Discontentment and Knowledge Spillovers in an Emerging High-tech Industry: A study of the Emergence of the RFID Industry

by

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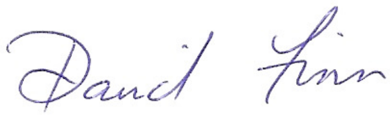

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ABSTRACT

This thesis is an inductive study of how entrepreneurs and their collaborators use or encourage knowledge spillovers to fuel technological innovations during the emergence of a knowledge intensive industry. Drawing on theories of the entrepreneurial process, innovation during industry emergence, and knowledge spillovers, this thesis seeks to explain the process by which entrepreneurs, facing market, organizational and technological uncertainty, use their existing knowledge to procure, share and create new knowledge during the early stages of an emerging industry. The core research question is why, when and how do knowledge spillovers occur in an emerging industry?

The thesis is based on an extensive case study of the RFID (Radio Frequency Identification) industry, including both interview data and analysis of patent data. The approach of data collection, analysis and theory development follows the systematic methodology articulated by Glaser and Strauss (1967), Glaser (1992) and Strauss and Corbin (1998) for developing a grounded theory. The qualitative research involved 57 in-depth interviews (45 interviewees) from around the world with the inventors and entrepreneurs who have shaped the emerging RFID industry.

The thesis makes a number of important contributions to existing literature.

First, it provides a comprehensive description of the emergence of the RFID industry in the United States and Europe with a focus on patent activity surrounding specific innovations and the nature of information flows between firms in the value chain.

Second, core findings are that the discovery, evaluation and exploitation of opportunities by individuals in the RFID industry were the result of knowledge spillovers that resulted from extensive social interactions; that knowledge spillovers can be instigated by entrepreneurs or their collaborators by molding or recognizing discontentment in potential knowledge workers, a process which is described as "discontentment provocation"; and that a core generative process to the emergence of a new industry is knowledge spillover. Contrary to existing literature, patents played a relatively insignificant role in knowledge spillovers relative to social interaction in the emerging RFID industry. Furthermore, knowledge spillovers were not geographically bound and localized within spatial proximity to the knowledge source.

Third, the analysis of the empirical data identifies the dimensions "discontentment", "human agency" and "social interaction" as underpinning the process that fostered the generation and propagation of knowledge during the emergence of this industry. The discontentment dimension, originating from negative forces, acts as a catalyst to trigger the process of human agency, the decision to pass on information and knowledge to another party. Human agency then leads seamlessly into social interaction, resulting in the acquisition, interpretation and/or sharing of information and knowledge. Discontented individuals were the knowledge conduits who diffused information and knowledge to entrepreneurs and their collaborators through social interaction.

Fourth, this thesis also advances the theory of knowledge spillovers in an emerging knowledge intensive industry by expanding upon the "Entrepreneurial Motivational Model" proposed by Shane et al. (2003). It introduces the triggering events that motivate an individual to seek change prior to the discovery of an opportunity and the social

exchanges which take place during different steps of the entrepreneurial process.

Overall, this study has important implications for those studying the entrepreneurial process, the emergence of new industries, and knowledge spillovers.

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GLOSSARY OF TERMS

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CHAPTER 1 - INTRODUCTION

1.0 Research Area

Knowledge spillovers across company boundaries play an important role in knowledge creation processes, technological change and in the evolution of a new industry, but little is known about the mechanisms and determinants of information and knowledge transfer in an emerging high-tech industry.

Knowledge creation is a dynamic generative process which gives rise to technological change from the intentional actions of individuals who respond to market incentives. But not everyone who contributes to technological change is motivated by market incentives (Romer, 1990). It takes agents of change to identify, evaluate and exploit opportunities. Therefore, with knowledge of the opportunity, entrepreneurs and their collaborators exploit knowledge. In this pursuit, knowledge spillovers have a crucial role to play in the entrepreneurial process.

Numerous studies have analyzed the patterns and effects of knowledge spillovers in the semiconductor and flat panel display industries examining inter-firm knowledge sharing (Appleyard, 1996) and the need to continually create new knowledge as the backbone of competitive advantage (Murtha, 2004). However, the role of the entrepreneur and his collaborators in utilizing knowledge spillovers to generate new knowledge, reduce uncertainty and form or expand an opportunity in an emerging knowledge intensive industry has not been the focus of much empirical research.

As technological change lies at the heart of economic growth, government R&D programs attempt to encourage innovation by subsidizing industry research projects. Therefore, understanding the events and modes of communication that facilitate the flow of knowledge will be of great importance for public policy makers in defining programs to stimulate knowledge spillovers.

1.1 RFID Industry

This study analyzes the evolution of innovative activity during the emergence of the Radio Frequency Identification (RFID) industry for the period 1970 to 2000.

The case study of a specific industry allows insights into the complex human influences and interactions that shape firms along the value chain, and ultimately industry growth.

The important features of the RFID industry in the United States during the early stages of application are the high mobility of R&D engineers, the significant role of small startup firms and intra-industry spin-offs in introducing technical and marketing innovations, and the extensive patent activity in an industry characterized by rapid technological change.

These unique aspects provide a basis for understanding the dynamics of the industry over time, but only by examining in depth the range of challenges and issues confronting the entrepreneurs and their collaborators in bringing technology and innovation to market in the face of fierce competition and financial constraints, is it possible to gain a meaningful understanding of the knowledge creation processes which led to innovative or imitative entrepreneurial activity in the earlier industry stages.

In its simplest form, RFID is an electronic replacement for barcode, improving the efficiency of data processes in a multiple of consumer, industry, military and government applications.

Despite its long history, RFID has really only taken off in the last decade, emerging as one of the most pervading computing technologies in history. New forecasts released by ABI Research indicate that the global RFID market will turn over approximately $9.7 billion by 2013, representing roughly a 15 percent compound annual growth rate for the period from 2008.

Investigating the birth and development of this knowledge intensive industry before RFID products became sufficiently affordable, standardized and reliable for widespread use, by collecting data on the history, actors, firms, the timing of inventions, products, services, markets, commercial networks, business practices, patent activity and geographic diffusion of knowledge, illustrates links between the exploitation of prior knowledge, knowledge spillovers and innovation in the entrepreneurial process.

The collective engaging activities of the entrepreneurs and their collaborators in this industry constitute a social system. The empirical evidence describing the actors, firms and events may also provide original insights into human motivation, behavior and interaction which support innovation, new venture creation or both.

The emergence of the RFID industry after the 1970s is particularly interesting because small start-up firms dominated the market, exploiting business opportunities in animal identification and access control, and exploiting technological breakthroughs originating in part from military projects, and in part from individual inventors, scientists and engineers. For survival, these small start-up firms had to have capabilities and enduring qualities which depended strongly on the strengths and weaknesses of the founding teams.

Although the social structures of the RFID industry have evolved with time, and the industry has shifted from a demand push to a demand pull condition, actors pursuing a new opportunity today will face similar challenges in dealing with other actors in the community, exploiting a stock of knowledge, innovating, navigating in a competitive environment, carving out a market niche and gaining legitimacy.

Therefore, this area of study should offer rich insights into the innovation process in a knowledge intensive industry which go beyond conventional wisdom of knowledge diffusion during the birth of a new industry.

1.2 What is RFID?

An RFID (Radio Frequency Identification) system is an integrated collection of components that implement an RFID solution. The components include a transponder, the identification device, commonly referred to as a tag, a reader or otherwise called an interrogator, application software and a communication network.

The core elements of an RFID tag are a microchip holding identification data, a means to encode RF with that data, connected to an antenna and packaged in a housing adapted to an application.

There are three types of tags; passive, semi-passive and active. Passive tags have no power source and draw their energy for communication from the electromagnetic field generated by the reader. Semi-passive tags are battery assisted tags having a battery to provide modulation for a reflected signal and thereby giving the tag a much greater range. Active tags contain a battery which powers the microchip and communication with the reader.

A reader is a device that can recognize the presence of a compatible tag (operating on the same frequency and under the same communication protocol) and read data from or write data to the memory of the tag. The interrogation technique between reader and tag can be radiative, inductive or capacitive coupling.

RFID enabled devices are used for the identification of objects, animals, goods and products in transit, and people. In the form of a credit card or key fob, they can be used to store electronic cash for payment and ticketing applications.

1.3 Prior Research and Literature Gap

To date, research has not explained adequately the process of how entrepreneurs, facing market, organizational and technological uncertainty, use their existing knowledge to procure, share and create new knowledge during the early stages of an emerging industry. In particular, how the acquisition, transfer and sharing of knowledge drives the innovation process.

The prevailing studies of knowledge spillovers in an emerging high-tech industry have typically revolved around: spillovers transmitted through the mobility of labor when inventors change organizational and collaborative affiliations (Stolpe, 2002): knowledge gathered through public and private channels as part of a firm's intelligence system (Appleyard, 1996); knowledge conditions being more conducive to new and small enterprises as opposed to incumbent firms in driving innovative activity (Audretsch and Fritsch, 2002); a social system which governs, integrates, and performs all of the functions required to transform a technological innovation into a commercially viable line of products or services delivered to customers (Garud and Van de Ven, 1987); a collective community process of entrepreneurship in terms of engaging organizations along the value chain (Mezias and Kuperman, 2001) and using patent data to quantify the intensities of knowledge diffusion to an industry by tracing the citation flows across issued patents (Jaffe et al., 1993).

Patent citations in a patent publication (granted patent or published application) identify "prior art" upon which the new invention builds. The citations only reference published documents and it is the duty of the individual or entity applying for the patent to disclose to the Patent Office all "prior art" known to that individual or entity to be material to the patentability of any claim in his or her application.

However, there is a non-access period of at least 12-18 months between filing a provisional or non provisional application and the actual publication of the patent which cannot be referenced by a third party. Therefore, using patent citation data to proxy the intensities of knowledge flow to an industry is flawed. Information pertaining to a new invention is likely to be outdated, particularly in an emerging technology, by the time that the patent (or application) is published. Knowledge flows during this non-access period are more likely to come from other sources which impact entrepreneurial activity and innovation.

An alternative approach to capture the unobservable process of knowledge transfer and sharing is to group firms into a technology cluster according to the types of product they manufacture or commercialize. For this purpose, patents filed by those firms in the technology cluster are downloaded from the United States Patent and Trademark Office (USPTO) patent database. By examining the priority date (filing date of earliest application), description of the invention and the patent claims of each patent, a picture can emerge of innovative time trends and overlapping technology which signal knowledge flows *before* publication of a patent.

By triangulating the patent data (priority date, description of the invention and patent claims) from each patent issued to those firms in the technology cluster with a wide range of qualitative and secondary data from different sources, reliable data on knowledge spillovers and the timing of certain inventions during the early emergent phase of an industry can be documented.

Opening the black box on knowledge spillovers and innovation in an emerging industry is the objective of this thesis. The missing gap in the literature is the link between prior knowledge, knowledge creation processes and the patent activity of firms and individuals in the industry.

Therefore, the overarching research question which this thesis seeks to answer is why, when and how do knowledge spillovers occur in an emerging industry?

This overall research question is developed into four research questions that informed the data collection and analysis. These are:

1. How do individuals identify opportunities in an emerging high-tech sector?

2. What triggers individuals to act on an entrepreneurial opportunity?

3. What is the extent and nature of innovation during the emergence of a knowledge based industry?

4. What facilitates knowledge spillovers in an emerging high-tech industry?

1.4 Rationale for the Research Methodology

In this study I interviewed the pioneers who spearheaded the evolution of the Radio Frequency Identification (RFID) industry. This allowed me to analyze knowledge spillovers across geographical boundaries and to identify the factors that drive the entrepreneurial process.

The inspiration for this research project can be traced back to my educational background in telecommunications and electronics, international marketing and business administration, and my entrepreneurial work in the Radio Frequency Identification (RFID) industry during the nineties.

Given my technical background and my experience in the RFID industry, I have been very interested in its emergence and in the mechanisms that influence the dispersion of market and technical knowledge in the RFID community. Therefore, my research project stemmed from a desire to study the phenomenon of knowledge spillovers in an emerging industry inductively, rather than from a desire to test a specific theory through deduction. At the beginning of the project, I found very little empirical studies in my cross-disciplinary review of the literature addressing this topic.

Although I have experience in the RFID industry, I decided to conduct an exploratory study of the emergence of this industry by interviewing those pioneers and entrepreneurs with whom I have had no previous business relationship or knowledge of the workings of their entrepreneurial ventures.

Focusing on the discovery of theory, I followed a grounded theory approach based on four research questions as guides for data collection, much in the spirit of Strauss and Corbin (1998), with some imports from procedures outlined by Eisenhardt (1989a) and Yin (1994). To formulate a theory of knowledge spillovers in an emerging industry, I systematically collected and analyzed the data using an iterative process of considering and comparing my initial literature review, the data itself and the emerging theory.

My objective was to analyze the data, focusing on the key findings and linking those findings to existing theoretical frameworks by conducting an additional literature review that could shed more light on the topic, and if necessary, to formulate propositions to describe the nature and consequences of knowledge spillovers in an emerging industry at the individual and community level, so as to develop these theories further.

1.5 Contributions

The thesis makes a number of important contributions to existing literature.

First, it provides a comprehensive description of the emergence of the RFID (Radio Frequency Identification) industry in the United States and Europe with a focus on patent activity surrounding specific innovations and the nature of information flows between firms in the value chain.

Second, core findings are that the discovery, evaluation and exploitation of opportunities by individuals in the RFID industry were the result of knowledge spillovers that resulted from extensive social interactions; that knowledge spillovers can be instigated by entrepreneurs or their collaborators by molding or recognizing discontentment in potential knowledge workers, a process which is described as "discontentment provocation"; and that a core generative process to the emergence of a new industry is knowledge spillover. Contrary to existing literature, patents played a relatively insignificant role in knowledge spillovers relative to social interaction in the emerging RFID industry. Furthermore, knowledge spillovers were not geographically bound and localized within spatial proximity to the knowledge source.

Third, the analysis of the empirical data identifies the dimensions "discontentment", "human agency" and "social interaction" as underpinning the process that fostered the generation and propagation of knowledge during the emergence of this industry. The discontentment dimension, originating from negative forces, acts as a catalyst to trigger the process of human agency, the decision to pass on information and knowledge to another party. Human agency then leads seamlessly into social interaction, resulting in the acquisition, interpretation and/or sharing of information and knowledge. Discontented individuals were the knowledge conduits who diffused information and knowledge to entrepreneurs and their collaborators through social interaction.

These are developed in a number of propositions. These five propositions emerged in the course of the iterative process of data gathering and analysis.

> *Discontentment, originating from negative forces, acts as a catalyst to kick-start the process of human agency, and human agency can drive the entrepreneurial process.*

> *Human agency, the capacity to make decisions and enact them, can lead to the diffusion of information and knowledge through social interaction of individuals or groups of individuals.*

The underlying mechanism which connects the individual or a group of individuals to a community of practice in the discovery, evaluation and exploitation stage of an opportunity is social interaction.

The three components of "discontentment", "human agency" and "social interaction" explain the pathway leading to knowledge spillovers in an emerging industry.

The pace of industry growth during the emergence of a knowledge-based industry is dependent on technological progress and knowledge spillovers.

Fourth, this thesis also advances the theory of knowledge spillovers in an emerging knowledge intensive industry by expanding upon the "Entrepreneurial Motivational Model" proposed by Shane et al. (2003). It introduces the triggering events that motivate an individual to seek change prior to the discovery of an opportunity and the social exchanges which take place during different steps of the entrepreneurial process. Based on this a model of entrepreneurial process is presented. This model integrates entrepreneurial emotion, cognition, motivation, human agency and social interactions, to explain the key stages of the entrepreneurial process.

Overall, this study has important implications for those studying the entrepreneurial process, the emergence of new industries, and knowledge spillovers.

1.6 Format of the Thesis

The remainder of this thesis is organized as follows: Chapter 2 forms the foundation for my research, presenting again the over-arching research question, reviewing the existing literature addressing this question and leading to the formulation of four specific research questions to guide my inductive research.

As an output of my research, chapter 3 presents a historical account of the emergence of the RFID industry leaning on the work of Dr. Jeremy Landt in his article "Shrouds of Time, The history of RFID" published in October, 2001. This article provided direction, but to the best of my knowledge, this study is the first identifiable academic review on the history of RFID which accurately captures the timing of certain inventions, the application of technology and the transition from ground breaking inventions to incremental innovations.

Chapter 4 describes the design and methodology of taking an inductive approach to exploring the research topic, concerned with theory-building rather than theory-testing. This chapter also explains the processes of data collection, fieldwork and coding that were used in this research. In the final section of this chapter, I return to the history of RFID for the period 1970 to 2000, defining the context of my research, providing a detailed account of the industry and the timeline of events (table 1) as a backdrop to understanding the firms investigated, before embarking on the analysis of interview data.

Chapter 5 examines whether novel or innovative ideas concerning a technology product spillover to individuals or rival firms through the publication of patent applications seeking to protect the invention, or whether the novel or innovative ideas spillover through social interaction before publication of an application.

Chapter 6 discusses the process of entrepreneurial magnetism and makes the creative leap from extensive interview data to analysis, by organizing the data into categories or dimensions (refer to table 4), leading to a more sophisticated understanding of the data. Within each dimension I identify the casual data fragments and elements which explain the pathway leading to knowledge spillovers in an emerging industry. To stimulate lateral thinking, I use data displays (figures I to III) to graphically present my research findings.

Chapter 7 discusses briefly the stages in the development of the RFID industry and summarizes the industry evolution process. It revisits the four research questions that directed this study. It presents an overview of the key findings from the analysis of the interview data, the time series analysis of patent applications and the industry evolution, culminating in the development of propositions. It then seeks to contextualize my endeavor in context with extant literature, exploring two themes in the light of my findings. It integrates the contributions made in this thesis and concludes by discussing the limitations of this research and implications for practitioners.

CHAPTER 2 - LITERATURE REVIEW

2.0 Preamble

As an outcome of my initial review of prior research, the overarching research question guiding this thesis is why, when and how do knowledge spillovers occur in an emerging industry? In reviewing the academic literature on the diverse topics of entrepreneurship, the insights gained serve as a point of departure in defining broader questions for field research. Because of the inductive nature of this research, the literature review primarily provides direction, prior to conducting the field work. With evidence from interview data, it may be necessary to return to the literature to examine disparities between empirical findings and the arguments of traditional theorists.

I will now turn to the literature, anchoring the research in several theoretical perspectives, summarizing important implications and identifying possible gaps in the literature.

2.1 Entrepreneurial Process

Shane and Venkataraman (2000: pp. 218) propose that the field of entrepreneurship involves "the study of sources of opportunities; the processes of discovery, evaluation, and exploitation of opportunities; and the set of individuals who discover, evaluate, and exploit them." Entrepreneurship is a way of thinking, reasoning, and acting that is opportunity obsessed, holistic in approach, and leadership balanced (Timmons, 1997) and encompasses acts of organizational creation, renewal, or innovation that occur within or outside an existing organization (Sharma and Chrisman, 1999).

Although there are multiple definitions of entrepreneurship, the above definitions provide a foundation for describing the entrepreneurial phenomena in an emerging industry, especially at the individual level in terms of the cognitive process of thinking and reasoning and the entrepreneurial behavior of action and reaction in the discovery, evaluation and exploitation phase of an opportunity, and at the firm level with acts of organization creation within or outside an existing organization.

The entrepreneurial process involves a great deal of technical, market and competitive uncertainty, which can only be managed by having or acquiring information and knowledge which offsets the gravity of the uncertainty in question.

Entrepreneurship is also a process that unfolds over time and moves through distinct but closely interrelated phases of discovery, evaluation and exploitation. At every stage individual-level variables, group or interpersonal-level variables, societal-level (technological, societal and economic conditions) variables play a role (Baron and Shane, 2007).

2.2 Entrepreneurial Traits, Motivation, Cognition and Behavior

Up until the nineties, a core focus of research in entrepreneurship was entrepreneurial innate characteristics, traits and personality, with a long tradition of empirical studies seeking to determine entrepreneurs as being distinctive in particular ways, especially in risk taking propensity and the need for achievement (Brockhaus, 1980).

In contrast to the trait perspective, Gartner (1988) describes entrepreneurship as a role that individuals undertake to create organizations and the behavior of the individuals is what enables organizations to come into existence.

The entrepreneur's passion, tenacity and skill affect organizational growth through communicated vision, goals and self-efficacy (Baum and Locke, 1989).

In the last two decades, research on the study of enterprising individuals has moved beyond the focus on entrepreneurial traits to the study of personal characteristics: motivation, cognition and behavior.

Shane, Locke and Collins (2003) argue that the development of entrepreneurship theory requires consideration of the motivation of people making entrepreneurial decisions. They assume that all human action is the result of both motivational and cognitive factors, the latter including ability, intelligence, and skills (Locke, 2000). They also argue that the variation among people in their willingness and ability to act on an opportunity has important effects on the entrepreneurial process.

Entrepreneurial motivations (need for achievement, locus of control, vision, desire for independence, passion and drive) influence many aspects of human behavior.

Also the motivations of the decision makers might influence the entrepreneurial process at each of its stages, and in concert with cognitions, recognized opportunities and environmental (economic and societal) forces.

Everything we think, say, or do is influenced by mental processes and so by taking a cognitive perspective to the field of entrepreneurship, we may gain a greater understanding of the entrepreneurial process and thereby be able to assist entrepreneurs in their efforts to start new ventures (Baron, 2004).

The heart of the cognitive process is associated with seeing, deciding and acting on opportunities. Before taking entrepreneurial action, there must be a perceived opportunity and intentions toward pursuing that opportunity (Krueger, 2000).

It is postulated that both social and cognitive factors play a role in the success of entrepreneurs. The ability to get along with others and a reduced tendency to engage in counterfactual thinking is a plus for entrepreneurs (Baron and Markman, 2000; Baron, 2000).

The entrepreneurial process is initiated and implemented by individuals or a group of individuals through volition and action. Key aspects of human behavior (e.g., decision making, problem solving, self-regulation of behavior) can contribute substantially to our understanding of the process through which entrepreneurs recognize and develop new opportunities (Shane and Venkataraman, 2000).

Sternberg (2004) suggests that in order to be successful, entrepreneurs need what he terms successful intelligence – a combination of all three forms of intelligence (analytical, creative and practical abilities).

