sense of aiming for understanding rather than short-run practical payoff, can be to the enduring benefit of both. (Rosenberg and Nelson, 1994, p. 347)

Rosenberg and Nelson's advice calls on the university to be strategic. As Bok has clearly said, one must "draw the line" between universities and industry and between the universities and the marketplace (Bok, 2003). Why does the university need to keep distance from "commercial criteria" to protect its "legitimate functions?" What do Rosenberg and Nelson mean in arguing that a condition for this is that research be "basic" rather than focused on "short run practical payoff?"

From the perspective of this research, drawing the line means distinguishing between the analytic logic behind the technology transfer model and the interpretive capabilities of the university. Respecting the division of labor calls for deep awareness of the distinction between interpretation and analysis in the innovation process. This is critical to preserving the university's distinctive contributions to industrial innovation. Rosenberg and Nelson (1994) argue that it is necessary to preserve the "basic" quality of research, clarifying that basic research is often misunderstood as having no practical value whatsoever. Instead, they suggest, basic research implies that practical benefits often emerge serendipitously, and that these benefits take much longer to materialize than in

more applied fields closer to the marketplace. As many have argued, however, in today's industry and university the distinction between basic and applied research and between science and technology is blurred. This distinction is thus not helpful to make choices when thinking about the university's role in enhancing industrial innovation. I suggest instead to think of the terms of engagement in the university's contributions to industrial innovation in terms of interpretive flexibility.

Proposition 3. University–industry relationships characterized by interpretive flexibility are compatible with the university's distinctive ability to make interpretive contributions to industrial innovation.

Together with the analysis of interpretive flexibility in this chapter, the case study findings suggest that preserving the interpretive capabilities of the university requires three things. First, it is necessary to preserve the public nature of the university as a social institution. Second, it is necessary to protect the exploratory nature of academic activity. Third, it is necessary to be aware of the many other channels of open conversation between industry and the economy and to preserve them.

To preserve the public nature of the university it is necessary to retain a clear separation between the public and the private. Universities are public spaces. The technology transfer model makes permeable the boundaries between the public and the private. Privatization of knowledge introduces secrecy into academic activity, creating barriers for the openness essential to nurture the university's interpretive capabilities. Secrecy hampers or shuts down conversations. In addition, by compromising the non-market nature of the university, blurring the boundaries between what is public and what

is private undermines the neutrality and public nature of the university, potentially discouraging external interlocutors from engaging with academics and the university as a whole in a spirit of openness and trust.

To preserve freedom of exploration in the university it is necessary to make the right choices in the issues, problems, or themes in specific university-industry relationships and in the third mission as a whole. The case study findings suggest that preserving the exploratory nature of the university requires consideration of two variables. First, problems, issues, or themes that have a long time horizon are preferable. As Rosenberg and Nelson suggest, "a policy of consciously broadening the range of industries under which there is university research is quite reasonable to contemplate. However, if that is to be a policy, it must be policy that looks to practical returns in the long run, not the short. It must, in brief, be a patient policy" (Rosenberg and Neson, 1994, p.346). The second way to nurture freedom of exploration is to set the terms of engagement so that there is flexibility and goal ambiguity. The combined effect of a long-term time horizon and goal ambiguity creates the freedom of exploration necessary to unleash the creative potential of interpretive capabilities. Engagements that are exclusively focused on problem-solving and on meeting short-term market or industry needs lack the exploratory element crucial to the university's interpretive capabilities.

Finally, to nurture the interpretive capabilities of the university it is important not to emphasize the technology transfer model at the expense of the many other ways in which knowledge flows between the university and the economy. The technology transfer model directs the flow of knowledge to a very narrow and specific channel (Feller, 1990;

Lee, 1996; Mowery, Nelson et al., 2001; Agrawal and Henderson, 2002; Cohen, Nelson et al., 2002; Mowery and Sampat, 2005). Too much emphasis on formal exchange through technology transfer might actually hinder rather than enhance the universities contributions to industrial innovation. It is thus important to preserve knowledge dissemination between the university and the economy through open communication channels such as publications, conferences, informal interactions and consulting, and student internships, which, compared with the translation of research into deliverables like patents, are far more important contributions of universities to industrial innovation. In Feller's words, "the existing tracks upon which academic research flows to the market are likely to become blocked if not broken apart as universities limit existing flows of information in order to divert faculty findings to specific firms. At stake is far more than issues such as temporary delays in the publication of faculty research in order to give corporate sponsors an opportunity to file patent applications... The result is likely to be lower rates of technological innovation" (Feller, 1990, p.343).

If too much emphasis is currently placed on the technology transfer model, it is partly because the multiple facets of the university's role in economic development are poorly understood and not properly articulated. To think strategically about their role, universities ought to become more self-aware of their multifaceted contributions to industrial innovation. This research, which has explored the university's role from the ground up, makes us deeply aware that the university's contributions to industrial innovation affect the innovation process itself. The university's effect takes place at levels of agency by enhancing the creative and problem-solving capacity of engineers,

managers, and policymakers as they work within the flow of the innovation process. This research also makes us aware of the fact that the university's innovation-enhancing effects are different for different industries and, in the two cases under study, vary according to the nature of the innovation process. For the university to become more self-aware and think more strategically about its role, a first step is to gain a nuanced and situated understanding of the innovation process. This dissertation makes a contribution by introducing the conceptual framework and language of the duality of innovation to examine the innovation process and the impact of the university in this process, and the logic of technology transfer.