Shane et al. (2003) suggest that recent research on entrepreneurship has ignored the role of human agency and that the attributes of the decision makers in a new venture influence the entrepreneurial process.

In summary, the term “cognition” used above, refers to an act or faculty for mental processing of information (seeing, perceiving deciding), applying knowledge, problem solving skills and acting on an opportunity. Motivation in conjunction with cognitive factors influences the transition from one stage of the entrepreneurial process to the next.

However, prior research is suggestive rather than conclusive in how motivations and cognition influence the transition from discovery of an opportunity to acting on an opportunity in an entrepreneurial process. Individual skills and abilities as well as knowledge of the industry and technology are seen as critical to success, but the acquisition, transformation and use of knowledge during this transition must influence the course of action and outcome. Researchers of entrepreneurship are also largely silent on the topic of emotion as being an integral part of the cognitive process.

2.3 Entrepreneurial Alertness and Action

Entrepreneurial alertness can be interpreted as "flashes of superior insight", the ability to imagine the future and see opportunities in an uncertain world (Kirzner, 1997). "Alertness must, importantly, embrace the awareness of the ways the human agent can, by imaginative, bold leaps of faith, and determination, in fact *create* the future for which his present acts are designed" (Kirzner, 1985: pp. 56). Therefore, entrepreneurship is both the alertness to new opportunities and the actions following the discovery of an opportunity (Kirzner, 1973).

The key aspect of knowledge relevant to entrepreneurship is "not so much substantive knowledge of market data as alertness, the "knowledge" of where to find market data. Once one imagines knowledge of market data to be already possessed with absolute certainty, one has ….imagined away the opportunity." Kirzner further clarified, "I view the entrepreneur not as the source of innovative ideas ex nihilo, but as being alert to opportunities that exist already and are waiting to be noticed" (1973: pp. 74).

Alertness depends on what agents know at some point in time and thus agents tend to discover what is in their interest to discover. However, entrepreneurial alertness and the possession of knowledge are not identical. Alertness is a prerequisite but not sufficient for entrepreneurial actions to operate effectively. Capabilities are necessary for the existence of entrepreneurial activity (Sautet, 2000).

Individual receptiveness and the ability to use information to create new means ends frameworks from pieces of information are the key attributes of alertness (Kirzner, 1997). Therefore, alertness is the discovery of an opportunity and the proactive coordination of information and knowledge inputs across space and time converts the discovery of the opportunity into an entrepreneurial action.

Entrepreneurs interact over time in a “multilayered web of relations” with other heterogeneous individuals. Individuals differ because their environments equip them with different information. They interact in a complex system in many different ways, evolving and adapting to each other, learning from each other, and sharing information and knowledge. Throughout the process, the agents in this complex system do not just passively respond to events but adapt trying to actively exploit whatever happens to their advantage. It is impossible to determine ex ante the final amount of entrepreneurial activity that will prevail, but the outcome of events is dependent on two elements: distribution of information and alertness. Therefore, information asymmetries create unexploited entrepreneurial opportunities (Minniti, 2004). It is the variation in information and knowledge held by alert entrepreneurs that serves as the basis for the discovery of opportunities. Knowledge problems or market misperceptions are identified, followed by entrepreneurial action directed towards the future.

Entrepreneurship is not simply the sum of individual actions but emerges as the unintended consequences of entrepreneurial choices, suggesting that the rate of entrepreneurship may depend less on the characteristics of individuals than the relationships between them (Minniti, 2004).

According to Mises, before there can be action, there must be thinking: "Man is in a position to act because he has the ability to discover casual relations which determine change … Acting requires and presupposes the category of causality: Only a man who sees the world in light of causality is fitter to act…" (1949: pp. 22). Thus, an entrepreneur acts on a definite idea about new potential opportunities or casual relationships, after mentally processing the information/ knowledge environment. Action allows the entrepreneur to adjust or correct their prior knowledge with new information or knowledge, leading to further action.

Mises declared that the entrepreneur "imagines conditions which suit him better, and his actions aims at bringing about this desired state" (1949: pp. 13). In essence, it is a belief that the outcome of future events can be rendered more satisfactory than they would be without entrepreneurial action. It is the dissatisfaction with the present that urges the entrepreneur to search for opportunities and to hold an expectation that his or her actions can improve the future. It is this uneasiness or self-driven desire to seek improvement, often created by past actions that are no longer capable of achieving their desired end that impels the entrepreneur to consciously search for a new opportunity and to make the decision to exploit the opportunity (Mises, 1949).

Entrepreneurial alertness can also be described as a distinctive set of perceptual and cognitive processing skills that direct the opportunity identification process (Gaglio and Katz, 2001).

Mental representation, interpretation and assessment of market events, situations, informational clues and changing environmental cues underpin the cognitive process of opportunity discovery if driven by entrepreneurial alertness. Identification or creation of an opportunity does not necessarily mean the opportunity will be pursued (Gaglio and Katz, 2001). Intrinsic motivation facilitating creative thinking is a crucial stimulus behind entrepreneurial action.

In perceiving and managing business risks, "entrepreneurs accept risk as given and focus on controlling the outcomes at any given level of risk; they also frame their problems spaces with personal values and assume greater personal responsibility for the outcomes" (Sarasvathy et al., 1998: pp. 217).

Alertness is not an attribute solely endowed by entrepreneurs, but rather everyone may be alert to certain kinds of information depending on the prevailing circumstances. Prior knowledge, experience or exposure to knowledge about a market condition, technological process and or production operation might generate an absorptive capacity that allows individuals to comprehend or interpret the value of information as it relates to other information. The ability to recognize the value of new, external information, assimilate it and apply to commercial ends is critical to the innovation process (Cohen and Levinthal, 1990). The innovative performance of an entrepreneurial firm or team is a function of the level of prior knowledge and the ability to exploit external sources of knowledge to generate new knowledge.

In summary, how market environments are conceived in the minds of entrepreneurs is dependent on the ability of the entrepreneur: to identify entrepreneurial opportunities, to recognize cross-linkages and patterns between conforming and non-conforming information, to view new information in terms of opportunities rather than risks, to self-motivate, to collect and process knowledge and to transform knowledge into innovation through entrepreneurial action and creation.

2.4 Innovation Process

Innovation that links market and technological opportunities is central to entrepreneurship (Drucker, 1985). Multidimensional in nature, at the operational level there are essentially three kinds of innovation in every business: innovation in product, process or service; innovation in the marketplace; and innovation in the various skills and activities needed to make the products and services and to bring them to market.

At the strategic level, there are at least two types of innovation in which firms can engage – disruptive and sustaining (Christensen, 1997). Sustaining technologies improve the performance of established products, while disruptive technologies bring to a market a very different value proposition. In general, disruptive innovation produces revolutionary change in markets while sustaining innovation leads to incremental change (Tushman & O’Reilly, 1996).

The Austrian economist Schumpeter had a theory of disruptive innovation essential to capitalist progress in which creativity led to the destruction of existing products, services, and market relationships by the profit-seeking actions of individuals (Schumpeter, 1934). By innovating, the entrepreneur thus disrupts the economic status quo, and as a result creates new market opportunities.

Therefore, the process of change involves creation and destruction as opposing poles of the entrepreneurial phenomenon.

But not all entrepreneurial efforts require Schumpeterian innovation spurring creative destruction, another perspective is provided by Kirzner (1973) who argued that the existence of opportunities requires only differential access to existing information.

Most founders of new technology firms come from existing firms in the same technology sector as the new venture. Most customers of new firms are established ones and often the same customers of the firm from where the founder originated. Most technologies used by new firms stem from knowledge created within established ones. This leads to the conclusion that most entrepreneurial opportunities are Kirznerian because most opportunities are constructive to established ways of doing things (Aldrich, 1999).

A Kirznerian opportunity involves entrepreneurial alertness and the recognition of an opportunity primarily through the process of discovery, whereas a Schumpeterian opportunity involves the creation of new knowledge, as well as its recognition (Aldrich, 1999). Therefore, a Schumpeterian opportunity breaks away from existing knowledge while a Kirznerian adapts existing knowledge.

Kirznerian opportunities reinforce established ways of doing things, whereas Schumpeterian opportunities disrupt the existing system (Shane, 2003).

The Schumpeterian and Kirznerian perspectives argue that the entrepreneurial process requires some form of innovative activity whether market, technological, organizational or financial innovation.

This innovation, the recombination of resources to create a new form of process, product or service, can be a ground breaking advancement or can be an innovative action involving discovery, emerging from alertness to new opportunities. The difference between Schumpeterian and Kirznerian innovation is the former involves the introduction of new information and the creation of knowledge superior in nature than differential access to existing information.

In the emergence of a high-tech industry there must be a point in time when the industry transcends from the creation of new knowledge (Schumpeterian) to the adaptation of existing knowledge (Kirznerian), and this change must also be reflected at some stage in the workings of the market process. This is not to say that Schumpeterian innovation stops at some stage in the emergence of an industry, but rather Kirznerian innovation prevails until such time as the industry is shocked by a new wave of technological advancement and adoption, a disequilibrating entrepreneurial activity for lowering costs and providing new and enhanced products and services.

2.5 The Nexus of the Individual and the Opportunity

Entrepreneurship in the creation of a new high-tech venture involves a sequential process and can be defined as the discovery, evaluation and exploitation of opportunities to introduce new goods and services, ways of organizing markets, processes, and raw materials through organizing efforts that previously had not existed (Venkataraman, 1997; Shane and Venkataraman, 2000). Venkataraman argues that the why, when and how certain individuals exploit opportunities appear to be a function of the joint characteristics of the opportunity and the nature of the individual. The three main areas, where enterprising individuals recognize valuable opportunities while others do not, can be attributed to knowledge differences, cognition differences and behavioral differences (Shane and Venkataraman, 2000).

Before technological change leads to new processes, products, markets, or ways of organizing, entrepreneurs must discover opportunities in which to exploit the new technology (Shane, 2000).

Potential entrepreneurs will discover different opportunities in a given technological change because they possess different prior knowledge (Venkataraman, 1997). Therefore, the discovery process is affected by prior knowledge and the ability to think laterally about problems associated with the potential opportunity which leads to the identification of more innovative opportunities (Shepherd and Detienne, 2005).

Building on this concept of discovery and exploitation, the entrepreneurial process of a technology venture involves much more of an enacted process of improvisation than an organized process of design and execution (Shane and Venkataraman, 2003). Time and again, an ability to improvise is a critical feature of the entrepreneurial venture in the face of ever changing technologies and external market conditions.

In summary, the nexus of the individual and the opportunity is considered the building block for a better understanding of the entrepreneurial phenomenon. This phenomenon requires the action of individual(s) who identify and pursue an opportunity. The sequence of events is discovery, evaluation and exploitation of an opportunity. The discovery is an individual cognitive process affected by prior knowledge, whereas the evaluation and exploitation of an opportunity can be a collective process.

If we relax the assumption that the innovation is associated with a Kirznerian opportunity, then the alert individual discovers the opportunity with limited input of new information.

However, being exposed to a possible entrepreneurial opportunity does not necessarily mean that the individual will recognize and act on the opportunity. Alertness means "a state of readiness to take action" which implies a predisposition to react.

Therefore, there must be some sort of trigger to push or pull an individual into an entrepreneurial process or the individual is compelled by negative or positive forces to search for opportunities. The question, therefore, becomes one of determining the individual factors that trigger change in a knowledge based industry at the discovery, evaluation and exploitation stage of an entrepreneurial process.

2.6 Prior Knowledge and Early Mover Advantage

Entrepreneurial opportunities exist because different people possess different information (Kirzner, 1997) and the opportunity discovery is a function of information in society (Kirzner, 1973). Because information is often distributed through a random process, some people possess information that others do not have through sheer luck (Nelson and Winter, 1982).

Through in-depth case studies, Shane (2000) argues that any given technological change will generate a range of opportunities that are not obvious to all entrepreneurs and they can and will discover these opportunities without searching for them. From another perspective, any given entrepreneur will discover only those opportunities related to his or her prior stock of knowledge (Venkataraman, 1997).

Empirical evidence supports the claim that early entry into, or the creation of, a market provides early mover advantages and thus increases profit potential. However, empirical research also suggests that pioneers, in general, have a greater risk of failure than later entrants (Lévesque and Shepherd, 2002). Mitchell (1991) argues that later entrants know more about the technical market, and competitive conditions than do earlier participants and so can fit their operations to the conditions. The disadvantages of being a first mover can arise particularly when new ventures enter an industry before technological and market uncertainties are resolved.

Prior knowledge, developed from work experience and education, is important to the process of entrepreneurial discovery, and influences an entrepreneur's ability to comprehend, infer and exploit information. However, in an emerging knowledge intensive industry, the prior knowledge of a single entrepreneur is insufficient to deal with all the variables and uncertainties confronting a new venture.

2.7 Community Perspectives of Entrepreneurship

Van de Ven and Garud (1989) propose an infrastructure for viewing an industry as a social system, emphasizing that the creation of an industry is a collective achievement requiring industry members (community of practice) and organizations both in the public and private sectors (networks of practice) performing critical functions to develop and commercialize a new technology. This infrastructure includes (i) institutional arrangements to legitimate, regulate, and standardize a new technology, (ii) resource endowments of scientific and technical knowledge, professional services, financing mechanisms and a pool of competent labor, (iii) the creation of a market of customers for products and services (iv) a population of competing firms and (v) proprietary technology and domains of activity.

In an emerging industry, successful entrepreneurs do not act in isolation but operate in a community made up of a population of engaging (e.g. competitors) and interdependent organizations (e.g. customers) that constitute the value chain. Thus, the success of a venture may be dependent on the actions of other entrepreneurs throughout the community (community perspective). The dynamics of a new industry creation is influenced by a range of entrepreneurial behaviors in supporting innovation and imitation, and ultimately determines the success of a collective process of entrepreneurship (Mezias and Kuperman 2000).

Van de Ven (1993) describes the entrepreneurial activity of cooperation and competition in the emergence of a new industry as "Running in packs", meaning that entrepreneurs coordinate with others as they develop and commercialize their innovation.

Strategic entrepreneurs form relationships with suppliers and customers as a way of acquiring knowledge, supplementing internal skills and generating new capabilities within the firm to exploit new opportunities (Macpherson, Jones and Zhang, 2004).

Cliff et al. argue that individuals with extensive experience in the core of an organizational field are more likely to act as "imitative entrepreneurs" in launching a new venture, reproducing existing routines, even if they question the ethical legitimacy (2006).

In summary, individual entrepreneurs may be more successful in pursuing the entrepreneurial path if they recognize that their success is dependent on the actions of other entrepreneurs within the community. Therefore, entrepreneurship along the value chain can create an opportunity for entrepreneurial activity in another part of the community.

If we overlay the collective process paradigm of entrepreneurship with the nexus of the individual and the opportunity, then it stands to reason that the interlinking mechanism which results in the acquisition or exchange of knowledge to fuel imitative or innovative activity must be social interaction.

If social interaction is the source of knowledge diffusion in a community of practice then we need to query the dimensions which trigger or facilitate this propagation at the individual, firm and industry level.

2.8 Knowledge Spillovers and Social Networks

Distinctive "Knowing How" capabilities are crucial to the performance of a person, a firm and an industry (Ryle, 1949), and it is the spill over of such knowledge which helps to fill the gaps in the imperfect knowledge of others. Knowledge is not only dispersed and incomplete but also changing, and assembling new combinations is the characteristic role of Schumpeter's entrepreneurs (Loasby, 1998 and 2002).

Public and private channels of communication play a central role in the transfer of useful know-how or information in a knowledge intensive industry (Appleyard, 1996). Access to knowledge can occur either through public channels: Internet, patents, newsletters, popular press, trade journals, professional conference presentations, industry association meetings, standards groups and trade shows; or through private channels: email, telephone, face-to-face meetings, networking with suppliers and customers, and visits to other companies' facility.

Innovative companies that exit an industry leave a lasting legacy and provide knowledge spillover benefits to surviving firms (Knott and Posten, 2005). Employee mobility, formal or informal interpersonal contacts and reverse engineering allow for the continued diffusion of the firm's technology. However, accessibility to private knowledge embedded in the firm's organizational structure is hampered (Hoetker and Agarwal, 2007).

Patents represent codified public knowledge revealed through the publication of patent applications and patents granted, thus enabling access to knowledge by firms other than the originators (Jaffe, 1986).

Tacit knowledge is private knowledge generated by the efforts of individual inventors and entire teams of employees, and resides at different levels within the social structures of organizations. Private and public knowledge are complementary requisites for the creation of new knowledge. Employee mobility is a key mechanism for knowledge diffusion (Almeida and Kogut, 1999) and for accessing private knowledge to reduce the tacitness and stickiness of knowledge (Von Hippel, 1994).

However, even when all (or most) of a team are able to move en masse to another firm, they face the challenge of functioning under new management and incentive systems (Hoetker and Agarwal, 2007).

Hoetker and Agarwal suggest from a technology strategy perspective that "firms should actively incorporate failed or failing companies in the sources of innovation from which they draw" (2007: pp. 464).

The process of organization emergence can be understood and predicted by viewing it as a quest for legitimacy. Strategic legitimacy by "engaging in improvising and resource combination behavior" to improve the perception by potential customers, employees and financiers may be more important than “conforming” legitimacy in explaining the emergence of an operational organization (Tornikoski and Newbert, 2007: pp. 313).

Research has shown that knowledge spillovers are geographically localized by comparing patent citations (Jaffe, Trajtenberg and Henderson, 1993).

On the other hand, it is argued that the propensity for innovative activity to cluster can be ascribed to the role of knowledge spillovers and not merely the geographic concentration of production (Audretsch and Feldman, 1996). More recent studies have also empirically verified that knowledge diffusion operates within geographical boundaries as much of the knowledge is tacit and uncodified, requiring personal contact and spatial proximity to be transmitted. And, the geographical concentration of rivals enhances competitiveness and stimulates innovative activity, firm growth, and entry (Baptista, 1999 and 2000).

Crucial to the survival and performance of a new venture pursuing radical innovation is how social network ties (strong and/or weak) support the entrepreneurial processes, i.e. discovery of opportunities, securing resources, and gaining legitimacy.

Strong ties are important in securing critical resources and facilitating the exchange of tacit knowledge and trusted feedback on the nature and viability of opportunities.

Weak ties (strangers in personal networks) are more beneficial in obtaining socio-political legitimacy (Elfring and Hulsink, 2003), and affect the speed with which information circulates to personal network members (Granovetter, 1973).

Knowledge diffusion associated with science-based innovation stems from the norm of openness and the incentives to publish which leads scientists to codify knowledge to a greater degree, thereby diffusing new knowledge to all capable of receiving it (Sorenson and Singh, 2007).

Strategic alliances form when firms are in vulnerable strategic positions either because they are competing in emergent or highly competitive industries or because they are attempting pioneering technical strategies. Also, firms in strong social positions led by experienced and well connected top management teams are more likely to cooperate with other firms (Eisenhardt and Schoonhoven, 1996).

Labor poaching is a key source of knowledge spillovers in high-tech industries, bestowing a competitive advantage for entrepreneurial firms (Alsleben, 2005).

In summary, Information and knowledge created by innovative technical firms which have exited an industry can be acquired by others paying only a fraction of the initial development costs incurred by the originator.

Employee mobility between rival firms represents another vehicle for the spread of information and knowledge among innovative firms along the value chain.

Through social networks (strong and/or weak), enterprising individuals search or uncover additional information about an opportunity.

The publication of patent applications reveals to the public detailed information concerning apparatuses, production processes, product attributes and manufacturing techniques, providing ideas and information for others to circumvent the inventive steps outlined in the patent claims.

Numerous studies have analyzed firm-level data on patents and patent citations to quantify the extent and impact of knowledge spillovers across geographical locations (for example, see Jaffe, 1986; Jaffe et al., 1993; Stolpe, 2002).

Referencing or citing "prior art" from patents and published patent applications, reveals the inventor's awareness of existing public knowledge upon which the citing patent builds. Some knowledge flows from the cited prior art, but in an industry characterized by rapid technological change and cumulative innovation, information pertaining to a new invention is more likely to be outdated by the time the patent or application associated with the invention is published by the United States Patent and Trademark Office (USPTO).

In the emergence of a high-tech industry knowledge spillovers can conceivably be a self-perpetuating process: a continuous human activity combining private and public knowledge with new inputs to facilitate the creation of still more knowledge.

Despite the utility of understanding the mechanisms of gathering knowledge through public and private channels, the literature is deficient in two ways: firstly, it has not fully addressed the role of agency where employees' motivation is not aligned to their firms' objectives, and the transfer and exchange of knowledge is through channels with limited legal recourse. Secondly, a glaring deficiency in past research in analyzing patents is ignoring the mechanisms of communication that actually permit knowledge to disseminate.

2.9 Agency Problem in a Knowledge-Intensive Industry

Agency theory is concerned with exchanges in which one party (principal) delegates knowledge-intensive tasks to another party (agent) or other parties (agents) who perform the tasks.

It is founded on the triad of agent opportunism, information asymmetry and risk preferences, along with an emphasis on efficiency. It is concerned with solving two problems: differing attitudes towards risk and the agency problem between principal and agent that are indigenous to a wide range of business transactions (Eisenhardt, 1989b).

Different risk preferences may lead to different actions, whereas the agency problem has three sources of tension: conflicting goals or incentives between the principal and the agent, information asymmetry between the principal and the agent, and difficulty in observing, monitoring and measuring agent's behavior and the outcome of the agent's work. As Eisenhardt aptly notes, "Overall, the domain of agency theory is relationships that mirror the basic agency structure of a principle and an agent who are engaged in cooperative behavior, but have differing goals and differing attitudes towards risk" (1989: pp. 59).

Agents pursuing their own interests at the cost of principals define agent opportunism, and can stem from information asymmetry between the principle and the agent. Specialized agents have better knowledge about their own skill and capabilities, work autonomously and know how effective their performance impacts the success of their employers. This kind of information asymmetry may lead to misrepresentation of the ability by the agent, resulting in action or behavior which may undermine the principals' interest.

In a knowledge organization, agency problems arise from conflicts or disagreements between decision makers (principal(s)) and highly skilled workers (agent(s)) related to a task, project, strategy, opportunity or technology, caused by information asymmetry and risks in the agency relationship or misalignment of objectives.

Technology entrepreneurship is a collective process that builds upon the efforts of many actors who have the ability and skills to discover, create and exploit opportunities that lie beyond the reach of most. Adopting a socialized view of actors, the development and emergence of a technological path cannot be attributed to any one individual actor, but rather involves the efforts of a multiplicity of actors. Technology generates as it accumulates knowledge inputs from actors and actors become interwoven into emerging paths they shape in real time with certain events triggering greater involvement (Garud and Karnøe, 2003).

Therefore, the development of technologies entails not just an act of discovery by alert individuals or speculation on the future, but also the creation of a new path or new opportunity through the distributed efforts of many actors (Garud and Karnøe, 2003).

Departing from a conceptualization that vests agency with specific individuals, Garud and Karnøe (2003) suggest that human agency is distributed across actors who are embedded in emerging technological paths.

Thus, agency theory may offer a theoretical perspective that can explain the complex motives and concerted actions of actors in shaping knowledge spillovers and new technologies in an emerging industry.

2.10 Industry Emergence

The generation of new knowledge based innovations is important not just to firms but also to regions and States (Drucker, 1993; Schumpeter, 1934). New growth theory argues that innovative activity is a key determinant of growth (Romer, 1990; Krugman, 1995). Regions that have successfully 'spawned' the commercialization of new technologies have enjoyed significant economic benefits (Audretsch and Lehmann, 2005). Therefore, the question of how innovation leads to the emergence of new industries is an important one.

Understanding the processes by which new industries emerge is of interest to scholars of entrepreneurship (Schumpeter, 1934; Romanelli and Schoonhoven, 2001), of economic growth (Audretsch, 1995; Porter, 1990), and of organizational studies (Aldrich, 1999; Hannan & Freeman, 1977). Industry emergence is typically described either in terms of innovations created and exploited by existing firms or by new firms. Innovation can occur within established organizations, reflecting a process of adaptation and transformation over time (Chandler, 1990; Child, 1997). An alternative perspective emphasizes that innovation, and hence the emergence of new industries, occurs through the creation and entry of new organizations (Hannan and Freeman, 1977; Aldrich, 1999).

Innovative insights occur when individuals are within existing organizations, as organizations are a store of knowledge (March, 1991). As innovation is important to organizational survival, organizations might be expected to seek to commercialize such innovations. However, there are a number of reasons why this might not occur. First, the economic outcomes of innovation are unpredictable, and the process of seeking to innovate can damage a firm's short term performance (March, 1991).

Second, organizations are often characterized by 'inertia' (Weick, 1995). Powerful forces from within organizations and from the external environment may promote stability in organizational strategy and structure. For example, managers may promote consistency in strategy as a means of defining the organizations purpose and thereby increasing customer loyalty and aiding in the attraction of resources to the firm. Third, the population ecology perspective argues that selection forces may positively 'favor' organizational forms that are characterized by structures that are difficult to change, leading organizations to under invest in innovation (Hannan and Freeman, 1984). Fourth, the cognitive and behavioral biases that lead to failure avoidance may result in managers avoiding projects with uncertain outcomes (McGrath, 1999).

An alternative explanation of industry emergence emphasizes the importance of entry by new firms during the early development of a new industry. Extant evidence suggests that many new industries are characterized by high levels of entrepreneurial activity during the early phases of development (Aldrich, 1999). Audretsch and Fritsch have argued that the mechanisms through which innovations occur differ across time and space, referring to specific times when new firms, as opposed to incumbent firms, have the advantage (2002). During these times, referred to as 'entrepreneurial regimes', the knowledge generated in some organizations 'spills over', as individuals seek to commercialize their innovations through the creation of a new firm. Acs and Audretsch have shown that small entrepreneurial firms are the driving force of innovative activity in certain industries, despite a lack of formal R&D activities (1988, 1990).

From a public policy practitioner perspective identifying the factors that explain the emergence of high-tech and knowledge intensive industry sectors is of particular interest. In many regions there is extensive policy efforts and investments to encourage new knowledge based economic activity. These efforts often include policies and programs to encourage and support the commercialization of technologies through the creation of new firms.

The process by which actors engage in knowledge coordination actions to generate new knowledge for an entrepreneurial opportunity is a key factor to technical progress. Understanding this process may help us to explain how new knowledge intensive industries emerge and in particular the entrepreneurial pathway which differentiates successful from unsuccessful entrepreneurial firms.

2.11 Economic Growth

The role of entrepreneurship in implementing innovations and enhancing rivalry is a key factor in stimulating economic growth. It is "at the heart of national advantage" (Porter, 1990: pp. 125). Linking entrepreneurship to economic growth means linking the individual level of many entrepreneurial actions to aggregate levels of firms, regions or industries.

Economic growth is typically measured in terms of firm growth and survival, and the entrepreneurial activity for regions to the economic performance of regions. A series of studies has identified that entrepreneurial activity, measured in terms of firm size and age, is directly related to growth. These findings hold that new firms and small firms grow systematically larger than large and established incumbents (Audretsch, 1995; Audretsch and Fritsch, 2002).

Acs (1992) claims that small firms play an important role in the economy serving as agents of change by their entrepreneurial activity, being the source of considerable innovative activity and stimulating industry evolution.

Economic growth is driven by technical progress and the accumulation of human capital (Romer, 1990). Under this framework, Romer links technical progress to the production of knowledge by research and development (R&D) workers and scientists at profit seeking firms. Knowledge spillovers are assumed among R&D workers sharing a social stock of knowledge within an economy or a sector. From empirical findings in the private sector, it is speculated that a high density of R&D workers enhances knowledge sharing and contributes to productivity of each R&D worker (Izushi, 2008).

Entrepreneurship generates growth because it serves as a vehicle for innovation and change, and therefore as a conduit for knowledge spillovers. Knowledge created endogenously results in knowledge spillovers, which allow entrepreneurs to identify and exploit opportunities. Thus, agents with new knowledge endogenously pursue the exploitation of knowledge (Acs et al., 2009).

Under the Romerian framework, growth in a knowledge intensive industry is endogenous as it is constructed by the actors who propagate, share and acquire information and knowledge over time, in performing their function to develop and commercialize new technology. Research on the effect of knowledge spillovers upon technical progress may yield valuable insights into growth dynamics of a knowledge-intensive industry

2.12 Entrepreneurial Challenges and Risk

The emergence of a new industry is a story of how individuals create Schumpeterian new combinations. Innovation, by its nature, starts with individuals (Loasby, 2001). Loasby argues that innovation requires an individual to perceive a situation as a problem and to respond to this problem in terms of 'imagining' solutions (2001). The perceptions of problems and the imaging of a solution is a situation specific event. Individuals typically draw on information that is local and perceptual in nature, what Boisot refers to as 'uncertain, weak, and fuzzy' information (1998). In seeking to develop this unstructured information into new products the challenges facing the individual, according to Boisot, are the need to understand causal relationships among underlying data and the need to identify the range of applications to which the information applies (1998). This process of creating and exploiting knowledge involves the codification and diffusion of knowledge, and therefore, over time the knowledge is more available to others.

Individuals seeking to commercialize new innovations through new firm creation face significant obstacles. This observation that the innovator faces many challenges is not new as nearly five hundred years ago, Niccolò Machiavelli wrote in *The Prince* that 'there is nothing more difficult to plan, more doubtful of success, nor more dangerous to manage than the creation of a new order of things' (1513). An emerging industry based on a technological innovation represents the emergence of a new order. It is a context defined by technological uncertainty; by the absence of established market mechanisms (Loasby, 1991); and by the absence of institutional supports for the emerging organizational forms (Aldrich and Fiol, 1994; Hannan and Freeman, 1984).

So in addition to the general entrepreneurial challenge of mobilizing resources in response to a perceived market opportunity, entrepreneurs during the early stages of an new industry may need to engage in activities that build market mechanisms, develop organizational, intra industry, inter industry and institutional legitimacy, as well as develop new technology (Aldrich and Fiol, 1994: pp. 649).

Janney and Dess (2006) contend that entrepreneurs launching a start-up operation in a knowledge-intensive industry face different challenges in attracting “idiosyncratic” resources (e.g. finance from outside investors, specialized knowledge workers) than do entrepreneurs operating within existing corporate entities. They argue that knowledge intensity also influences risk decisions. As knowledge intensity increases with the growth of an entrepreneurial firm, concerns for information asymmetry increase, as does the need to protect information and knowledge from diffusion (Janney and Dess, 2006). Conversely, as knowledge intensity increases in an emerging industry, so does the requirement on the entrepreneurial venture to acquire more information and knowledge to fuel the innovation engine. Paradoxically as it maybe, entrepreneurs in an emerging industry walk the tightrope of acquiring, sharing and protecting knowledge at different stages in the entrepreneurial process. Therefore, social capital must play a crucial role in the acquisition and protection of knowledge.

2.13 Research Questions

Informed by these perspectives on the processes by which new innovations occur and are commercialized, this research sets out to provide an empirical description and analysis of the emergence of the RFID industry. It seeks to identify the generative mechanisms that would describe and explain the evolution of a knowledge based industry in terms of the knowledge and actions of the lead inventors and entrepreneurs in the industry.

Collectively, the literature has suggested that individuals in a knowledge based industry drive the entrepreneurial process in the discovery, evaluation and exploitation stage of an opportunity through mechanisms which breed change and result in a complex interaction between individuals, firms and a community of practice.

The central research question "Why, when and how do knowledge spillovers occur in an emerging industry?" guided the literature search, but the intellectual insights from the readings have pointed to different echelons of knowledge spillover in an emerging industry which require several questions to capture all aspects of knowledge spillovers at the individual and industry level, and to provide direction in terms of the field work.

Emerging from the central research question and the literature review, the field work and interviews were shaped by four broad research questions. For research questions 1 and 2 the unit of analysis is the individual, while for research questions 3 and 4 the unit of analysis is the broader industry.

1. How do individuals identify opportunities in an emerging high-tech sector?

2. What triggers individuals to act on an entrepreneurial opportunity?

3. What is the extent and nature of innovation during the emergence of a knowledge based industry?

4. What facilitates knowledge spillovers in an emerging high-tech industry?

Given that the literature reveals possible gaps in the understanding of knowledge spillovers in the community of an emerging industry, this inductive research follows the evolution of Radio Frequency Identification (RFID) for the time frame of 1970 to 2000 with the objective to formulate a theory for knowledge spillovers.

In the next chapter, I provide an insight into the major historical inventions and trends in the emergence of the RFID industry.

CHAPTER 3 - THE RFID ERA

3.0 The History of RFID

Radio Frequency Identification (RFID) technology uses the principles of radio broadcasting and radar technology, and its history can be traced back to the discovery of electromagnetic theory.

In 1906, a Swedish-American electrical engineer Ernst Frederick Werner Alexanderson demonstrated the first continuous wave generation and transmission of radio signals.

In 1917, Nikola Tesla, a Serbian-American physicist and engineer, established principles regarding frequency and power level for the first primitive radar (Radio Detection and Ranging) unit. Radar sends out electromagnetic waves for detecting and locating an object by the reflection of the radio waves. The reflection determines the range, altitude, direction, or speed of both moving and fixed objects. Radar's significance was quickly understood by the military, so many of the early developments were shrouded in secrecy.

During World War II, the Germans were able to identify friendly aircrafts when the pilots rolled their planes in a particular way as they returned to base, effectively changing the radio signal transmitted back to the receiving station, thus alerting the radar crew on the ground that they were German planes and not Allied aircraft.

In the late 1930s, the British Air Force led by Scottish physicist Robert Alexander Watson-Watt implemented an airborne "Identification Friend or Foe" (IFF) system, the precursor of modern IFF systems.

This IFF system used an “active” transmitter installed in the aircraft which in the presence of a radar system began broadcasting a signal back that identified the aircraft as a “friend”.

RFID operates on this same principle. A signal is sent to a transponder, which wakes up and either reflects back a signal (passive system) or broadcasts a signal (active system).

The paper by Harry Stockman “Communication by means of Reflected Power” published in October 1948, describing the utilization of re-radiation from a target when the target is subjected to any kind of modulation, marks the start of radiative ultra high frequency (UHF) transponders, forty-one years before electronic toll collection was implemented.

In his visionary concluding remarks, he stated that “evidently, considerable research and development work has to be done before the remaining basic problems in reflected-power communication are solved, and before the field of useful applications is explored.”

Significant progress in Stockman’s vision would not be achieved until the development of the transistor, integrated circuits, low voltage – low power complementary metal oxide semiconductors (CMOS), electrically erasable programmable read-only memory (EEPROM), microprocessors and communication networks.

Following technical developments in radio and radar in the 1930s and 1940s, several explorations of the 1950s related to UHF transponder technology, including the works of Frank Lee Vernon’s, “Application of the Microwave Homodyne” in 1952, Donald Harris’, “Radio Transmission Systems with Modulatable Passive Responder” filed as a patent application in 1952 and the long-range transponder systems of “Identification, Friend or Foe” (IFF) for aircraft in 1959.

In March 1960, the application of Donald Harris of Palo Alto, California was granted as a patent (Serial No. 2,927,321) making him one of the first inventors of technology directly related to RFID passive tag technology. His invention relates to "radio transmission systems in which one of the stations in communication is designed to be portable, or is otherwise so located as to render its operation from commercial power supplies not feasible, or undesirable."

Research and development in RFID continued in the 1960s, with Roger Harrington investigating electromagnetic theory in his papers "Field Measurements using Active Scatterers" and "Theory of Loaded Scatterers" in 1963-1964.

Other significant RFID related inventions include Robert Richardson's "Remotely Actuated Radio Frequency Powered Devices" in 1963, Joseph Vogelman's "Passive Data Transmission Techniques utilizing Radar Echoes" in 1968, and Otto Rittenbach's "Communication by Radar Beams" in 1969.

The commercial RFID applications in the late 1960s started with the use of "1-bit" tags for electronic article surveillance (EAS) to counter the theft of merchandize. The anti-theft systems used either microwave (generation of harmonics using semiconductors) or inductive (resonant circuits) technology.

Work on RFID systems as we know them began in earnest in the 1970s. Research laboratories and academic institutions such as Los Alamos Scientific Laboratory (LASL), Northwestern University, and the Microwave Institute Foundation in Sweden were actively working on RFID.

Alfred Koelle, Steven Depp, and Robert Freyman from LASL presented their work on "Short-Range Radio Telemetry for Electronic Identification Using Modulated Backscatter" in 1975 and Bengt Henoch et al. filed a patent application on a "Device for Registration of Objects" in 1976.

Large companies were also developing RFID technology, such as Raytheon's Raytag in 1973: "An Electronic Remote Data Readout System" by Nathan Freedman, presented at Carnham Conference on Electronic Crime Countermeasures in April 1973, Fred Sterzer of RCA Laboratories developed an "Electronic License Plate for Motor Vehicles" in 1974, Richard Klensch of RCA developed an "Electronic Identification System" in 1975, Thomas Meyers and Ashley Leigh of Fairchild Industries developed a "Passive Encoding Microwave Transponder" in 1978.

In the latter systems, an interrogator illuminates a passing tag with microwave energy at one frequency. The tag radiates back a code modulated carrier at the second harmonic of the interrogation frequency.

Entrepreneurial companies, individual inventors and engineers were also active in the development of RFID. In 1973, the patent "Transponder Apparatus and System" invented by Mario Cardullo and William Parks describes a tag powered by the interrogating beam, but having both receiver and transmitter like a conventional IFF transponder. The tag also had its own read and write capability. In the same year, Ronald Palmer and Charles Walton invented a card with an embedded inductively coupled passive transponder used to gain access to a door equipped with an RF reader.

In another group of RFID systems as described in the patents "Identification System" by Donald Neild from General Electric London in 1966, "Interrogator-Responder Identification System" by Jorgen Vinding in 1967, "Improvement in or relating to Vehicle Identification Systems by John Ryley from Plessey in 1968, "Transponder for an Automatic Vehicle Identification System" by Thomas Hutton from Westinghouse in 1976, "Inductively Coupled Transmitter-Arrangement" by Thomas Kriofsky and Leon Kaplan in 1975, "Animal Identification System" by James Rodrian in 1978, "Detection Plate for an Identification System" by Harm Kip and Tallienco Fockens in 1980 and "Identification Device" by Michael Beigel in 1982, the principle of inductive coupling is exploited for object identification.

In the 70s and 80s, companies started to develop low frequency (125 KHz) transponder/reader systems, with the transponders packaged in various types of housings, such as animal tags encapsulated in glass, access control badges in the format of a credit card, and industrial tags molded in epoxy resin the shape of a coin.

Over time, newcomers to RFID moved up the radio spectrum to high frequency (13.56 MHz) and targeted select applications.

RFID systems using physical phenomenon that can be detected remotely using radio waves without the use of CMOS circuitry in the tag were developed in the early 80s, Paul A. Nysen of X.Cyte Inc. developed a surface acoustic wave (SAW) passive transponder system using piezoelectric crystal. In 1986, the Norwegian company Micro Design AS was awarded a contract with Statens Vegvesen (Norwegian Public Roads Administration) for the development of the "Q-Free" Tolling System using SAW technology. In 1988, the first Q-Free Tolling System was installed in Trondheim.

In the 90s, standard CMOS RFID chips with nonvolatile EEPROM from semiconductor vendors who had previously developed customized RFID ASICS for the pioneering companies in the 80s, permitted new participants to enter the market quickly and kick started volume manufacturing of identical tags that could be personalized through programming.

The development in the 90s of microwave Schottky diodes on regular CMOS integrated circuits permitted the construction of microwave tags that contained a single integrated circuit, a capability previously limited to inductively coupled RFID transponders. Companies active in this pursuit were IBM (the technology later acquired by Intermec in December 1997), Micron Technology (John R. Tuttle) and Single Chip Systems (Bruce B. Roesner).

RFID deployment developed somewhat differently in various parts of the world. In Europe, the greatest interests were in short-range low frequency inductive systems for livestock identification, access control and industrial applications.

In the mid 90s, high frequency inductive systems were used in automatic fare collection and in payment applications. Toll road applications using radiative transponder systems were successfully deployed in the United States.

Under the radar screen, the niche applications of access control, companion and laboratory animal tagging in the United States saw wide scale deployment.

In the 90s, the primary development effort was performance improvement of the RFID tags, production automation or outsourcing manufacturing, cost reduction programs and optimization of packaging RFID chips which demanded new process techniques.

With the emergence of ISO standards in the late 90s, RFID proliferated into new applications such as supply chain management, cashless payment, ticketing, brand authentication and electronic documentation.

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CHAPTER 4 - RESEARCH METHODLOGY

4.0 Introduction

In Chapter 3, I presented a historical account of the evolution of the RFID industry, demonstrating that advancements in the technology and commercialization required significant inventions and interaction among scientists, inventors, engineers and entrepreneurs before applications of RFID entered mainstream. I will return to the history of RFID at the end of this chapter highlighting the context under which my exploratory research was undertaken.

This research attempts to describe the process of knowledge spillovers during the emergence of a knowledge based industry, using an inductive case study approach to explore retrospectively the complex path from invention and innovation to the dispersion of information and knowledge.

My primary focus is on the diffusion (movement) of explicit and implicit (tacit) knowledge within an organization and the underlying mechanisms that influence the dispersion of such knowledge to the community (interpersonal networks).

The unidirectional transmission, exchange or spread of innovative knowledge (technological clues to solutions) over time among the members of a social system can be deliberate, unintentional or planned. Human agency, behavior, motivation and involvement of the information-providing and seeking individuals within an emerging industry are the areas of inquiry.

Since the literature (as reviewed earlier) reveals possible gaps in the understanding of knowledge spillovers in an emerging industry, grounded theory and the case study approach were deemed to be an appropriate method of use.

4.1 Research Design

To formulate a theory from data on the phenomena of "knowledge spillovers", I chose to follow in-part the systematic methodology articulated by Glaser and Strauss (1967) and Glaser (1992) for developing a grounded theory. As Glaser and Strauss (1967) pointed out "Most hypotheses and concepts not only come from data, but are systematically worked out in relation to data during the course of the research", which implies a process of discovery from the overlap of data collection, coding and interpretation.

The grounded theory approach requires not only that data and theory be constantly compared and contrasted during data collection and analysis, but also that the emerging theory drives on going data collection (Locke, 1996). "Whether the theory itself is static or developmental, its generation, by this method and by theoretical sampling, is continually in process. In comparing incidents, the analyst learns to see his categories in terms of both their internal development and their changing relations to other categories" (Glaser and Strauss, 1967: pp. 114).

Glaser underscores that grounded theory is not a qualitative research method, but advocates "whatever comes the researchers way while studying a substantive area" can be used in the comparative process. This means that during the research endeavor, not only interview or observational data, but also surveys or statistical analyses can be used.

However, I did not follow Glaser's restrained approach of maintaining distance and independence from the phenomena I was studying. Also, Glaser advocates the position that the researcher should not bring any "a priori" knowledge to the research endeavor, which is clearly not the case in my research. Instead, I leaned more towards the grounded theory approach proposed by Strauss and Corbin (1990), interrogating the data I gathered to arrive at conceptual categories.

For further analytic guidance, I have also turned to the workings of Eisenhardt (1989a) and Yin (1994) on case study research. Eisenhardt (1989a: pp. 534) defines the case study as a "research strategy which focuses on understanding the dynamics present within single settings." Therefore, the case study method has the virtue of providing an in-depth picture on a particular set of circumstances within some real-life context.

Although I have an engineering background in the RFID industry, my focus is on the discovery of theory using findings "grounded" in reality which emerge from experience based data collected from in-depth interviews with the pioneers and entrepreneurs of the RFID industry. To avoid distorting the theory discovery process with pre-existing hypotheses on knowledge spillovers, I have deliberately interviewed those individuals with whom I have had no previous business relationship or knowledge of the workings of their entrepreneurial ventures. Therefore, the primary objective of the research methodology is theory discovery rather than hypothesis testing and validation.

I started out by delimiting the research challenge to the research questions and chose a mixed research strategy of induction (qualitative in nature) and deduction (quantitative in nature) to enhance the quality of my research method and to achieve a richer understanding of the entrepreneurial processes.

However, as my research aims to study a particular subgroup of entrepreneurs in the RFID industry, the population of entrepreneurs may not be sufficiently large enough to provide a basis for statistical analysis and comparison.