Building on greater self-awareness of their contributions and a grounded understanding of the innovation process, universities need to be more proactive in clearly articulating their contributions to industrial innovation in their home regions and beyond. Universities should work to articulate, in particular, the incomplete understanding of the innovation process behind the conventional approach to the role of universities in economic development. This bias narrowly considers the university's contribution to industrial innovation in analytic terms. This belief has led to the creation and improvement of institutional setups to enhance competition, create markets for intellectual property, and incentives for new business formation. There is nothing wrong with this fundamental and all-important set of innovation-enhancing policies. The problem comes when these mechanisms are assumed to be the *only* route for universities to enhance the ability of companies to innovate. But interpretive capabilities, the distinctive contributions of the university to industrial innovation, stem from its distance

from the market. It is especially important for innovation policymakers to recognize in practice the importance of interpretation in the innovation process. When it comes to policies aimed at fostering the university's economic development role, policymakers should not insist or limit the university's role to the technology transfer model. Doing may undermine the most distinctive contributions of universities to industrial innovation.

7 Limitations and further research

Like all research, this dissertation has limitations. The first limitation is associated with the methodology. Because this is an interview-based qualitative study of two industries in two industry clusters, it cannot provide conclusive and highly-generalizable categories. Further research in other companies within these systems, and most importantly in other innovation systems, would be required to achieve a higher level of abstraction and generalizability. A primary avenue for future research is to enhance the external validity of the concepts and categories emerging from this research by considering other industries and local innovation systems.

Second, within the cases the inquiry focused on one specific aspect of the innovation process as a device to highlight either the interpretive or the analytic sides of the process. However, the duality of innovation implies that both interpretation and analysis are necessary, albeit for different purposes, during the innovation process. Thus, additional research in these two settings would be necessary to apprehend how the duality plays out in full. This is especially necessary in Tampere, where machinery companies are delivering products to the market, not just integrating knowledge across disciplines. In addition, the inquiry focused only on specific transitions in these industries over a given period of time, and as such, the characterization of the innovation process builds on temporally circumscribed evidence. Additional historical research on these two settings would be necessary to explore how the innovation process itself has evolved.

The third limitation is the focus on one single industry within each locale. Tampere is also home to an important information and communications industry, and Charlotte is the

second most important center of banking in the United States. The Tampere University of Technology and UNC Charlotte both have interactions with these and other industries in their respective locales. The findings in this study only refer to the machinery industry in Tampere and the motorsports industry in Charlotte. Additional research would be necessary on the relationships of these two academic institutions to other local industries in order to gain a more comprehensive understanding of the roles their contributions to industrial innovation in Tampere and Charlotte.

The fourth limitation is the reference to "the university" throughout this study. University-industry interactions usually unfold at lower levels of analysis: a research group and individual members of the academic communities in each case. Universities are complex organizations, and as such there are variations in how individual research units or individual faculty members relate to other industries. The level of aggregation in this study, referring to "the university," thus has inherent limitations. Additional research focusing on how specific research units contribute to industrial innovation would be necessary to investigate how interactions vary within the same university.

In addition to the research necessary to address the limitations of this study, this dissertation suggests several avenues for future research.

First, it seems important to carry out more case studies of failed or struggling university–industry interactions. Most of the research done on the subject, and the examples usually cited by policymakers, are cases of successful, working university-industry relationships. A great deal of insight emerged in this dissertation from the

struggles of NASCAR teams and UNCC to build a relationship, highlighting things to consider in practice when attempting to foster university–industry interactions.

Second, an important research project is to investigate the duality of innovation in educational programs. Each case study in this dissertation suggests avenues for research in engineering education, such as the importance of combining a classroom experience and a practical experience as a way to bridge the duality. Additional research on this important subject is necessary, not only for engineering education, but also for other areas like management and policy.

Third, both case studies show that local companies depend on sources of knowledge and technology beyond the boundaries of their region. Machinery companies in Tampere and NASCAR teams in Charlotte search for innovation and problem-solving assistance with business partners, universities, and research institutes at the national and international levels. In the NASCAR case, in particular, most of the innovation support provided by local organizations is non-local. This suggests that the emphasis on "local innovation systems" and "industry clusters" is misplaced. It is thus necessary to perform additional research about the interplay of the local/national/global triad and how it plays out in the innovation process of different industrial sectors. A promising research avenue in this respect would be to examine how the duality of innovation affects the geographic scope of a firm's interactions during the innovation process.

Fourth, beyond the university's role, additional research is necessary to understand the actual difference that geographic agglomeration makes for an industry's ability to innovate. The case studies in the empirical core of this dissertation show two highly-

successful geographically concentrated industries. However, both the nature of their innovation process, their interactions with other organizations, and the role of the local university in each case are radically different. Promising avenues include research to advance our understanding of the role of trust and informal institutions, as well as what may be called "clock-speed advantage" that firms may get by being geographically agglomerated.

Fifth and finally, these latter two points raise the question of substitutability of the university's contributions to industrial innovation. Both case studies show that different companies interact with a diverse set of organizations that enhance their innovation process. The university is only one among many in a constellation of innovation-support organizations in each industry. In some cases, the same function is carried out by a different organization. A better understanding of substitutability seems particularly important for the university's interpretive role. While it is well understood that technology transfer may take place from a variety of research organizations, the creation of organizations or initiatives that substitute for interpretive space, to give an example, merits additional research.

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