4.2 Phenomenological Framework

My sampling strategy was to identify and interview all those that were involved in the pioneering phase of the RFID industry.

My focus was to write up a chronological record of events, identifying how the collective activities of the individuals and firms resulted in the birth of the RFID industry.

During the data collection phase, I analyzed each source of evidence separately and compared the conclusions from the different analyses. In using the "constant comparative method" proposed by Glaser and Strauss (1967), explanation and theory were fashioned directly from the emerging analysis of the data. This method proceeded in three stages: incidents in data were coded into categories or dimensions, properties within each category were examined and interaction of or connections between different categories were noted, and from this pattern analysis, the foundation of a theory on knowledge spillovers was generated.

I also combined multiple sources of evidence, observational data and documentation (secondary data) to complement data obtained through the interviews, a process of data triangulation. The advantage presented by using multiple sources of evidence is the development of *converging lines of inquiry* (Yin, 1994) and to reduce the likelihood of misinterpretation.

Instead of using patent citation data to investigate the phenomena of knowledge spillovers in the emerging RFID industry, I used the information presented in the patents (priority date, description of the invention and patent claims) issued to those leading firms in the animal identification technology cluster according to the syringe implantable transponder product which they produced or commercialized.

I then triangulated the data pertaining to patents in tandem with interview and secondary data to crosscheck and corroborate the timing of certain inventions. By measuring the same phenomena from different angles, an accurate and reliable picture of knowledge spillovers during the early emergent phase of the industry was ascertained. I will return to this topic in my time series analysis of patent data in chapter 5.

Following my analysis, I formulated propositions that state the relationships of the emergent theoretical framework on knowledge spillovers in the evolution of a knowledge based industry.

Throughout the analysis and proposition formulation stages of the process, I moved intensively between data, the emerging theory and earlier literature.

4.3 Identifying Interview Subjects

From the global trade association (AIM) for RFID, technical journals and Internet links to RFID companies, I was able to identify most of the high-tech entrepreneurs and inventors in the United States and Europe who have spearheaded the development, production and marketing of low and high frequency transponders during the period between 1970 and 2000. These individuals, with whom the above mentioned phenomena were or are very salient, have played a key role in driving the process of innovation within the RFID industry. This rigid approach in predetermining the individuals to be investigated goes against the grain of grounded theory which stipulates an incremental collection process of deciding after each step of analysis what data to collect next. However, in studying knowledge spillovers in an emerging industry, it is appropriate to have at the onset an overall perspective of the industry, before an interactive process of data collection and analysis can be initiated.

4.4 Pilot Phase

The pre-study phase began in October 2006, involving a number of test interviews with pioneering entrepreneurs of the RFID industry in the United States and the development of initial constructs to help shape the design of the research strategy.

The purpose of the pre-test phase (first pass at data gathering) was to explore the problem of collecting data empirically and to identify critical issues that merited deeper understanding and investigation. This approach by no means suggests a bias to aspects of the phenomena yet to be discovered, "a priori theorizing", but rather sets the direction for open-minded exploration.

As a result of the initial interviews, I re-oriented the focus of my research.

4.5 Data Collection

The case study seeks to elucidate in an emerging high-tech industry the variety of ways how entrepreneurs attract other entrepreneurs to the same opportunity and under what conditions innovation spills over to the community at large (e.g. competitors, customers, suppliers, investors, consultants, bankers, lawyers, etc). In using grounded theory, I have been flexible in my collection of data using semi- to non-structured interviews and following unexpected leads, thus there is to some degree an overlap of data analysis with data collection.

The interviews were conducted in quiet surroundings such as in hotels or in the firm's conference room and lasted, on average, three to four hours each.

I begin with a narrative retrospective description of the life stories of the entrepreneurs and their companies (in the start-up phase the entrepreneur and the company are one of the same), relying to some extent on historical recall. The basic aim was to describe the setting, the people and the events that had taken place in the RFID industry.

It is recognized that narratives are recollections of the events of the past and the entrepreneur's interpretation of these events. To avoid incorrect recollection of events, I first contacted experts and informants who had worked for the respective entrepreneurs. Each of the respondents provided a validity check on the others' recollection of events. The insights and information provided by these individuals also helped to define the boundaries of my investigation.

I chose not to use verbal history recording (actuality), although regarded as an accurate collection of the subjective evidence given by the memoirist in dialogue with the interviewer, as a number of the entrepreneurs are involved in litigation cases concerning patent infringement and wanted that their story remain confidential.

Instead, at every interview I took notes, without thinking specifically of the research questions, and just let the entrepreneurs tell their story, asking questions from time to time about some situations or events. After writing up their stories and highlighting specific quotes, I sent the written-up text (interview notes) back to them for correction. Each interview generated an insight and allowed for a unique pattern to emerge before I pushed to generalize patterns across the RFID industry.

In order to create a fuller description of the course of events, I relied on a narrative approach backed up by secondary data in the form of patent applications to pin down the timing of the RFID innovations, judgments from litigation cases concerning patent infringement, legal agreements between rival companies, shareholder agreements, business plans, memorandums, purchase orders, non-disclosure agreements, travel itineraries and contractual agreements between companies and their employees.

The main purpose of the narratives was to create and optimize an understanding of the RFID industry, to give the reader the means to recognize the critical issues and to learn from the story-telling. As exploratory research is inherently inductive in its reasoning, I balanced my qualitative evidence from interviews and observations with a systematic investigation of the timing and frequency of patent applications (quantitative data) to increase the reliability of data collected.

Therefore, to avoid interpretative subjectivity and remain objective within the paradigm of inquiry, I evaluated the raw data from my qualitative research by tracking the patterns of patenting novel ideas and inventions filed as applications at the U.S. Patent Office.

4.6 Fieldwork

The RFID industry is characterized by an entrepreneurial regime where small agile firms tended to have an innovative advantage. The industry's evolution is described in detail in chapter 3 and in table 1 at the end of this chapter.

I studied the individuals who discovered and exploited opportunities in the emerging RFID industry for the period 1970 to 2000.

As described above, I chose to follow the systematic methodology articulated by Glaser and Strauss (1967), Glaser (1992) and Strauss and Corbin (1998) for developing a grounded theory, a process of data collection, coding and analysis.

My qualitative research has involved 57 in-depth interviews (45 interviewees) around the world with the inventors and entrepreneurs who have shaped the emerging industry of RFID. The travel time to each destination was one to two days and each interview lasted three to four hours. The 45 interviewees represent 21 separate firms from the industry (refer to appendix B for details).

I have documented on 450 pages (approx. 90,000 words) the emergence of the RFID industry via a series of "stories", each of which outline the events as recalled by the 45 individuals and substantiated by secondary data in the form of newspaper clippings, photo material, company records and litigation proceedings.

I decided not to include this series of stories as part of the appendix, largely because of the overwhelming volume of diverse information which would distract away from the core theme of this endeavor, but rather I tabulated the important findings from each interview into categories and I will present my findings on each firm in my analysis of the interview data.

Given the time periods that were covered in the interviews, my interview data is liable to recollection bias. I sought to improve the reliability of interview data by collecting evidence from several sources and by interviewing respondents several times.

In addition to the interviews, I have tracked the pattern of patenting novel ideas by the players within this industry, which illustrates the timing of certain inventions and their geographical origin.

4.7 Coding

According to Eisenhardt (1989a) "analyzing the data is the heart of building theory from case studies, but it is the most difficult and least codified part of the process." In order to generate reliable theory across the 45 narrated chronologies, the search for themes and patterns make intuitive sense (Miles and Huberman, 1994).

To look at the data collected in divergent ways, Eisenhardt (1989a) advocates selecting categories or dimensions, and then look for within group similarities coupled with differences.

In practical terms, I summarized each interview into "An Introduction" and "RFID Opportunity", allowing me to identify key themes and patterns at the individual level and across firms within the RFID industry. Once recurrent themes became apparent, I returned to the interview transcripts and field notes, and began the process of coding.

This essentially meant, going through the stories to identify data fragments or incidents ranging from a word, phrase to several sentences. I categorized each of these data units to describe what was happening in each.

The interviews yielded six main categories of data analysis for the 21 innovative firms under investigation:

- Discontentment
- Exposure to Opportunities
- Alertness
- Human Agency
- Social Interaction
- Knowledge Spillover

Additional variables under the categories "Discontentment", "Human Agency" and "Social Interaction" were also defined to yield greater pattern-matching across firms with the objective of generating greater confidence in the robustness of the theory being developed in this thesis.

Additional sub-themes distilled from the data include emotional intelligence and the use of litigation to side track a rival firm in the market.

Before continuing with the analysis of the data, it is helpful to step back and summarize the grounded theory methodology employed and how the research data itself is used to generate theory.

> "….[using grounded theory] procedures and techniques…the steps of theory building [include] conceptualizing, defining categories, and developing categories in terms of their properties and dimensions – and then later relating categories through hypotheses or statements of relationships.

> Conceptualizing is the process of grouping similar items according to some defined properties and giving the items a name that stands for that common link. In conceptualizing, we reduce large amounts of data to smaller, more manageable pieces of data. Once we have some categories, we want to specify their properties. We also want to show how our concepts (categories) vary dimensionally among those properties. Through specification and dimensionalization, we begin to see patterns… Thus, we have the foundation and beginning for theory building (Strauss and Corbin, 1998: pp. 121)."

As Strauss and Corbin explain above, large amounts of data are reduced to manageable pieces of data, then the data is codified in terms of categories, the related categories are brought together in terms of statements of relationships or propositions and some of the categories are specified in terms of their properties. The emerging pattern is the foundation for theory building.

4.8 Validity and Reliability

The quality of any empirical social research should meet the same criteria of reliability and validity as the traditional scientific method. To ensure the validity of my findings, I collected data from multiple sources, wrote up interview notes which were reviewed by key informants and I developed a database of evidence in the form of electronic folders storing fact books covering the entrepreneurial stories for each of the 21 firms investigated as well as secondary data collected in the field. To answer the validity question: Did conclusions stem from evidence or was it a case of subjective interpretation? I guard against selective interpretation by making the raw data available for an external observer to inspect.

To increase the reliability of my findings, I examined all patent applications filed by the respective firms at the U.S Patent Office to establish the timing of certain innovations and the patent claims surrounding these innovations which significantly increased the rigor of my research evaluation.

4.9 Research Context: The RFID industry 1970 - 2000

In the article from Dr. Jeremy Landt "Shrouds of Time, The history of RFID" published by AIM (The Association for Automatic Identification and Data Capture Technologies) on October 1, 2001, Landt traces the ancestry of RFID back to radio broadcast and radar technology. He is one of the scientists from Los Alamos National Laboratories in New Mexico that developed the RFID technology in the 1970s for the United States federal government. The RFID industry was in its' infant stage of experimental field trials and the Los Alamos Laboratories developed animal transponders (hereinafter referred to as tags) operating at ultra high frequency (UHF) in the microwave range. During the 80's, he was one of the founders of Amtech, which specialized in active UHF tags (with batteries) for railway rolling stock identification and electronic toll road collection. The implementation of UHF tags in toll collection began in Europe in 1987 and followed quickly in the United States by a number of deployments during the early 90's. Landt's history is incomplete as he focused on UHF systems and skimmed over one of the most significant part of the RFID industry, especially in terms of volume, namely passive inductive tags for animal identification, access control, time and attendance, vehicle immobilizer systems, ski passes, ticketing, automatic fare collection, parking lot access, campus ID, micro-payment, vending and many other applications.

Commercial applications of RFID entered mainstream in the early 90s with volume production of passive inductive tags (without batteries) in the form of implantable glass tubes and plastic rings for animal identification, credit-card size badges for access control and buttons/coins for industrial applications, operating in the low frequency (LF) band (125 KHz – 134 KHz).

By the mid nineties, new technology developments in high frequency (HF) tags operating at 13.56 MHz coupled with the creation and adoption of international standards expanded the functionality of passive RFID devices, into ticketing and payment applications using the form factor of a smartcard.

Today, high frequency RFID technology is used in electronic passports for cross border control, in contactless smartcards for electronic payment transactions offering flexibility and convenience for consumers, and in proximity cards for secure building access.
RFID is also a hot topic in the fields of manufacturing and logistics, improving the efficiency of the processes in the supply chain, using UHF tags.

In the above paragraphs I have discussed the applications of RFID over several decades, without specifically describing the technical functionality of an RFID system. Before embarking on the analysis of data and in effort to avoid getting lost in technical jargon, it suffices to say that a typical RFID system consists of tags, readers, application software and a computing hardware system. The system with which the reader communicates usually runs software that stands between readers and applications. This software is called middleware.

A passive tag (without batteries) is an identification device storing information about an object (for tracking purposes); an animal or a person (for identification); a person's credentials (for payment transactions), consisting of an integrated circuit (IC) with a memory, connected to an antenna and packaged in a housing in various form factors.

A reader is a device that can recognize the presence of a compatible tag (operating on the same frequency and under the same communication protocol) and read or write data to the memory of the tag.

A passive tag draws its energy for communication from the electromagnetic field generated by a reader. The reader can then inform another computing system via a wired or wireless network about the presence of the tracked item, the identity of a person at a security check or the country of origin of an animal scanned.

With this background on the history and application of RFID, my research focuses primarily on the pioneers of low and high frequency passive tags in the period between 1970 and 2000 which is deemed to capture the emergence of the RFID industry, as we know it today.

From my comprehensive research into the history of RFID, my analysis of technical journals and patents, an attempt is made to provide an overview of the stages in the emergence of the RFID industry as outlined in table 1 "RFID Timeline." This table illustrates chronologically the early explorations of RFID prior to the 1970s, the pioneering phase of inventions in the 70s and early 80s with the transition from analog to digital technology, and the shift from inventions to incremental innovations from the mid 80s.

Table 1

RFID TIMELINE

Radio Frequency IDentification

Early Explorations of RFID prior to the 1970s

1900 - 1969

1906	Ernst Frederick Werner Alexanderson demonstrates the first continuous wave generation and transmission of radio signals.
1917	Nikola Tesla establishes principles regarding frequency and power level for the first primitive radar (Radio Detection and Ranging) unit.
1935	The British Air Force led by Scottish physicist Robert Alexander Watson-Watt implements an airborne "Identification Friend or Foe" (IFF) system, the precursor of modern IFF systems.
1946	Léon Theremin develops the technique of using modulated backscatter from an RF beam powered device.
1948	The paper by Harry Stockman "Communication by means of Reflected Power" describes the utilization of re-radiation from a target when the target is subjected to any kind of modulation, and marks the start of radiative UHF transponders.
1952	Frank Lee Vernon publishes his work on "Application of the Microwave Homodyne."
1952	Donald B. Harris files a patent application entitled "Radio Transmission Systems with Modulatable Passive Responder" making him one of the first inventors of radiative technology directly related to RFID passive tag technology.
1952	Norman J. Woodland and Bernard Silver invent those ubiquitous black and white lines found on virtually all consumer products, namely linear barcodes.
1959	Identification Friend or Foe (IFF) long-range transponder systems for aircraft, reaches breadboard demonstration stage.
1963-1964	Roger Harrington investigates electromagnetic theory in his papers "Field Measurements using Active Scatterers" and "Theory of Loaded Scatterers."
1965	Jorgen Vinding files a patent application describing an identification system for identifying responders when brought within inductive coupling proximity of an interrogator.
1966	Arthur J. Minasy develops the first electronic article-surveillance (EAS) device, the now-ubiquitous small tags and disks attached to store merchandize to counter theft.

1970s - Pioneering Phase - Transition from Analog to Digital Technology

1970 - 1979

1970	Mario Cardullo and William Parks file a patent application entitled "Transponder Apparatus and System" describing a tag powered by the interrogating beam, having both receiver and transmitter like a conventional IFF transponder. The tag also has its own read and write capability.
1970	Leon M. Kaplan and Thomas A. Kriofsky file a patent application entitled "Inductively coupled passive responder and interrogator unit having multi-dimension electromagnetic field capabilities", generating a unique predetermined electromagnetic coded information field in response to the presence of the electromagnetic power.
1973	Ronald Palmer and Charles Walton invent a card with an embedded inductively coupled passive transponder used to gain access to a door equipped with an RF reader.
1974	Roland Moreno invents the concept of a contact memory card. The first mass use of the cards is for payment in French pay phones, starting in 1983.
1975	The scientists, Alfred Koelle, Steven Depp, and Robert Freyman, at Los Alamos Scientific Laboratory (LASL) present their radiative RFID work to the public sector on "Short-Range Radio Telemetry for Electronic Identification Using Modulated Backscatter."
1976	The first company which attempts to commercialize the developments at LASL is Identronix, formed through the efforts of J. Coleman Hensley, the USDA liaison officer from the Department of Agriculture stationed at Los Alamos.
1973-1978	Large companies were also developing radiative electronic identification systems: Raytheon, RCA Laboratories and Fairchild Industries.
1977	Harm Kip and Tallienco Fockens of Nedap file a patent application entitled "Detection Plate for an Identification System", which describes a digital circuit comprising a resonant circuit, switching device and coding method.
1977	Nedap begins supplying molded neck collar identification tags for cattle to equipment suppliers of automatic feed systems.
1979	Michael Beigel of Triple I invents the first miniaturized implantable tag and files a patent application entitled "Identification Device" describing a closed coupled identification system for verifying the identity of an animal, object or other thing, has a probe including a circuit adapted to be connected to a source of alternating current and a separate, preferably miniature, circuit adapted to be implanted within or attached to the animal, object or thing.

1980s - Early adoption of RFID

1980 - 1989

1983 France Rode of Sielox develops the first digital electronic proximity identification system operating at the preferred frequency of 13.56 MHz.

1983 Paul Nysen of X-Cyte develops surface acoustic wave (SAW) passive transponder technology.

1984 Thomas Milheiser of IDI, files a patent application on an inductive coupling identification device employing frequency shift key demodulation and Manchester encoding.

1984 The second company to spin-off from LASL is the Amtech Corporation.

1984 From IDI, the beginning of electronic identification of animals as we know it to day, in which glass encapsulated microchips are implanted under the skin of an animal using a 12 gauge hypodermic needle.

1986 The Norwegian company Micro Design AS is awarded a contract with the Norwegian Public Roads Administration for the development of the "Q-Free" Tolling System using SAW technology. In 1988, the first Q-Free Tolling System is installed in Trondheim.

1986 Theodore Geiszler of Indala is the father of capacitive coupling, inventing an electrostatic proximity card powered by magnetic coupling with an RFID reader.

1987 Texas Instruments (TI) in Almelo, Netherlands is confronted with a Dutch project to supply a small implantable device for electronic identification of livestock. In 1989, a separate division for RFID is established under the trade name TIRIS.

1987 EM Microelectronics Marin develops an RFID ASIC for the access control company Chubb Lips in Dordrecht in the Netherlands. The antenna for the transponder chip is integrated into the silicon device, a technique called "coil on chip."

1989 Josef Schuermann of TIRIS in Germany invents an inductive low frequency RFID tag employing half duplex communication.

1989 Amtech designs, manufactures and installs the first North American electronic toll collection system in Dallas, Texas.

1990s - Commercial Applications of RFID enter mainstream

1990 - 1999

1991 Hughes Aircraft acquires the access control business from IDI and establishes the entity Hughes Identification Devices, later renamed HID.

1991 Åke Gustafson of Sokymat automates the production of glass encapsulated transponders using a technique of flyer winding and directly connecting the ultra fine wire ends of a microcoil to gold bumps on an RFID chip.

1993 Roland Koo of Mikron recognizes the opportunity in automatic fare collection and sets about to develop a contactless smart card chip operating at 13.56 MHz, baptized "Mifare" as a replacement for tickets in mass transit.

1993 Insurance companies in Germany forces luxury car manufacturers to use an immobilizer device to prevent a vehicle from being "hot wired" after entry is achieved.

1994 AmaTech develops the wire embedding technology that revolutionizes the manufacture of transponders for high frequency (HF) contactless smart cards. In 1997, AmaTech completes the development of the prelaminated inlay which is the inner sandwich layer of a contactless smart card or electronic passport.

1995 Theodore Geiszler of Motorola Indala invents the BiStatix technology, a radio frequency identification tag deriving power from an electrostatic field generated by a nearby reader. The breakthrough in the technology happens at silicon packaging in 1997, when a capacitive coupling RFID chip is mounted on a flexible substrate with two printed ink electrostatic antennas.

1997 Hans-Diedrich Kreft of Angewandte Digital invents the dual interface (contact/contactless) chip card.

1999 The Auto-ID center is created to develop the Electronic Product Code (EPC), a global RFID-based item identification system intended to replace the Universal Product Code (UPC) barcode symbology used for tracking trade items in stores.

2000s - Emergence of Standards & Wide Scale Deployment

2001 - ....

2001 Alien Technology acquires WaveID and develops UHF tags based on EPCglobal standards. In addition, Alien mounts silicon dice on substrates using Fluidic Self Assembly (FSA).

Source: Author

CHAPTER 5 - TIME SERIES ANALYSIS OF PATENT DATA

5.0 Introduction

The priority date on patent applications allows one to track the timing of innovative ideas by the pioneers of the industry.

Starting in June of 1995, inventors in the United States have been able to file a provisional application on a novel idea and are allowed a “grace period” of one year from the date of filing to complete the patent application with additional material related to the original subject matter. The patent application is made public 18 months after the first filing date, the so-called priority date, for everyone to view.

Prior to June 1995, there were only non-provisional applications (utility and regular) and the publication thereof was the date the patent application was granted. This meant that patent applications prior to June 1995 remained a secret until the day of publication and depending on the number of consultations with the examiner at the U.S. Patent Office concerning patent claims, the duration between application filing and publication could theoretically range from 18 months to several years.

According to U.S. patent law (35 USC § 102), a person shall be entitled to a patent unless the invention was patented or described in a printed publication in the United States or a foreign country or in public use or sale in the U.S., more than one year prior to the date of application for patent in the United States.

Each individual associated with the filing and prosecution of a patent application has also a duty of candor and good faith in dealing with the U.S. Patent Office, which includes a duty to disclose to the Office all information known to that individual to be material to the patentability of any claim in his or her application.

The pertinent question in the evolution of the RFID industry is "What facilitates knowledge spillovers during the emergence of the industry?"

An important innovation in the RFID industry was the development of the syringe implantable glass encapsulated transponder. I will now track the patents related to this innovation, and in the process describe the interactions between those individuals and firms filing such patents.

5.1 Syringe-Implantable Transponder for Animal Identification

5.1.1 International Identification Inc.

International Identification Inc. (Triple I) was established in 1978 based on the idea from Eugene Moses to implant an identification device in animals. The founding members were Eugene Moses, Thaine L. Clark, Dr. Edward E. Tindall and William J. Ganz.

In November 1978, Bill Ganz engaged Michael Beigel, a MIT graduate in Electrical Engineering, to develop an implantable identification device for thoroughbred race horses.

The first miniaturized transponders, the size of a chicklet (chewing gum), were not injected with a hypodermic needle, but surgically implanted on June 16, 1979 into two horses, belonging to Dr. Edward Tindall.

In July 1979, Wallace Cullen of Mechanical Precision, Inc. in Flemington, New Jersey delivered a prototype of an injection mechanism, comparable to a hypodermic needle, designed to subcutaneously implant identification chips under the skin of an animal.

The engineering efforts of Michael Beigel came to an abrupt end when Thaine Clark's wife cut off the supply of finance for the RFID project.

On August 12, 1980, on the authorization of Thaine Clark, Michael Beigel conducted a telephone conversation with Vern Taylor and an engineer allegedly called Joe Sprawls from his home in Warwick New York which lasted between 30 and 60 minutes, to outline his inventions in RFID. Michael was under the assumption that they had signed a non-disclosure agreement with Thaine Clark's company International Identification Incorporated (Triple I).

Prior to the telephone conversation Michael was briefed by Thaine to explain the RFID technology to Vern Taylor.

During the summer of 1981, Thaine Clark met with Vern Taylor in Denver Colorado to further discuss the technology developed by Triple I. Vern Taylor's focus was on electronically identifying horses and had started the company Identification Devices Inc. (IDI) in September 1980 to pursue the opportunity.

> Beigel's patent (U.S. 4,333,072) describes (i) a closed coupled identification system for verifying the identity of an animal, object or other thing, has a probe including a circuit adapted to be connected to a source of alternating current and a separate, preferably miniature, circuit adapted to be implanted within or attached to the animal, object or thing. (ii) More specifically, the invention concerns a system wherein an identifying device is

> implanted within or imbedded beneath the surface of the thing to be identified so that there is no visual indication of the presence of the identification device. (iii) Such identification systems are extremely useful in the identification or verification of identification of livestock, particularly thoroughbred horses, etc. (iv) Since it is necessary to make the identification device as small as possible, particularly in cases where it is to be implanted beneath the skin of an animal, it is desirable to eliminate the need for active and energy-storing devices which restrict the minimum size and weight of such devices.

Although in the description of the invention, Michael Beigel describes the method of implanting an identification device beneath the skin of an animal, there is no mention of same in the claims. The mediocre claims discuss primarily the functionality of the electronic circuitry.

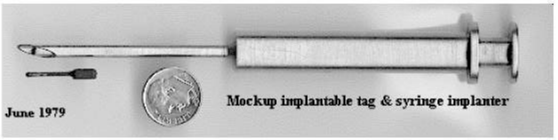
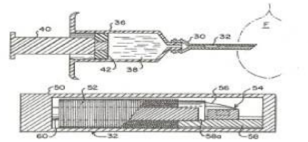
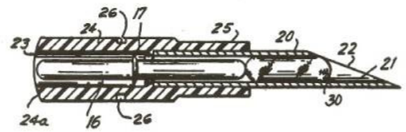
According to Michael Beigel, after filing the patent application followed by examination at the U.S. Patent Office, there was no money to engage a patent attorney to improve on the merit of the patent claims.

The Beigel patent was issued and published on June 1, 1982.

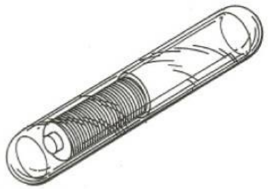
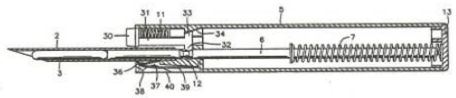
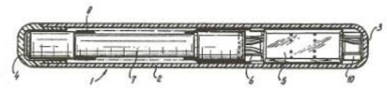
In table 2, the abstracts from granted patents filed in the period between 1979 and 1996 on syringe implantable glass encapsulated transponders for animal identification are presented.

Table 2

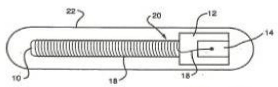
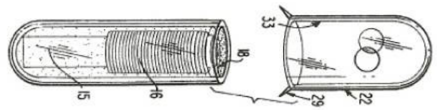
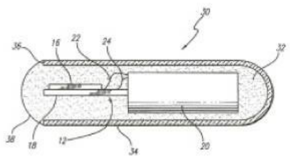
Inventive Steps: Syringe Implantable Glass Encapsulated Transponder for Animal Identification

1. International Identification Inc., USA	**2. Identification Devices Inc., USA**	**3. Bio Medic Data Systems Inc., USA**
U.S. Patent 4,333,072	U.S. Patent 5,211,129	U.S. Patent 5,074,318
Title: Identification device	Title: Syringe-implantable identification transponder	Title: Animal marker
Lead Inventor: Michael Beigel	Lead Inventor: Vern Taylor	Lead Inventor: Neil E. Campbell
Priority Date: August 6, 1979	Priority Date: February 25, 1986	Priority Date: October 6, 1986
		
U.S. patent 4,333,072 describes a closed coupled identification system for verifying the identity of an animal, object or other thing, has a probe including a circuit adapted to be connected to a source of alternating current and a separate, preferably miniature, circuit adapted to be implanted within or attached to the animal, object or thing. The probe circuit is held adjacent the implanted circuit for mutually inductively coupling the circuits so that a load applied to the implanted circuit has an effect on the current in the probe circuit. A programmable load is included in the implanted circuit, along with means for sequentially connecting and disconnecting the load to and from the implanted circuit in response to alternating current cycles in the probe circuit, according to a predetermined code program. A signal is derived from the probe circuit having a waveform corresponding to the coded program in the implant circuit. Further means are employed to decode the waveform and to display a number or other representation corresponding to the code program and indicating the identity of the implanted circuit, and, hence of the animal, object or thing.	U.S. patent 5,211,129 describes an improved transponder for transmitting an identification of an animal or the like is described which is sufficiently miniaturized to be syringe-implantable, thus avoiding the necessity of surgical procedures. The transponder comprises a coil which receives an interrogation signal and transmits an identification signal in response thereto. The transponder receives the energy required for transmission by inductive coupling to an interrogator.	U.S. Patent 5,074,318 describes a system for implanting a solid marker in an animal is provided. The apparatus includes a hollow tube having an entrance and an exit opening. A support is provided for supporting a hollow tube. A plunger is slideably disposed between a first position and a second position within the support. The plunger cooperates with the support and the tube. The plunger engages the marker proximate to the entrance opening of the tube, and ejects the marker through the tube when the plunger is moved from a first position to a second position. The hollow tubes are stored within the support in at least two groups. A gate prevents a tube from the second group from being displaced before the tubes from the first group as depleted.

Inventive Steps: Syringe Implantable Glass Encapsulated Transponder for Animal Identification

4. AVID Inc., USA		**5. Nedap, Netherlands**		**6. Texas Instruments Inc., Netherlands**
U.S. Design 321,069		U.S. Patent 5,284,479		U.S. Patent 4,992,794
Title: Animal Identification Transponder Tag		Title: Animal marker		Title: Transponder and method for the production thereof
Lead Inventor: Hannis L. Stoddard, III (Norco, CA)		Lead Inventor: Hendrik J. de Jong		Lead Inventor: Arnoldus M. Brouwers
Priority Date: August 31, 1988		Priority Date: August 30, 1989		Priority Date: October 10, 1989
				
U.S. design 321,069 describes the ornamental design of an animal identification transponder tag.		U.S. patent 5,284,479 describes an implanter for implanting an implant (3) in an animate being (14) includes a housing (15) on which the inner end of a hollow injection needle (2) is mounted, a plunger (6) mounted in the housing and adapted to extend into the hollow needle through the inner end of the needle, and a locking element (8, 32) for engaging with and retaining the plunger (6) against the force of compression spring (7) in a position where the plunger extends into the hollow needle for a predetermined distance.		U.S. Patent 4,992,794 describes an implantable transponder has a plastic holder having a hollow interior and preferably a rough outer surface, a transmit/receive unit within the hollow interior of the holder, and an electronic element electrically connected to said transmit/receive unit within the hollow interior of said holder. The transmit/receive unit includes a core and coil assembly which may be impregnated with wax, and the hollow interior of the holder is at least partially filled with a plastic filler material such as polysiloxane.

Inventive Steps: Syringe Implantable Glass Encapsulated Transponder for Animal Identification

7. Trovan Limited, GB	**8. Bio Medic Data Systems Inc., USA**	**9. AVID Inc., USA**
U.S. Patent 5,025,550	U.S. Patent 5,840,148	U.S. Patent 5,963,132
Title: Automated method for the manufacture of small implantable transponder devices	Title: Method of assembly of implantable transponder	Title: Encapsulated implantable transponder
Lead Inventor: Glen L. Zirbes	Lead Inventors: Neil E. Campbell & Donald Urbas	Lead Inventor: Jay Yoakum
Priority Date: May 25, 1990	Priority Date: June 30, 1995	Priority Date: October 11, 1996
 Fig. 1		
U.S. patent 5,025,550 describes an improved automated method for the manufacture of small implantable passive transponder devices is presented in which semiconductor wafer die are bonded to a conductively coated tape leadframe. This tape, with die attached, is injected molded to form a cap around the leads and the attached die, such that the exposed portion of the leads extend laterally from the cap. A ferrite core is attached to the base of the cap, and a fine coil wire, dispensed from a specially designed applicator, is automatically bonded to one of the leads protruding from the cap body. The wire is subsequently wound around the ferrite core and terminated by automatic attachment to another of the protruding leads. The assembled device is thereafter encapsulated within a small glass housing.	U.S. Patent 5,840,148 describes an improved identification marker and method of assembling the marker is provided, which includes the steps of providing a glass vial and filling the glass vial with a quick curing liquid to a predetermined volume corresponding to at least the volume wherein the unfilled volume of the vial is equal to the displacement volume of an IC circuit hybrid and antenna. The IC circuit hybrid and antenna are placed in the vial so as to be entirely enveloped by the liquid. A cap is placed on the vial and the liquid is cured. Preferably, the cap is an anti-migration cap so that when the transponder is implanted in an animal, it prevents the transponder from sliding out.	U.S. Patent 5,963,132 describes an EID or RFID transponder having an encapsulant with an open end to allow insertion of the transponder circuitry and a phase changing material such as an epoxy used to both secure the circuitry of the transponder within the encapsulant and seal the open end of the encapsulant.

Source: Author

5.1.2 Identification Devices, Inc.

Vern Taylor of Identification Devices Inc. (IDI) was aware of the engineering efforts of Michael Beigel, following his telephone conversation on the morning of August 12, 1980. From the visit of Thaine Clark in Denver during the summer of 1981, he saw Beigel's tiny encapsulated transponders, an injectable device and a reader. He would have also been aware of Michael Beigel's patent (U.S. 4,333,072) filed August 6, 1979 and granted June 1, 1982.

In the 1983 business plan of Identification Devices Inc. (page 7), mock-up readers and wands as well as an injectable transponder are illustrated.

In February 1986, Vern Taylor filed a patent application (Ser. No. 832,684) incorporating the knowledge he gained from his discussion with Michael Beigel and his meeting with Thaine Clark.

> U.S. patent 5,211,129 (the '129 patent) describes an improved transponder for transmitting an identification of an animal or the like is described which is sufficiently miniaturized to be syringe-implantable, thus avoiding the necessity of surgical procedures. The transponder comprises a coil which receives an interrogation signal and transmits an identification signal in response thereto. The transponder receives the energy required for transmission by inductive coupling to an interrogator.

From U.S. patent 5,211,129, Vern Taylor claims the invention of a "transponder for syringe implantation" integrated into a needle "having a sharp end adapted to pierce the skin of an animal." The inventive step over the prior art of Beigel is that the transponder is "sealed with a material having properties equivalent to glass."

Claim 1

A transponder for syringe implantation in a host animal including fish or other living creatures for responding to an interrogation signal from a remote signal generator over a monitoring period extending at least over a plurality of months, comprising:

(c) means for maintaining said coil and said integrated circuit means in predetermined relationship to one another for accommodating passage thereof through the interior of a syringe needle; wherein the length of said transponder is not more than about 0.5 inch and its cross-sectional area is not more than about 0.01 square inches, and

(d) means encapsulating said coil, said integrated circuit means and said maintaining means as a unit sealed with a material having properties equivalent to glass for preventing leakage of the internal fluids of said host animal into said unit for the duration of said monitoring period.

Claim 4

The transponder of claim 3, wherein said encapsulation means is glass.

Claim 7

The combination of claim 6, wherein said transponder is located within a tubular portion of said cannula having a sharp end adapted to pierce the skin of an animal.

Vern Taylor adapted the concept of a syringe implantable transponder based on the information and knowledge he had gained from Michael Beigel and Thaine Clark, and lodged a patent application in February 1986 which was published and issued on May 18, 1993, some seven years after filing.

This meant that the written description of the IDI invention and patent claims remained a secret till May, 1993, which implies that any information pertaining to the invention which disseminated into the industry must have been through the mechanism of product marketing or social interaction between IDI management and employees with their stakeholders.

Prior to filing their patent application in February 1986, IDI revealed their innovative ideas in the following newspaper article in January 1985: Page 60 – Rocky Mountain News, Denver, Colorado
Monday, January 7, 1985

Westminster firm banks on tiny ID implants

By Jim Hendon

Rocky Mountain News Staff Writer

"Cliff Prough displayed on his finger tip an integrated circuit, or "chip," the size of a particle of sand. Next he showed an electronic coil no bigger than a pencil lead and wrapped with wire finer than a human hair.

Prough is director of marketing services for Identification Devices Inc., a Westminster high-technology company with 40 employees that's planning to hire another 125 to 150 people in the next 12 to 18 months.

The tiny components shown by Prough are the heart and brain of a product the size of a grain of rice. Implanted permanently and harmlessly under the skin of an animal, the plastic-encased device carries a unique number that can be read by a simple scanner.

One of several products, the implantable is the main reason the company said it can expand now to prepare for orders it is expecting soon.

The company, which is marketing its products in 20 countries, said it is the world leader in the development of tiny, implantable identification units. The company's technology is unique, said Prough, because of the way it uses harmless, electromagnetic energy to allow extraction of the information from the implants.

A division of the National Marine Fisheries Service has been interested in the implantable since 1982, said Prough and has tested it on migrating salmon.

Another application would be in laboratory animals, said Prough. One Albuquerque lab may buy 15,000 implantables a year, he said.

Orders like that could lead to high-volume production and push the unit price down to $5 or less, he said. The labs now must use other means – such as tattoos or tags – to permanently mark their mice, rabbits and other test animals.

The company recently received an order for test implantables to monitor 88 elephants in a Florida wild animal park. The Australian Institute of Marine Science has bought some implantables for monitoring the "crown of thorns" starfish, which need to be studied because they destroy valuable coral reefs.

The company is pushing hard to convince the swine industry to use the devices, which allow automated inventory control as well as identification of pigs. Prough said about 85 million pigs are harvested in the United States alone each year.

A horse thief was indirectly responsible for the creation of Identification Devices. When one of his family horses was stolen, company founder and chairman Vern Taylor became interested in permanent devices to identify animals.

After a career in consumer finance, Taylor and a partner pursued an electronic optical device that took "fingerprints" from the callus that grows on a horse's front leg.

They founded Equine Services to develop that device, hoping that the thoroughbred horse-breeding industry would embrace it as a means of verifying the identity of prize animals. Later, he sold his interest in that company and used the money to start Identification Devices Inc. in 1980.

Since then, Taylor and about 250 private stockholders have invested about $3 million in the company, which Prough said is now doing about $2 million in annual sales.

Identification Devices still has hopes that the horse-breeding industry will embrace its implantable device. Prough said he has received purchase orders from breeders.

At Rockwell International's plant in Rocky Flats, conceptual tags from Identification Devices are being tested for possible use in employee identification and restriction access to certain plant areas.

Taylor has no engineering background, despite the fact that his company has developed what may be the leading device of its kind in the world.

Identification Devices already earns much of its revenues by supplying a device worn by dairy cows to a company that builds the device into its automatic feeding and monitoring system."

The above newspaper article reveals that the identification device holding a unique number is the size of a grain of rice, operates using electromagnetic energy, and can be implanted under the skin of an animal.

The applications for the device include identification of migrating salmon, laboratory and zoological animals, livestock and thoroughbred horses.

Other potential applications include access control to restricted areas and the identification of milk producing cows during the feeding process.

The objective of the newspaper article was to attract investors as well as customers, but in doing so, IDI divulged the technology and the potential markets for the product, before filing a patent application, and thus making other individuals aware of the opportunities in electronic identification.

The following paragraphs will demonstrate that the novel ideas and inventions of Identification Devices Inc. were modified and patented by customers, suppliers and former employees.

5.1.3 Bio Medic Data Systems, Inc.

In 1985, the conventional method of identifying laboratory animals was by toe clipping, ear clipping or tattooing, and Neil E. Campbell of Bio Medic Data Systems, Inc. (BMDS) recognized the need to find an alternative solution.

In 1984, Neil found an article describing an electronic system to replace tattoos or freeze branding on expensive racing horses from a company called IDI in Colorado.

He met with Vern Taylor, when he was developing the early stage prototypes operating on the principle of electromagnetic inductive coupling.

Neil Campbell had many interactions with the engineering staff of IDI and could follow the development progress on implantables.

The original implantables were plastic encapsulated transponders, ultrasonically sealed. But unknown to the engineers at IDI, micro holes in the material left the devices highly hydroscopic. Because of the dynamic movement of rodents, moisture seeped into the holes or cracks over time resulting in corrosion and eventual failure of the implanted transponders.

Neil and his engineering team recognized the leakage problem and made IDI aware of it.

In an IDI inventory report dated June 28, 1985, engineering samples of implantables using paralyene coating were been tested. And from the minutes of a product planning meeting held on July 22, 1985, the leakage problem associated with the plastic encapsulated animal transponders was critical and the search for an alternative package with the help of the external consultant Dr. Gerald Loeb was underway.

In July 1985, Dr. Gerald Loeb recommended an encapsulation package made of glass. Thereafter, the veterinary consultant Dr. Ralph Knowles of IDI began a number of biocompatibility and transponder migration studies on horses, birds, cows, dogs and cats using glass encapsulated transponders, completing his field trials in May of 1986.

With knowledge of the leakage problem using polypropylene and the solution of using a glass tube to house the transponder electronics, Neil Campbell filed a patent application on October 6, 1986 (Ser. No. 919,152) on the invention of an "implanting apparatus" which can be "injected subcutaneously into a laboratory animal" and "comprising a glass capsule having therein an electronic transponder." In addition, he cites a coating material covering the glass encapsulated transponder to prevent migration in an animal. In the internal report of IDI, the anti-migration material is paralyene.

The BMDS patent application was filed seven months after the IDI application.

From the abstract of U.S. patent 5,074,318 assigned to Bio Medic Data Systems, Inc., with Neil E. Campbell as lead inventor, it is not clear what problem the invention solves and documents (e.g. press releases from IDI or newspaper articles) material to the patent examination process are not disclosed in the related documents.

> The U.S. patent 5,074,318 describes a system for implanting a solid marker in an animal is provided. The apparatus includes a hollow tube having an entrance and an exit opening. A support is provided for supporting a hollow tube. A plunger is slideably disposed between a first position and a second position within the support. The plunger cooperates with the support and the tube.
>
> The plunger engages the marker proximate to the entrance opening of the tube, and ejects the marker through the tube when the plunger is moved from a first position to a second position.

From the claims however, the inventive steps are clear and precise, claiming a device for implanting a glass encapsulated transponder beneath the skin of an animal, in particular a laboratory animal, and said glass encapsulated transponder is coated with an anti-migration material.

> Claim 1
> A marker adapted to be injected subcutaneously into a laboratory animal by an implanting apparatus comprising a glass capsule having therein an electronic transponder, and anti-migration means covering at least a portion of said capsule, said anti-migration means preventing migration of the marker from said laboratory animal.
>
> Claim 2
> A marker as claimed in claim 1, wherein said anti-migration means includes a layer coating at least a portion of the surface of the capsule.

From the detailed description of the preferred embodiments, the inventive steps are outlined in greater depth:

> In an exemplary embodiment, marker 30 is a glass capsule having therein an electronic transponder 35 containing identification information about the animal. This is used by way of example only.
>
> It has been observed that when a glass encapsulated transponder 35 is implanted in a laboratory animal, migration of the transponder out of the wound of the animal can occur. Accordingly, in a preferred embodiment, one-half of marker 30 is coated with a layer 83 having a high coefficient of friction.

The BMDS patent application with the priority date October 6, 1986 was published and issued on December 24, 1991, 17 months before the publication of the ‘129 patent from IDI.

5.1.4 American Veterinary Identification Devices, Inc.

IDI was merged with the Canadian company Destron in 1987, operating thereafter under the name of Destron/IDI.

The next company to replicate the technology of Destron/IDI was the franchise distributor of IDI transponders for exotic birds, namely American Veterinary Identification Devices, Inc. (AVID) in Norco, California. The founder, Dr. Hannis L. Stoddard III, purchased the Triple I patent from Michael Beigel and consortium in June 1986 through the middleman Chris Possis.

In 1987, Douglas Hull partnered with Hannis, and Michael Beigel was engaged to develop an RFID system which circumvented the existing prior art.

In December 1987, Douglas Hull and Joseph William Kunst of AVID went to Thailand to meet with Peter Yewdall of SVI, Destron/IDI’s manufacturing sub-contractor of transponder devices and readers.

AVID filed design patents in August 1988 on the design of a reader (Des. 318,658) and transponder (Des. 321,069), similar in design to those of Destron/IDI. The design was published and granted on October 22, 1991.

5.1.5 Nedap N.V.

The pioneering work of IDI and Destron/IDI was known throughout the RFID community and various rival companies in Europe tried to patent similar ideas to those which originated from IDI.

Nedap's U.S. patent 5,284,479, filed first in the Netherlands (NL 8902186) on August 30, 1989, made no reference to the IDI or Destron/IDI technology in its disclosure. And at the time, neither the IDI nor the BMDS patent applications were published in the United States.

> The U.S. patent 5,284,479 describes an implanter for implanting an implant (3) in an animate being (14) includes a housing (15) on which the inner end of a hollow injection needle (2) is mounted, a plunger (6) mounted in the housing and adapted to extend into the hollow needle through the inner end of the needle, and a locking element (8, 32) for engaging with and retaining the plunger (6) against the force of compression spring (7) in a position where the plunger extends into the hollow needle for a predetermined distance.

Although the patent is silent concerning a syringe implantable transponder, the wording of "implanting an implant in an animate" can be considered the same for one skilled in the art of animal identification. For one, in the background of the invention reference is made to a prior art implanter which "can be used for implanting via the hollow injection needle a usually cylindrical implant, containing for instance a medicinal preparation or an electronic circuit for remote detection, in animate beings, such as cattle."

This verifies that the concept of tagging animals using a glass encapsulated transponder was transmitted to alert entrepreneurs, potential competitors, suppliers, customers and other stakeholders through social interaction and through the marketing efforts of IDI to promote their product worldwide.

5.1.6 Texas Instruments B.V.

In 1989, Texas instruments established a division in Freising, Germany called TIRIS to develop RFID systems for "Livestock Tracking and Farm Management."

The spark which initiated the decision to set up a company in RFID was the request from a customer in the Netherlands seeking to find a technology partner for the development of electronic tags for identifying pigs. The customer, Tradimex Metalplast in NH Vianen, had contacted the sensors division of Texas Instruments in Almelo, at the time managed by G.F.T. Bekkers, looking to tag some 20 million pigs by 1990.

In October 1989, just six weeks after the patent application of Nedap, Texas Instruments filed a patent application (Ser. No. 419,043).

> The U.S. patent 4,992,794 describes an implantable transponder has a plastic holder having a hollow interior and preferably a rough outer surface, a transmit/receive unit within the hollow interior of the holder, and an electronic element electrically connected to said transmit/receive unit within the hollow interior of said holder. The transmit/receive unit includes a core and coil assembly which may be impregnated with wax, and the hollow interior of the holder is at least partially filled with a plastic filler material such as polysiloxane.

In the description of the invention, Texas Instruments ruled out glass as the encapsulation medium, but accepted that it permits “easy sterilization and simple implantation.” They make reference to the fact that “it has been found that such transponders "drift" in the body of the animal during its development.” The object of their invention is to use an encapsulation, essentially of plastic material. According to their teaching, “plastic material adheres to the tissue of the animal, as a result of which “drifting” is largely avoided.”

One year later, Texas Instruments filed a foreign patent application with the priority date of October 9, 1990, in which they revert back to a closed glass casing in which electrical components are placed. The application was granted as patent (U.S. 5,148,404) on September 15, 1992 without referencing the prior art of IDI or Destron/IDI.

In examining the claims, two additional novel ideas emerge, namely the sealing of the glass tube can be at least at one end and the glass can be colored green to support the sealing process. The latter novel idea is most probable knowledge spillover from the glass tube vendor, i.e. Schott Glaswerke in Landshut Germany.

> Claim 6
> A method for the production of a transponder comprising the steps of providing a tubular glass casing, introducing therein said electrical component, heat sealing of at least one end of said glass.
>
> Claim 11
> The transponder of claim 1, wherein said closed glass casing of said transponder is green.

5.1.7 Trovan/EID Inc.

The next company to emerge from the enthusiastic entrepreneurial spirit of Vern Taylor was Trovan with headquarters in the Isle of Man and a distribution network primarily through EID (Josef Mašín) in Santa Barbara, California and Euro ID in Euskirchen, Germany (Ulrich Usling).

To develop an inductive coupling transponder the size of a grain of rice and encapsulated in glass, Josef Mašín went to the consultants and engineers who were on the development team of Destron/IDI. He met with Dr. Gerald Loeb who was one of the inventors of the '129 patent.

Apart from the electronics, Trovan followed the same development steps as their rival firms, encapsulating the antenna and electronic assembly in a glass tube which is mounted in a "syringe-like dispenser" for implanting in an animal.

Their inventive steps in 1990 are directed at the process of automating the production of implantable transponders.

> U.S. patent 5,025,550 describes an improved automated method for the manufacture of small implantable passive transponder devices is presented in which semiconductor wafer die are bonded to a conductively coated tape leadframe. This tape, with die attached, is injected molded to form a cap around the leads and the attached die, such that the exposed portion of the leads extend laterally from the cap. A ferrite core is attached to the base of the cap, and a fine coil wire, dispensed from a specially designed applicator, is automatically bonded to

one of the leads protruding from the cap body. The wire is subsequently wound around the ferrite core and terminated by automatic attachment to another of the protruding leads. The assembled device is thereafter encapsulated within a small glass housing.

5.1.8 Patent Circumvention

After the official publication of the ‘129 patent from IDI on May 18, 1993, the next round of patent applications to maneuver around the accepted claims by the U.S. Patent Office began.

However, in May 1993, Destron/IDI started litigation against Trovan for infringing their ‘129 syringe implantable patent for animal identification. In the same year, Destron/IDI merged with Fearing. The legal battle with Destron Fearing went from 1993 to 1995 and the litigation process cost some 2.5 million USD for each party.

It is interesting to note that the court proceedings were attended by several rival firms from the RFID industry. Attorneys on both sides presented their case using the ‘129 patent claims as the foundation for their defense or attack, revealing the strength or weakness of the patent. Therefore, the court proceedings provided knowledge spillover benefits to the rival firms, by highlighting the boundaries of the patent claims, allowing the rival firms to find alternative engineering solutions which did not infringe the ‘129 patent claims.

To circumvent the '129 patent which stipulates that the glass encapsulation be sealed to prevent leakage, Neil Campbell of Bio Medic Data Systems and Donald Urbas of UMG came up with the novel idea of having one end of the glass encapsulation open like a test tube or vial, but sealed with a bio compatible cap to prevent migration when injected into an animal.

> Their U.S. patent 5,840,148 filed June 30, 1995 describes an improved identification marker and method of assembling the marker is provided, which includes the steps of providing a glass vial and filling the glass vial with a quick curing liquid to a predetermined volume corresponding to at least the volume wherein the unfilled volume of the vial is equal to the displacement volume of an IC circuit hybrid and antenna.
>
> The IC circuit hybrid and antenna are placed in the vial so as to be entirely enveloped by the liquid. A cap is placed on the vial and the liquid is cured. Preferably, the cap is an anti-migration cap so that when the transponder is implanted in an animal, it prevents the transponder from sliding out.

In other words, the open ended vial is partially filled with a ultra violet (UV) curable adhesive, the electronics are inserted into the vial containing the curable material and an anti-migration cap is affixed to the open end of the vial to create the encapsulation.

However, Bio Medic Data Systems failed to disclose to the U.S. Patent Office the prior art of Vern Taylor, although the '129 patent was published and granted on May 18, 1993.

Just over a year later, on October 11, 1996, before publication of the Bio Medic Data Systems patent application, the company AVID filed a patent on a similar idea of leaving an open end in a glass tube to allow the insertion of the electronic components, but with one slight difference of filling the glass tube with epoxy to seal the open end.

> The U.S. patent 5,963,132 describes an RFID transponder having a glass capsule with an open end to allow insertion of the transponder circuitry and a phase changing material such as an epoxy used to both secure the circuitry of the transponder within the glass capsule and seal the open end of the glass capsule.

In Avid's patent application, they disclosed the prior art from Vern Taylor ('129 patent).

5.1.9 Collaborating Evidence

In 1978, Eugene Moses, a founding member of International Identification Inc. (Triple I) read an article about the scientist Stanley Moss at the University of Utah who was working on a tiny, implantable sensor chip, the so-called "superprobe" which could be inserted into a patient's arm to give continuous reading on the vital chemicals in his blood. This initial spark of information gave rise to the idea of implanting an identification device in animals using a hypodermic needle.

In June 1979, Michael Beigel turned the idea into reality when he created a plastic encapsulated transponder device and reader.

In August of 1980, Vern Taylor picked up on the idea of a syringe implantable transponder for animal identification, after discussing the invention with Michael Beigel and then seeing his engineering results in the summer of 1981.

At IDI in Westminster Colorado, Vern followed the same engineering steps as Michael Beigel, creating a plastic encapsulated transponder the size of a grain of rice, to be injected beneath the skin of an animal.

The IDI engineering team was innovative, pioneered the development of low frequency inductive transponders and readers, beta tested their products in applications to study salmon migration patterns and identification of laboratory animals, and worked interactively with their customers to solve technical issues. It was a learning process which defined the boundaries of application for RFID technology.

Neil E. Campbell and his engineers at Bio Medic Data Systems, Inc. (BMDS) helped to identify the technical hurdles in laboratory animal identification, especially the leakage problem in plastic encapsulated transponders. Both companies patented the idea of a syringe implantable glass encapsulated transponder in 1986.

What follows is not invention but replication of other people's ideas and then seeking patent protection for those modified ideas.

The first company to replicate the technology of IDI and BMDS, and file a patent with engineering modifications was the company AVID.

On September 18, 1985 a meeting was held between Dr. Ralph Knowles and Dr. Hannis Stoddard of AVID to discuss the identification of parrots using an implantable transponder from IDI. In March, 1986 a contract was prepared appointing AVID as a franchise distributor for IDI products to cover the identification market for exotic birds.

In August 1988, Hannis Stoddard filed a design patent 321,069 on a transponder device which is similar to the glass encapsulated device developed by IDI in 1985 and 1986.

In the world of technology there are no geographical boundaries for knowledge spillovers. In 1989, Nedap and Texas Instruments in the Netherlands each filed a patent application on an implantable transponder based on knowledge of the RFID system from Destron/IDI.

In addition, Texas Instruments were aware of the development efforts at Datamars in Switzerland to produce a glass encapsulated transponder for companion animal identification, given that the IC design center of Texas Instruments (TI) in Rieti in Italy (close to Rome), produced the first batch of RFID wafers for Datamars in September 1988.

In 1990, Josef Mašín of Trovan started the development of a glass encapsulated transponder, having knowledge of the Destron/IDI product and having met with Vern Taylor several times. Later in 1993 after the merger of Destron/IDI with the Fearing Corporation, Destron Fearing sued Trovan for patent infringement, and although Destron Fearing won the case after two years of litigation, it almost bankrupts the company, without financial compensation from Trovan.

As the market for animal identification grew, so did the number of litigation cases.

In 1995, Neil Campbell of Bio Medic Data Systems and Donald Urbas of UMG came up with an alternative method of packaging the glass transponder, to strengthen their patent position and circumvent the ‘129 patent from Vern Taylor.

Bio Medic Data Systems filed in June of 1995 the application 497,480 without disclosing the prior art of the ‘129 patent. Bio Medic Data Systems had a duty to disclose the best prior art known at the time of filing, but failed to do so.

And finally, before publication of the Bio Medic Data Systems patent application on an alternative method for packaging a glass transponder, AVID patented a similar idea in October 1996.

AVID sued the Swiss company Datamars, S.A. and its U.S. subsidiary Crystal Import Corporation for alleged patent infringement and false advertising in the Eastern District of Texas in which the plaintiff was AVID and Datamars was the defendant.

The Texas case was tried to a jury in May 2006. The jury found Datamars liable for willfully infringing three AVID patents: the 5,235,326 patent (which is directed to RFID readers and tags) and the 5,214,409 and 5,499,017 patents (which are directed to RFID tags), and assessed damages of $26,981.

Note: “willful” infringement can incur treble damages in the United States. However, a recent ruling in 2007 by the United States Court of Appeals for the Federal Circuit raised the bar for "willful infringement" claims in patent cases, making it more difficult for patent owners to collect treble damages.

The jury also found Datamars liable for unfair competition and false advertising, and assessed damages of $6,000,000.

After the trial, Datamars filed a motion seeking a ruling that the '326 patent is unenforceable for inequitable conduct. On September 28, 2007, the Court granted that motion.

The outcome of the litigation case was to tarnish Datamars' reputation and block them entering into the U.S. market for companion animal identification.

5.2 Analysis

Before I proceed with conclusions for this chapter, I will first present in table 3 the sequence of events, the flow of knowledge, the geographical location of inventors and the timing of patent applications and issuance.

TABLE 3 Knowledge Spillovers and Geographic Boundaries

Timing	Geographical Location	Sequence of Events	Comments
August 6, 1979	Warwick, New York, USA	Michael Beigel (Triple I) files a patent application describing an identification system for verifying the identity of an animal, object or thing	The patent application was granted June 1, 1982. (U.S. Patent 4,333,072)
August 12, 1980	Broomfield, Colorado, USA	Michael Beigel reveals in a telephone conversation with Vern Taylor (IDI) the idea of subcutaneously implanting a plastic encapsulated transponder underneath the skin of animal using a hypodermic needle	Dispersion of Knowledge
October 4, 1984	Denver, Colorado, USA	Flavio Audemars, a Swiss supplier of copper wire is introduced to Vern Taylor Flavio recognizes the incredible opportunities in the application of the technology	Entrepreneurial Magnetism
January 7, 1985	Denver, Colorado, USA	A newspaper article reports on technological developments at IDI, highlighting technical achievements, markets and applications of RFID	Disclosure of Information

July, 28 1985	Bethesda, Maryland, USA	An external consultant to IDI, Dr. Gerald Loeb, recommends an encapsulation package made of glass to replace plastic to protect the transponder electronics from animal body fluids	Problem Solving
February 25, 1986	Westminster, Colorado, USA	Vern Taylor (IDI) files a patent application incorporating the knowledge he gained from his discussion with Michael Beigel, but specifying glass, as proposed by Dr. Gerald Loeb, as the encapsulation medium to house the transponder electronics Towards the end of 1985, Vern Taylor is forced to leave IDI	The patent application was granted and published May 18, 1993 (U.S. Patent 5,211,129)
October 6, 1986	Maywood, New Jersey, USA	Neil Campbell (BMDS), a customer of IDI who identified the leakage problem of using plastic encapsulated transponders for laboratory animal identification, files a patent application on the invention of an "implanting apparatus" which can be "injected subcutaneously into a laboratory animal" and "comprising a glass capsule having therein an electronic transponder."	Sharing of Knowledge The patent application was granted and published on December 24, 1991
December, 1987	Bangkok, Thailand	Douglas Hull from the company AVID in Norco, California visits IDI's manufacturing subcontractor in Thailand for transponders and readers	Acquisition of Knowledge
June, 1987	Westminster, Colorado, USA	IDI merges with the Canadian company Destron	Financial crisis at IDI

August 31, 1988	Norco, California, USA	AVID files design patents on the features of an RFID reader (Des. 318,658) and transponder (Des. 321,069), similar in design to those of Destron/IDI	Knowledge Protection
November 1, 1988	Westminster, Colorado, USA	Vern Taylor meets Josef Mašín with the intention of selling his RFID technology, independently of Destron/IDI, but negotiations fail because Vern does not deliver on his promise	Later, Josef Mašín starts the company Trovan/EID in Santa Barbara
December, 1988	Lugano, Switzerland	Flavio Audemars forms a joint venture with the Italian company Datalogic creating the entity Datamars, to compete directly with Destron/IDI The company Datamars files patent applications on the functionality of the electronics, but neglects to innovate on the packaging leaving themselves open to litigation	Replication of the IDI invention
August, 30 1989	Groenlo, Netherlands	Nedap files a patent application (NL 8902186) describing an implanter for implanting a cylindrical implant containing an electronic circuit for remote detection	Replication of the IDI invention
October, 10 1989	Wierden, Netherlands	Texas Instruments files a U.S. patent application (Ser. No. 419,043) describing an implantable plastic transponder, just six weeks after the patent application of Nedap, and a year later they file another patent application using glass as the encapsulation medium	Replication of the IDI invention

May 25, 1990	Santa Barbara, California, USA	Josef Mašín (Trovan/EID) engages the IDI consultant, Dr. Gerald Loeb and an ex-IDI engineer Jerry Tuneberg to develop a glass encapsulated transponder the size of a grain of rice, filing a patent application on the automation of said device	Replication of the IDI invention
May 18, 1993	Boulder, Colorado, USA	The original IDI patent (5,211,129) is granted and published Destron/IDI litigates against Trovan for patent infringement During the court proceedings in 1995, the enforceability of patent claims are discussed	Disclosure of Information
November, 1993	St Paul, Minnesota, USA	Destron/IDI merges with Fearing to create the entity Destron/Fearing	Financial crisis at Destron/IDI
June 30, 1995	Evergreen, Colorado, USA	With knowledge of the content and patent claims of the '129 patent, Neil Campbell of BMDS and Donald Urbas an ex-employee of IDI come up with the novel idea of having one end of the glass encapsulation open like a test tube, but sealed with a bio-compatible cap to prevent migration in animal tissue	Incremental innovation
October 11, 1996	Norco, California, USA	AVID files a similar patent on the idea of leaving one end of the glass encapsulation open, but sealed with epoxy	Incremental innovation

The original invention by Michael Beigel in 1979 was modified by IDI, because of excessive failure rates of plastic transponders in the field, caused by animal fluids leaking into the electronics which was identified by IDI's customer BMDS (Neil Campbell). On the recommendation of Dr. Gerald Loeb, glass replaced plastic and so began the market for companion and laboratory animal identification using glass encapsulated transponders. Three American companies BMDS, AVID, Trovan/EID and three European companies, Nedap, Texas Instruments and Datamars replicated the technology of IDI before their patent was published in May 1993.

Therefore, knowledge spillovers occurred before IDI's patent application was granted and published. And knowledge spillovers are not geographically bound in the RFID industry, as the technology was replicated by suppliers, customers and rival firms in the United States and Europe.

At the start of this chapter, I presented a research question: What facilitates knowledge spillovers in an emerging high-tech industry?

Based on the findings cited in this chapter in dealing with the disclosure of patents as a source of knowledge spillovers, I will partially answer this question, but will delve more deeply into the topic in my overall analysis of the data collected.

From the evidence presented, novel or innovative ideas concerning an invention may spill over to individuals or rival firms through a plethora of interlinking mechanisms:

- Marketing to promote the firm, its product or services to investors, customers, suppliers and potential employees through personal selling, exhibitions, trade fairs, industry associations, advertising, public relations, publicity, press releases and media coverage

- Communication through dialogue with shareholders, employees, managers, customers, suppliers, present and potential competitors, consultants, present and potential investors, government agencies and other stakeholders in the community
- Intellectual Property Disclosure with the publication of patent applications, industrial designs and trademarks describe the entrepreneurial opportunity and provide knowledge inputs for others to replicate and/or circumvent
- Litigation transforms written information in the form of patents into knowledge by defining the enforceability and boundaries of patent claims during court proceedings for everyone to access

Marketing, communication, information disclosure, litigation and technological advancements through creation or innovation are all events involving human action and reaction. They form the basis for social interaction.

The pioneers of innovation developed processes, products and services, exuding knowledge into the community for others to replicate. Rampant in the emergence of the RFID industry was adaptation of the ideas of others and seeking to protect the intellectual property under the umbrella of patent law.

Accordingly, scientists, inventors and entrepreneurs during this emergence process operated in an environment of high uncertainty where the inventive steps of their innovation may have been patented by others or knowledge spillovers on aspects of their innovation leaked to rival firms who patented their ideas, exposing them to litigation and invalidation of their patents in the years that followed.

Patent litigation in the United States entails substantial costs and diverts management attention of a rival firm from commercial activities. It is also an effective tool to attack a firm without intellectual property and through a court injunction prevention of entry to a key market or halting of production are possible outcomes. Rumors of an uncertain future also help to fuel the attack.

In the RFID industry, firms rely on intellectual property rights for their competitive advantage either as a defensive mechanism, to protect their technology, to extract royalties or deliberately to block entry to markets protected by patents.

In concluding, novel or innovative ideas concerning an invention spillover to individuals or rival firms through social interaction before the publication of a patent application by the U.S. Patent and Trademark Office, validating the construct "knowledge spillovers" as an integral part of the evolution process in the emergence of a knowledge-based industry.

CHAPTER 6 - ANALYSIS OF INTERVIEW DATA

6.0 Introduction

The next part of the work that constitutes inductive research is data analysis, involving the search for themes and patterns within and across each of the innovative firms investigated, in order to generate insight. In the first section of this chapter I discuss the role of Vern L. Taylor in the emergence of the RFID industry and the concept of "entrepreneurial magnetism." Then I organize the interview data documented as a series of stories on each firm (approx. 90,000 words) into categories or dimensions as outlined in table 4 for interpretative analysis, to allow a picture to unfold. In my research findings I further define the influencing elements derived from casual data fragments, driving each of the critical dimensions which foster the spread of knowledge in the RFID industry.

6.1 Entrepreneurial Magnetism

One of the striking aspects of the interview data was references to Vern L Taylor. This was highlighted in the previous chapter by showing the influence of his syringe implantable glass encapsulated transponder for animal identification on the patent behavior of other entrepreneurs in the industry. I will now briefly outline how Taylor influenced other entrepreneurs. I came to describe this process as 'entrepreneurial magnetism.'

Vern L. Taylor attracted many entrepreneurs and inventors to the opportunities in RFID. For one, many of his former employees at IDI left and established their own RFID businesses in the vicinity of Denver Colorado. Suppliers in the value chain also recognized the opportunities and set up in competition with IDI.

The first company to replicate the technology developed by IDI in Westminster, Colorado was the coil vendor company Audemars from Lugano, Switzerland. Flavio Audemars was introduced to Vern Taylor on October 4, 1984 by Alex Studer of Imetra, the North American agent of Audemars. The company had extensive experience in winding microcoils for the watch industry and the manufacturing process was ideal for producing transponders. Flavio recognized the opportunity, put a development team together in 1986 within Audemars, and later established a joint venture entity called “Datamars” in 1988 with Parvis Hassen Zade as managing director.

The second company interested in the electronic identification of animals was the customer Bio Medic Data Systems (BMDS). IDI worked closely with BMDS on plastic encapsulated transponders for insertion into laboratory animals and during the experimental trials, engineers at BMDS discovered the reason for high transponder failure in rodents. The solution, glass encapsulation to protect the transponder electronics, became the de-facto standard in the industry.

The third company to replicate the technology was the franchise distributor of IDI transponders for exotic birds, namely American Veterinary Identification Devices, Inc. (AVID) in Norco, California. The founder, Dr. Hannis L. Stoddard III, purchased the Triple I patent from Michael Beigel and consortium in June 1986. In 1987, Douglas Hull partnered with Hannis, and Michael Beigel was engaged to develop an RFID system which circumvented the existing prior art from IDI.

The fourth company to copy the engineering developments of IDI in 1988 was Donald Urbas, an ex-employee of IDI, who started the company Urbas Manley Group (UMG) in Evergreen, Colorado. Their immediate customer was Bio Medic Data Systems (BMDS) managed by Neil Campbell.

The fifth company to emerge from the enthusiastic entrepreneurial spirit of Vern Taylor was Trovan with headquarters in the Isle of Man and a distribution network primarily through EID (Josef Mašín) in Santa Barbara, California and Euro ID in Euskirchen, Germany (Ulrich Usling).

The sixth company to enter the glass encapsulated transponder market which was a supplier of assembled coils in unsealed glass tubes to Destron/IDI in 1988, was Sokymat, a microcoil winder for the watch industry located near Vevey in Switzerland. Sokymat, managed by the inventor Åke Gustafson, went on to produce transponders for Trovan (Josef Mašín) in 1989.

Later, Nedap and Texas Instruments in the Netherlands entered the animal identification market using glass encapsulated transponders.

Vern Taylor's entrepreneurial spirit was infectious; he was the spark plug who ignited the RFID industry. I defined this infectious process as "entrepreneurial magnetism." It conveys the notion that entrepreneurs and their collaborators alert other entrepreneurs in the value chain to the same or similar opportunity in an emerging industry.

6.2 Interview Data

This section consists of excerpts from the empirical data, providing background information on the 21 RFID firms investigated in the time frame from 1970 to 2000 and illustrating the key findings of my research.

For each firm involved in the RFID industry for the period 1970 to 2000 (as illustrated earlier in table 1 "RFID Timeline") I state the firm name, country of origin, year of start-up of the firm, or where applicable, year of 'inventive step' by the firm, the name of the interviewee, the application and technology of the firm, and what might be regarded as the main 'innovation' of the firm. I then summarize what happened in the firm, based on the interview data, in terms of six initial categories, identified from initial phases of the interviewing, the ongoing review of the literature, and my on-going attempts to understand the emergence of the RFID industry and the nature and extent of knowledge spillovers in the industry. These categories are:

- Discontentment
- Exposure to opportunities
- Alertness
- Human agency
- Social interaction
- Knowledge spillover

In a more practical sense the categorizing of the interview data reflected the following events in the stories relayed through the interviews:

- What was the state of mind the entrepreneur had prior to starting the business. Why did the entrepreneur leave an existing organization to start a new firm? This emerged under the heading of 'discontentment', to reflect what appear to be 'negative' experiences of the entrepreneur prior to the initiation of the new venture.

- What did the individuals know about the industry, in terms of technology or applications, prior to start-up? Why did these entrepreneurs 'discover' or identify opportunities? This data emerged into two categories, ‘exposure to opportunities’, which describes the opportunity confrontation, and ‘alertness’, which describes the more specific identification or discovery of the specific business opportunity the new venture was created to exploit.

- What did these individuals do to initiate their new businesses? This category was labeled ‘human agency’ to capture the efforts that individuals undertook.

- A clear theme in the interviews was the extent of social interactions between some of the entrepreneurs and inventors. These may relate to the development of knowledge about the technology or market or to efforts to initiate the new business. These parts of the interviews were categorized as ‘social interaction.’

- Finally, a focus of the research was to understand the specific ‘knowledge flows or spillovers’ in the RFID industry. Where interviewees referred to specific incidents of aspects of their knowledge, invention or market insight, and how it related to others or was copied by others, this was categorized as ‘knowledge spillover.’

In the tables that follow I present my categorization of each interview under these headings. What I have sought to do is capture the essence of each entrepreneurial story, and to illustrate this with specifics, rather than presenting a complete ‘summary’ of each interview.

It should be noted that most entrepreneurs in the RFID industry after the mid eighties used differential access to existing information to exploit an opportunity. In the transition from analog to digital technology in the 1970s, a few entrepreneurs were innovative, breaking away from existing knowledge and creating new products. Their inventions were not replicated quickly, nor did they gain market traction as will be discussed in the evolution process in chapter 7.

The objective of the analysis is to look for patterns in the empirical data at the individual, firm and industry level so as to formulate answers to the research questions, secondly to deduce from the data, dimensions which influence events in the discovery, evaluation and exploitation stage of an entrepreneurial opportunity and thirdly to define the key construct which shapes the evolution process of the emerging (knowledge-based) RFID industry.

Table 4
Tabulated Evidence from the Emerging RFID Industry

Company 1:	Communications Services Corp. (ComServ) & Telserv Corp., USA	**Application & Technology**	Toll road collection & railway stock identification using IFF transponder technology
Year of Entrepreneurial Venture or Inventive Step:	1970	**Innovation**	William Parks III developed a system operating on the same principle as the Identification Friend or Foe (IFF) which uses energy from the interrogating beam to power the transponder and features a rewritable memory for the ID number.
Interviewees:	Mario W. Cardullo & William L. Parks III		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
As the years passed as planning officer in the forecast methodology office of planning research and services at Communications Satellite Corporation (COMSAT) in Washington, Mario Cardullo became more & more frustrated with the management of COMSAT in dragging their heels on implementing his proposed maritime and mobile communication satellite concept, later put into practice as the International Maritime Satellite. At the time of Mario Cardullo's visit to Jonker Business Systems, William Parks was looking to move on from Jonker.	The funding by COMSAT to find markets for satellite communication was extensive and Mario was exposed to many applications involving the transmission and reception of data. **Social Interaction** In the spring of 1969, on a return flight from St Paul to Washington, Mario met an IBM engineer implementing an optical identification system (CARTRAK) for railway stock using reflective color bar code attached to the side of each railway car.	The IBM system had a number of shortcomings, namely the optical reflectors were easily damaged or vandalized, dirt and mud would obscure the reflected surface and the data from the color bar code was read-only which limited the usefulness of the system. Mario recognized the opportunity to replace bar code on railway stock using electronics. **Human Agency** Mario began preparations to start his own business, investigated various concepts, and around July 1969 he had the vision to establish a start-up company. He knew several individuals suitable who had various competencies for the new venture, namely John Miller Marketing & Sales (having previously worked for Martin Marietta), Jim Jordan Finance and William L. Parks Electronic Development, who eventually turned Mario's idea of a transponder black box into reality.	"The idea presented to the New York Port Authority was to equip cars with the device and collect tolls on the fly. The device would be like a "Pitney Bowes" postage meter. The user would pay to have a dollar amount put into the device by the toll authority. The toll would then be subtracted from the device as the car drove through the toll collection area at speed. We proposed that in the event that a car's device did not have enough balance to pay the toll that a picture would be taken of the license plate and driver of the car." The ideas and concepts presented by the ComServ / Teleserv team to the New York Port Authority (NYPA) eventually spilled over to large corporations.	Emotional Intelligence: Mario realized that William Parks was the engineer with the knowledge to turn his idea into reality. He was also aware that William Parks was looking to move on from his present employer Jonker Business Systems. Within two years of demonstrating the transponder technology to the New York Port Authority, the NYPA had decided in the first phase to test a system from four manufacturers: General Electric, Glenayre Electronics, North American Philips and the Union Switch & Signal division of Westinghouse Air Brake Co. The article "The Toll Highway Faces Automation" in the magazine Electronics of November 8, 1973 on page 74 describes the pilot tests on San Francisco's Golden Gate Bridge and in New York's Lincoln tunnel using the automatic vehicle-identification system.

Tabulated Evidence from the Emerging RFID Industry

Company 2:	Proximity Devices, Inc. (PDI) USA	**Application & Technology**	Access control using inductive coupling technology
Year of Entrepreneurial Venture or Inventive Step:	1972	**Innovation**	Charles Walton created the analog version of RFID, a variation of inductive coupling involving sweeping a frequency band.
Interviewee:	Charles Walton		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
Charles was ambitious, an independent thinker and his boss at the time summed it up "you are ahead of your schedule at IBM". In 1969, Charles' career had plateaued at IBM and in the same year he was not given recognition for his hard work in the form of a pay rise which ultimately trigged his discontentment. Charles neighbor had done well as an independent and it was now time for Charles to take a leap of faith and create something for himself.	The basic principle of the electronic key is based on a grid dip meter used by amateur radio operators to measure the resonant frequency of radio frequency circuits. By bringing an unknown coil (secondary coil) up to the reading coil (primary coil) of a dip meter, which measures the amount of electromagnetic field absorption, one observes a dip in the voltage of the sweeping oscilloscope from the output of the grid meter when the primary coil is near the resonance frequency. **Social Interaction** PDI also tried to sell the RFID invention to General Motors, but the auto executives rejected the idea as too "Buck Rogers".	Although the development of disk drives at IBM were far removed from the notion of electronic locks, the IBM eccentric Ronald Palmer saw the connection between notches on mechanical keys and sweeping a frequency band using the principle of magnetic induction to create codes. Shortly after Charles left IBM in 1970, in a discussion with Ronald Palmer, they both came up with an idea of an electronic key in the shape of a credit card for access control. **Human Agency** Walton started his own company called Proximity Devices in Sunnyvalle, California in 1972 with Noel Alton as partner.	Walton's digital version of the analog proximity card was also the first patent to be associated with the abbreviation RFID and was granted to Charles Walton in 1983 (U.S. Patent 4,384,288). On this new single carrier frequency system, he studied the FCC regulations and in the ISM (Industrial, Scientific and Medical) radio bands, chose the frequency of 13.56 MHz which permitted more power radiation. There was a challenge to 13.56 MHz by competitors, but it was a 2 watt system operating in a kilowatt market, and was approved.	Charles Walton is a hands-on inventor, who created the analog version of RFID and then created and pursued his development of the digital version and who made his choice of frequency and associated system paramount in its day has proved the test of time.

Tabulated Evidence from the Emerging RFID Industry

Company 3:	Los Alamos Scientific Laboratory (LASL), USA	**Application & Technology**	Animal identification using radiative coupling technology
Year of Entrepreneurial Venture or Inventive Step:	1973	**Innovation**	Steven W. Depp and his team developed a radiative backscatter UHF system running at 915 MHz to track cattle. The backscattered signal is modulated by the transponder to produce a sub carrier, and the coding is provided by modulating the sub carrier with a serial code.
Interviewee:	Steven W. Depp		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
Although LASL developed a portable interrogator-transmitter-receiver and a passive transponder for implantation in an animal, which identified the animal being interrogated by a 15-digit decimal number and reported that animal's temperature to one tenth of a degree Celsius, there was no real intention to market or sell the technology.	At the request of the U.S. Department of Agriculture and the U.S. Department of Energy, Los Alamos Scientific Laboratory (LASL) developed a passive UHF transponder to monitor the health status of cows and a system for tracking nuclear materials. **Social Interaction** Howard Baldwin was involved with the U.S. Department of Agriculture (USDA) and saw electronics as playing a role in increasing productivity in agriculture by improving management practices and disease detection capabilities. He posed the agricultural problems and anticipated the applications; Steven and Alfred Koelle designed the circuits, Robert Freyman was the radio frequency expert and Paul Salazar assembled the devices.	The USDA representative at Los Alamos was Coleman Hensley, who consulted closely with the LASL team. He saw the opportunity and looked to start his own company in animal identification. **Human Agency** Steven realized that the technology was not going to be exploited by LASL and it made sense for an external company to commercialize the technology, but licensing or selling a government patent was a bureaucratic feat. Coleman established in 1976 the company Identronix in Santa Cruz in California, and Steven Depp, Jeremy Landt, Ron Bobbet and Alfred Koelle acted as LASL consultants for the transfer of technology.	The system was demonstrated at the U.S. Animal Health Association conference in St. Louis in late 1973 and received enthusiastic reception. It was next demonstrated at a meeting in Oklahoma City to a cross section of livestock-industry representatives, including feedlot operators and farm bureaus. At a meeting in 1976, Steven gave a demonstration to the Department of Agriculture, military outfits and as the CIA got wind of the technology, they showed up as well. At the end of the presentation, one of the transponders went missing!	The animal application was extremely price sensitive, and it was a tough business venture to start out with, to convince the livestock market to implant transponders in animals. It was an economic challenge which eventually led to the bankruptcy of Identronix in the early 80s. Only when the scientists at Los Alamos decided to take a leap of faith and start their own entrepreneurial venture did the transfer of technology spill over to commercial industry, resulting in the formation of Amtech Corporation in 1984.

Tabulated Evidence from the Emerging RFID Industry

Company 4:	Nederlandsche Apparatenfabriek (NEDAP), Netherlands	**Application & Technology**	Animal identification using inductive coupling technology
Year of Entrepreneurial Venture or Inventive Step:	1976	**Innovation**	They reversed engineered the Knogo anti-shoplifting system and an automatic feeding system for cows using electronic collar tags from the Dutch company DACA.
Interviewees:	Harry Kip and Koos Fockens		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
	In 1974, Koos Fockens went to the C&A clothing store in Amsterdam to examine an anti-shoplifting system. The technical concept of an anti-shoplifting tag stems from the principle of a grid dip meter which monitors changes in energy levels as a result of the absorption by a resonant circuit passing close to the reading coil of the grid dip meter. **Social Interaction** At a birthday party in the summer of 1976, Cees Kluft learnt of a computer feeding system for cows on an experimental farm (Waaiboer Hoeve) under development by the Agricultural University IMAG Wageningen. Although the Director Ruud Paijens knew nothing about electronics he turned to the watch industry in Switzerland for guidance and quickly recognized the impact of electronics on mechanical timepieces.	Cees Kluft, salesman at Nedap, alerted his engineering colleagues Harry Kip and Koos Fockens in 1974 to the business opportunity in anti-shoplifting tags and two years later to the opportunity of tagging cattle. **Human Agency** Kluft's alertness to opportunities and the commercial director's entrepreneurial spirit (Ruud Paijens) made it possible for the engineering department to undertake development risks and fast track projects, even without the presence of a customer. Ruud Paijens was afraid that people would steal the electronic identification idea and had Harry and Koos write up swiftly their innovative ideas on the analog digital circuitry and a patent was filed in November 1976 (U.S. 4,196,418).	Harry Kip and Cees Kluft went to see the feeding system, developed and manufactured by the Dutch company DACA of Lelystad, and picked up the idea of an electronic collar around the neck of a cow as a means to identify the animal and automate the feed process. With the ideas from the test farm, Nedap developed a complete cattle feeding system, including the transponder, reader, programming system, plastic housings and mechanical parts.	Nedap developed their first application specific integrated circuit (ASIC) transponder chip in 1982 at a leading semiconductor company and went on to develop several ASICs in the years that followed. In 1988, RFID system knowledge spilled over to a semiconductor company, with a rival company gaining access to their knowledge.

Tabulated Evidence from the Emerging RFID Industry

Company 5:	International Identification Inc. (Triple I), USA	**Application & Technology**	Positive identification of thoroughbred horses, and to prevent fraud in horse racing events using an implantable inductive coupling transponder device
Year of Entrepreneurial Venture or Inventive Step:	1979	**Innovation**	Michael Beigel developed the first concept of an injectable read/write transponder the size of a grain of rice.
Interviewees:	Michael L. Beigel & Dr. Edward E. Tindall		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
Michael Beigel had worked on synthesizers and musical sound effect devices, and his former company Musitronics had just been sold off after having reached the top of its field internationally, by a board of directors who would rather pursue a musical toy instead of digital audio.	At the time, Edward Tindall was editor-in-Chief of "The Journal of Equine Medicine and Surgery", Vet. Pub., Princeton, NJ and ran a mobile veterinary service business in Stockton, New Jersey. **Social Interaction** The founding members (Eugene Moses, Thaine Clark, Edward Tindall & William Ganz) invited the New York Jockey Club to inspect the new technology. In a letter from the Deputy Executive Director, Robert L. Melican of The Jockey Club, 380 Madison Avenue, New York, N.Y. 10017 dated November 30, 1979 to Dr. Edward E. Tindall, Stockton, New Jersey 08559: "The Jockey Club, after demonstration and several meetings with the principals of International Identification, Inc., concerning the Corporation's electronic identification system for the equine, is interested in the concept you have presented."	Eugene Moses came up with the idea of implanting an identification device in animals, perhaps having read the 1978 article on "Superprobes" for insertion into a human body. **Human Agency** In September 1979, Thaine Clark's wife Deborah, cut off the supply of finance for the RFID project, as Thaine was having an affair with another woman Jackie DeVoe, a Buchs County art agent. In the process of their divorce, Thaine removed some paintings from their house and set it on fire on July 31, 1981.	On August 12, 1980, on the authorization of Thaine Clark, Michael Beigel held a telephone conversation with Vern Taylor et al. from his home in Warwick New York which lasted between 30 and 60 minutes. Mike was under the assumption that they had signed a non disclosure agreement. During the summer of 1981, Thaine Clark met with Vern Taylor in Denver Colorado to further discuss the technology developed by Triple I. Vern Taylor's focus was on electronically identifying horses and had started the company Identification Devices Inc. (IDI) in September 1980 to pursue the opportunity. In a letter from Michael Beigel on November 16, 1993 to William Ganz, Edward Tindall and Eugene Moses, Michael informed them about the invention of a "Syringe Implantable Transponder" from Destron Fearing formally Destron/IDI and IDI which was granted as a patent (U.S. 5,211,129) on 18 May 1993. He further stated that "It is clear from the records we have on hand at this time that the results of III work were misappropriated by Vern Taylor when he started IDI."	Where Triple I folded, it was the start of IDI and the beginnings of Avid. The invention of a syringe implantable identification transponder was patented by Vern Taylor in February 1986.

Tabulated Evidence from the Emerging RFID Industry

Company 6:	Sielox Systems, Inc., USA	**Application & Technology**	Access control using digital inductive coupling techniques
Year of Entrepreneurial Venture or Inventive Step:	1980	**Innovation**	Dr. France Rode developed one of the first digital electronic proximity identification systems operating at the preferred frequency of 13.56 MHz.
Interviewee:	Dr. France Rode		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
When France handed over the reigns of business leadership to his partner Ali Bologlu, the company ploughed along financially boot strapped slowing up their rate of progress. Ali was opposed to the sale of Sielox to Checkpoint Systems, although the company was practically bankrupt, as it undermined his position as CEO.	France immigrated to the United States during the revolution of digital electronics, worked at Hewlett Packard and was one of the engineers who co-developed the first scientific pocket calculator in 1971. **Social Interaction** France did not sever his ties with HP and remained on as a part-time employee, taking leave of absence to pursue his own venture which took almost two years of preparation. In 1981 France started the development of a customized 13.56 MHz RFID chip with on-board capacitor, with the support of his colleagues, two brothers Lojze & Jomez Trontelj at the University of Ljubljana (*Univerza v Ljubljani)* together they designed the chip layout.	Before starting the RFID Company Sielox Systems Inc. in 1980, it was at Hewlett Packard (HP) where France came up with the idea of developing a contact secure identity card. He got the idea of inductive coupling from the Grid Dip Meter principle, used to measure resonance. **Human Agency** It was quickly realized that the best way forward was to be acquired.	In October 1983, France built a digital "proximity reader" and improved on its design with several iterations during the period between 1984 and 1985. Around the same time, Charles Walton filed a patent application "Electronic Proximity Identification System with Simplified Low Power Identifier" on December 9, 1983, issued as a patent (US 4,580,041) on April 1, 1986. France filed a similar patent application in August 1988 with Charles Walton as co-inventor, issued as patent (US 4,918,416) on April 17, 1990. Both cited their preferred frequency of operation at 13.56 MHz.	France filed his first independent patent (US 3,944,976) on August 9, 1974 describing an electronic security key and lock mechanism using a dynamic coding technique. The basic ideas in his patent were to be the technical foundation of getting his own business started some years later. France's background was in digital technology and Charles Walton was a consultant to Sielox on analog tuned circuits. France had discovered the industrial frequency of 13.56 MHz (ISM) before he met Charles and his approach to the RF proximity card was to digitize the inductive coupling. Charles applied for two patents on his own, claiming to be the sole inventor of the 13.56 MHz digital transponder, but France was able to prove that he was a co-inventor as the circuit diagrams at Sielox were exactly the same as those from Charles Walton in his patent disclosure.

Tabulated Evidence from the Emerging RFID Industry

Company 7:	Identification Devices, Inc. (IDI), USA	**Application & Technology**	Electronic identification of thoroughbred race horses, tracking salmon migration patterns and integrating RFID into automatic animal feed systems
Year of Entrepreneurial Venture or Inventive Step:	1980	**Innovation**	In 1985, IDI developed the first commercial glass encapsulated transponder operating on the principle of inductively coupling at a frequency of 400 KHz, which was to have a major impact on the animal identification industry.
Interviewees:	Dominick Alston, Ben Polzkill and Thomas Milheiser		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
Towards the end of 1985, on the verge of bankruptcy, Vern Taylor was bought out by a Chicago based venture capitalist. As part of his buyout & severance package he was allowed to set up a marketing company called Taymar, selling IDI microchips for implanting in livestock. Unfortunately, it did not take long for Vern to renege on his agreement to sell solely into the livestock industry which caused a rift between the parties.	Vern L. Taylor began working on ways to identify horses after a family mare was stolen in 1971. His first ID company was Equine Services, Inc. of Broomfield, Colorado which developed and marketed an electronic scanning device that could positively identify any horse by its knuckles, those calluses on the inside of the horse's legs. He sold his interest in Equine Services and used the money to start his second ID Company "Identification Devices Inc." in 1980. **Social Interaction** To finance his new venture, Vern convinced some private stockholders, many from his church, to invest and raised approximately $ 2 million in seed capital.	Vern was aware of the engineering efforts of Michael Beigel, following his telephone call on the morning of August 12, 1980. From the visit of Thaine Clark in Denver during the summer of 1981, he saw Beigel's tiny encapsulated transponders, an injectable device and a reader. **Human Agency** Vern attempted to continue the business of RFID in competition with IDI, raising additional capital for his company Taymar in 1988, by licensing exclusive sales territories for Europe and the Middle East to the German entrepreneur Ulrich Usling.	Vern attracted many entrepreneurs and inventors to the opportunities in RFID. For one, many of his former employees at IDI left and established their own RFID businesses in the vicinity of Denver Colorado. Suppliers in the value chain also recognized the opportunities and set up in competition with IDI. In 1984, Dominick Alston, Ben Polzkill, Mick Simon and Thomas Milheiser left to start the RFID Company Telsor.	Emotional Intelligence: Vern Taylor was astute and he surrounded himself with people who could turn his vision into reality. In 1982, Vern engaged Thomas Milheiser, a senior electronics engineer from Martin Marietta, to develop the IDI transponder. His invention was patented in February 1984 (U.S. 5,166,676) citing Beigel's patent as prior art. The reason why Vern Taylor engaged Dr. Ralph C. Knowles to work as a full time consultant for IDI was to legitimize his business. Ralph had 27 years service behind him with the United States Department of Agriculture (USDA) in Washington DC, of which 18 years was in the same position. The money was good, but the job satisfaction had declined and at the latter stages of his career at USDA, he was assigned an unpalatable task.

Tabulated Evidence from the Emerging RFID Industry

Company 8:	Amtech Inc, USA	**Application & Technology**	Electronic toll collection and rail car identification using radiative coupling technology developed by Los Alamos Scientific Laboratory
Year of Entrepreneurial Venture or Inventive Step:	1984	**Innovation**	They created the standard for tagging railway stock, trucks and containers in North America.
Interviewee:	Jeremy Landt		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
	In 1975, Steven Depp hired Jeremy Landt to join the development team at Los Alamos Scientific Laboratory in New Mexico working on the electronic identification of livestock and transport vehicles, using microwave technology. In 1984, he co-found Amtech Corporation, to commercialize the RFID developments at Los Alamos. **Social Interaction** Gary Seawright was the primary entrepreneur and left his job as program manager at Los Alamos Labs, mortgaged his house, wrote the business plan, raised the seed money, did the marketing and kept the team together to realize the dream of Amtech Systems. They created the standard for tagging railway stock, trucks and containers in North America.	The first business plan for the use of the Los Alamos RFID system was for management of dairy animals, but it did not attract investors to put up the capital. It was the visionary entrepreneur, David Cook (founder of Blockbuster Video Fame) who saw the promise and put Gary Seawright on the right track of concentrating on the transport industry. **Human Agency** In 1983, Amtech was incorporated to commercialize the Los Alamos RFID system. In early 1984, Gary Seawright resigned from Los Alamos Scientific Laboratory as program manager for the RFID program, to focus full time on launching the technology.	UNOVA (mother company of Amtech) acquired RFID semiconductor technology from IBM Corporation in December 1997.	Up to 1980s very few developments at the Los Alamos Scientific Laboratory (LASL) had spun off and been adapted for commercial operations. But in the early 80s, U.S. Congress had instructed the national laboratories to transfer technology to the private sector so that the public could benefit from the investment of research dollars. From the fall of 1984, Jeremy Landt, Rand Brown, Alfred Koelle and Paul Salazar took leave of absence from LASL for a period of 2 years, knowing that they would be accepted back, should the venture fail.

Tabulated Evidence from the Emerging RFID Industry

Company 9:	Audemars/Datamars SA, Switzerland	**Application & Technology**	Companion animal identification using glass encapsulated inductive coupling transponders
Year of Entrepreneurial Venture or Inventive Step:	1986	**Innovation**	Production of passive radio frequency identification (RFID) devices using accumulated experience manufacturing stepping motors for the watch industry.
Interviewee:	Flavio Audemars & Parvis Hassan-Zade		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
In 1986, after Vern Taylor was oust out of IDI, Flavio met with Charles Cushing in an effort to strike a deal and settle outstanding payments owed to Audemars; Flavio decided to go into competition with IDI.	In 1981, Audemars began production of stepping motors for analog quartz movements with the introduction of emerging technology and processes such as laser welding, coil winding and micro-component assembly. It was a period of transformation from the mechanical to the electronic timepiece. **Social Interaction** Vern Taylor showed Flavio the IDI transponders consisting of an antenna using aluminum wire, connected to a miniature printed circuit board (PCB) mounted with a chip and discrete components, and packaged in a synthetic material to protect the electronics. The Americans at the time were not alerted to using ultra fine copper wire for the transponder antenna. Hence, the first RFID product from IDI used aluminum wire to produce micro-coils.	In October 1984, the managing director of the family run business Audemars, Flavio Audemars, met with Vern Taylor in Denver, Colorado. Listening to Vern Taylor describing the potential of RFID, Flavio recognized the incredible opportunities in the application of the technology. He saw the technical synergy associated with manufacturing microcoils for the watch industry and producing transponders the size of a grain of rice. **Human Agency** In 1986, Flavio convinced his friend Parvis Hassan Zade from the Swiss watch industry to pursue the new venture in animal identification, having showed him a transponder, without mentioning that it was not developed by his company.	Donald Urbas, Gordon Woolley and Daniel Koturov visited Audemars in Lugano, Switzerland, passing on information pertaining to the manufacture of plastic injectable transponders. Datamars' participation in the ISO standards committee was to "piggy-back" on the knowledge of Nedap and TI **"EVERYONE ON THE ISO COMMITTEE HAD A SECRET AGENDA"** Parvis Hassan-Zade April 3, 2007	The first spin-off of IDI was the Telsor Corporation started by former employees, Dominick Alston, Ben Polzkill, Thomas Milheiser and Mick Simon, in 1984. The second company to compete with IDI in 1986 was the coil vendor Audemars SA from Switzerland. In 1988, Audemars established a separate entity Datamars in Cadempino, a partnership between Audemars and Datalogic in Italy, to produce passive radio frequency identification (RFID) devices using its accumulated experience manufacturing stepping motors for the watch industry. The technology of micro-coil winding, wire termination and micro-part assembly was pivotal in producing a glass encapsulated transponder, the size of a grain of rice with a diameter of 2mm and a length of 12mm.

Tabulated Evidence from the Emerging RFID Industry

Company 10:	Indala, Inc., USA	**Application & Technology**	Access control using a combination of capacitive and inductive coupling for transmission and power
Year of Entrepreneurial Venture or Inventive Step:	1986	**Innovation**	Theodore Geiszler is the father of capacitive coupling for radio frequency communication between a reader and a transponder device.
Interviewee:	Theodore Geiszler (Ted)		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
The only thing Ted was worry about was the competitor Destron/IDI.	The static field technology used in perimeter fencing from Stellar Systems was a natural extension for the development efforts at Indala, creating proximity cards using electrostatic technology (capacitive coupling) for communication. **Social Interaction** At the time, there were no standard RFID chips on the market, and Ted turned to the watch and hearing aid industry for technical guidance.	After selling his second company Stellar Systems to the Wachenhut Corporation in 1979, Ted worked from home on his next entrepreneurial venture, investigating the access control system from Schalge Electronics, developed by Charles Walton. He recognized the innovative step by shifting from analog to digital encoded technology for proximity cards. **Human Agency** Although Ted was the father of capacitive coupling, the Motorola management were alien towards him and Noel Eberhardt, a loyalist to the old Indala brigade who had to do things behind closed doors.	There was a shift from capacitive to inductive coupling in 1989 when Ted became aware of the technology from Vern Taylor.	In 1993, Indala, having over 80% of the access control market with a turnover of 16 million USD with 40 employees was acquired by Motorola. The new management took a corporate approach to a dynamic industry focusing primarily on volume business which had not been developed and applying an inflexible stance to the proximity market, giving their rival HID a chance.

Tabulated Evidence from the Emerging RFID Industry

Company 11:	Destron/IDI, USA	**Application & Technology**	Animal identification and access control using low frequency inductive coupling technology
Year of Entrepreneurial Venture or Inventive Step:	1987	**Innovation**	Financial Engineering: Daryl Yurek & Herbert Marshall came up with the idea of a Symposium on Animal ID and invited industry experts and government officials from around the world to participate in seminars at the offices in Boulder, Colorado. After the first event in Boulder Colorado, the Animal ID Symposium continued on the island of Prince Edward, Sardinia and Malta, and became a closed hub, as the entry fee for participation was 100,000 dollars.
Interviewee:	Daryl Yurek		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
At the time, Destron, a publicly traded company on the Alberta Stock Exchange was operating under the Canadian equivalent of Chapter 11 proceedings. Difficult operating circumstances chiefly due to a lack of funds. **"THE DRIVING FORCE IN THE COMPANY WAS BAD CIRCUMSTANCES"**	Daryl Yurek had a strategy of linking the data collection system for slaughter houses with a disposal device for identifying animals which would give him an "open ended opportunity." **Social Interaction** Destron/IDI continued pioneering the technology, but put more emphasis on marketing and educating the potential customers and opinion leaders of the technology on a worldwide scale by organizing workshops, symposiums, participating in annual association meetings, scientific meetings, lobbying standard organizations and animal health regulators.	With his background in computer science and anti-theft devices, Daryl understood the potential of RFID and went on a deliberate search for technology companies in this field. **Human Agency** The biggest move forward was when the company was most threatened; the chapter 11 circumstances of Destron forced the merger with IDI; continued losses of Destron/IDI forced the creativity of the marketing stunt and the return to losses from the Jim Seiler debacle forced the creativity of the Fearing merger.	"In under funded entrepreneurial ventures, people communicate within the community and knowledge travels fast. In the RFID industry, most inventions presented in patents come from the cross pollination of other peoples' ideas by stealing and cheating, a cesspool of thievery." Daryl Yurek 20/09/2007	Litigation: In 1993, Daryl filed a lawsuit against the competitor EID/Trovan for infringing the Destron/IDI syringe implantable transponder patent (US 5,211,129). Nedap, AEG and Texas Instruments (TI) were also infringing the Destron/IDI syringe injectable patent.

Tabulated Evidence from the Emerging RFID Industry

Company 12:	Bio Medic Data Systems Inc., USA	**Application & Technology**	Identification of laboratory animals using an implantable glass encapsulated transponder
Year of Entrepreneurial Venture or Inventive Step:	1987	**Innovation**	To circumvent the IDI syringe implantable transponder patent (US 5,211,129), glass rods were purchased with one side sealed like a glass tube and the other side then filled with biocompatible glue.
Interviewee:	Neil Campbell		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
In May 1983, Donald J. Urbas joined Identification Devices, Inc. and just before the merger with the Canadian company Destron, Don resigned because of friction with IDI management. During the latter part of his stay at IDI, he worked closely with Bio Medic Data Systems (BMDS) on the development of a wand scanner to identify laboratory rats. After leaving IDI, he continued to work with BMDS as a consultant.	Neil Campbell joined Becton Dickinson, the syringe disposable company in 1972 as the R&D director of laboratory equipment products. **Social Interaction** The method of implanting a glass sealed passive transponder under the skin of a laboratory animal as a means to provide reliable positive identification was tested in 1989 by the Sandoz Research Institute in East Hanover, New Jersey. The major concern in the report was the possibility of solid-state carcinogenesis developing during a two-year biological assay. For the scientific community at the time, the electronic identification of laboratory animals and specimens was seen as a way to significantly enhance the reliability of research results on drugs to improve human life and eradicate certain diseases.	In 1985, the conventional method of identifying laboratory animals was by toe clipping, ear clipping or tattooing, and Neil Campbell of BMDS recognized the need to find an alternative solution. Neil recognized the opportunity to use an RFID device as a productivity tool in an overall system which would be used by toxicologists, pharmacologists, and other researchers to link the electronic identification of animals to research data in a database. **Human Agency** There was a real concern of Destron/IDI going out of business, as it was an intimidation process to deal with the management of the company. Neil accelerated the R&D capability at BMDS to get more vertically integrated.	Donald Urbas was the knowledge conduit who transported transponder and reader technology from IDI to BMDS.	Eighteen months after leaving IDI in May 1983, Donald Urbas started the company UMG in Evergreen and worked on readers and implantables for laboratory animals with BMDS.

Tabulated Evidence from the Emerging RFID Industry

Company 13:	Avid Identification Systems, Inc. USA	**Application & Technology**	Identification of exotic birds & micro-chipping pet animals using an implantable glass encapsulated transponder
Year of Entrepreneurial Venture or Inventive Step:	1987	**Innovation**	Databases were established storing the identification code of each animal implanted with a glass encapsulated transponder. Loss animals brought to animal care professionals could be identified and returned to their owner.
Interviewee:	Douglas Hull		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
Joe Hitt of Destron/IDI sold the US franchise for pet animals to InfoPET Systems (Jack Greenberg) in 1988, which was considered a major mistake as it gave rise to Avid. Hannis Stoddard felt betrayed having worked closely with Destron/IDI over a number of years.	Vern Taylor's vision of electronically identifying animals with a transponder also rubbed off on the veterinary doctor Hannis L. Stoddard III, who started the company American Veterinary Identification Devices (Avid) in Norco, California around 1985 to identify exotic birds being imported into the United States. **Social Interaction** In December 1987, Douglas Hull and Joseph William Kunst met with Peter Yewdall of SVI in Thailand, the principle vendor of transponders and readers to Destron/IDI.	Dr. Hannis Stoddard had a veterinary clinic at San Pedro and was known for treating exotic animals. **Human Agency** Avid filed patents with engineering modifications, based on the design and innovations of the Destron/IDI glass encapsulated transponder and handheld portable RFID reader.	With the help of Michael Beigel, Hannis Stoddard copied the IDI transponder and reader, improving on performance and encryption features.	On September 14, 1985, Dr. Hannis Stoddard met with Dr. Ralph Knowles to discuss the implantation of parrots using an IDI transponder. In March 1986, a contract was prepared appointing Avid as a franchise distributor of IDI transponders. Avid started with the identification of exotic birds, but quickly formed alliances with pharmaceutical companies distributing their product to veterinary clinics for micro-chipping pet animals. By 1992, Destron Fearing and Avid created an industry standard in the United States for companion animal identification, preventing European competition from entering the US market.

Tabulated Evidence from the Emerging RFID Industry

Company 14:	Texas Instruments, (TIRIS), Germany	**Application & Technology**	Livestock identification using injectable tags (glass encapsulated transponders)
Year of Entrepreneurial Venture or Inventive Step:	1987	**Innovation**	Josef Schuermann invents an inductive low frequency RFID tag employing half duplex (HDX) communication.
Interviewee:	Josef Schuermann		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
Rumors of a uncertain future plagued TIRIS on a reoccurrence basis. The TIRIS global manager was Dave Slinger in Dallas, Texas. The decision to get into the RFID industry in 1989 was half hearted. No one really had the vision of where it would go.	At the time, the IC design center of Texas Instruments (TI) in Rieti, Italy was developing an RFID ASIC (Application Specific Integrated Circuit) for the company Datamars in Lugano, Switzerland. **Social Interaction** By chance in 1987, the Materials & Controls Division of TI in Almelo, Netherlands was confronted with a Dutch project to supply a small implantable device for electronic identification of livestock.	In the late eighties, semiconductor companies like Hughes Semiconductors Newport Beach, California a division of Hughes Aircraft, Microelectronics Marin, near Neuchâtel Switzerland a division of the watch company SMH and TI Semiconductors Freising, Germany a division of Texas Instruments were looking to move up the value chain and produce not only silicon but a complete packaged product to improve margins. **Human Agency** Between 1987 and 1989, Josef Schuermann worked in undercover to develop the HDX transponder at Texas Instruments.	Tom Payne joined IDI in 1984. Shortly before his arrival, Cliff Prough, director of marketing services handled the sale of 100 transponders and loan of a reader to Texas Instruments, New England. Later TI became a major competitor in animal identification. TI joined the ISO committee to set a standard for animal identification (ISO 11784, 11785) and it is the opinion of Josef that more knowledge about RFID disseminated from Nedap and TI than from the other committee members.	In 1989, a separate division for RFID was established under the trade name TIRIS. Unfortunately, the market for livestock identification never emerged because of resistance from farmers to implant a costly transponder with no economic benefit; the lack of an international standard, and the objection to having glass in meat during the slaughter process. TIRIS focused on all potential RFID projects with the hope of gaining traction in the RFID industry before anyone else. Their lack of focus, vision and entrepreneurial spirit meant that success was going to take time and significant financial expenditure.

Tabulated Evidence from the Emerging RFID Industry

Company 15:	UMG Inc, USA	**Application & Technology**	Identification of laboratory animals using injectable glass tube transponders
Year of Entrepreneurial Venture or Inventive Step:	1988	**Innovation**	Donald replicated the IDI glass encapsulated transponder and reader for laboratory animals.
Interviewee:	Donald J. Urbas		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
There was a big lay-off at IDI in 1986, with the sacking of half of the engineering staff. In May 1987, Don handed-in his resignation to Whit Patten.	At the age of 28, Don started at IDI as quality control manager on May 23, 1983 reporting to Tom Milheiser at the technical operations center in Littleton. On the recommendations of John Bradin in October 1984, Don was given the responsibility for all production operations. In an organization announcement on September 19, 1985 from Gordon Woolley in his capacity as acting director of quality assurance, Don joined the development department reporting to John Bradin. He worked on the transition from plastic injectable transponders to glass tube transponders. In September 1986, Don was working on a "Lab Wand Scanner" for Bio Medic Data Systems. The handheld scanner was to be used for short range reading of implantable transponders in small animals, card or badge transponders on cages or other containers. **Social Interaction** "All that might be in my mind, but Vern had that motivating effect on young engineers."	"I did not want to be affected by a salesman inability to pick the right application and produce sales. Pure independent engineering houses working on application specific projects and being paid upfront was actually a rather new concept back in the 80s." **Human Agency** After leaving IDI, with the permission of Charles Cushing, Don continued to work with Bio Medic Data Systems (BMDS) as a consultant.	Towards the end of 1985, Don was involved in experiments on the sealing of glass rods as the packaging alternative for the implantable transponder devices. Don took a good engineer from Destron/IDI and set up shop in competition.	Don started the company UMG in Evergreen and worked on readers and implantables for laboratory animals with BMDS. The glass rods were purchased with one side sealed like a glass tube and the other side then filled with biocompatible glue. This production method allowed BMDS to circumvent the original IDI patent.

Tabulated Evidence from the Emerging RFID Industry

Company 16:	Sokymat SA, Switzerland	**Application & Technology**	Glass encapsulated transponders for animal identification and immobilizer devices
Year of Entrepreneurial Venture or Inventive Step:	1988	**Innovation**	In 1991, Sokymat automated the production of glass encapsulated transponders using a technique of flyer winding and directly connecting the ultra fine wire ends of a microcoil to gold bumps on an RFID chip.
Interviewee:	Åke Gustafson		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
Certain entrepreneurs exploited Åke's intellectual genius to solve technical problems and later claimed merit for his inventions. According to Åke, you can rely on nothing! "An entrepreneur earns the money by taking ideas from someone else, and gaining the honor of the invention."	Åke Gustafson acquired the Swiss coil winding company Sokymat near Vevey in Switzerland, initially making microcoils for the watch industry. **Social Interaction** In 1977, Åke was invited to an entrepreneurial networking event. While drinking white wine with a promoter from the industrial development board in the Canton of Fribourg, he was offered to purchase a company in difficulties for a good price. It was Sokymat, a coil winding company started by Italians. During a trip in Asia, Åke met on a plane a Scottish person, Peter Yewdall from the company SVI, who was manufacturing & assembling microcoils at his plant in Thailand. In the conversation, Peter invited Åke to visit his facility in Bangkok. There, he saw how microcoils were being soldered to a radio frequency identification chip for a company in Boulder, Colorado.	The inventor, Åke Gustafson, led the development in 1959 of the Tetra Pak milk carton as we know it today. Some years later after leaving Tetra Pak in 1964, he acquired the Swiss coil winding company Sokymat near Vevey in Switzerland, initially making microcoils for the watch industry. **Human Agency** Sokymat supplied microcoils for a certain time to SVI, until Jim Seiler of IDI, later Destron/IDI came on the scene and requested assembled coils directly from Sokymat. Åke understood the coordination problem for Destron/IDI making coils in one location, connecting the wire ends of the coils by hand in Bangkok at SVI and encapsulating the electronics in a glass tube in Boulder. He envisaged an integrated solution.	Åke also attracted other entrepreneurs to the same industry, giving rise to the company Metget in Sweden which copied the "direct connection" method. Metget was formed in September 1995, and the development team re-engineered the Sokymat transponder machine for ferrite core transponders into a flat coil transponder machine required in the production of industrial tags and contactless cards.	Litigation is common place in the RFID industry, a weapon of business aggression in which rival companies or arch enemies are rendered lame in the marketplace or financially destroyed by their opponents. Joe Masin started a patent litigation process against Sokymat on June 24, 1994, claiming that Åke had stolen the direct connection method from Trovan. At the time, Sokymat had enormous success with the vehicle immobilizer, while Trovan had failed to gain a foothold on the animal ID market.

Tabulated Evidence from the Emerging RFID Industry

Company 17:	Trovan Ltd, Great Britain / Euro ID Usling GmbH, Germany / EID Inc., USA	**Application & Technology**	Electronic identification of livestock using glass encapsulated transponders
Year of Entrepreneurial Venture or Inventive Step:	1989	**Innovation**	In 1989, Philip Troyk invented a dual antenna, low frequency glass encapsulated transponder using PSK modulation.
Interviewee:	Josef Mašín & Ulrich Usling		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
Joe operates as a "lone ranger", has a basic understanding of technology, does not work for anyone and despises endless meetings where lawyers decide in the background. Joe will not take NO for an answer – "NO" is a challenge	In 1987, the German entrepreneur Ulrich M. Usling was introduced to Vern Taylor, who was selling the animal identification distribution rights for Europe and the Middle East. Ulrich M. Usling understood the enormous business opportunity, acquired the exclusive sales rights, but was unaware that Vern Taylor's company Taymar had engineering difficulties to produce high performance RFID tags. Ulrich M. Usling introduced Josef Mašín, a wealthy businessman from Santa Barbara California, to the idea of electronically identifying animals. **Social Interaction** "Joe was fantastic at seeking out ideas, capturing know how from everyone and basically turning the ideas into his own." Åke Gustafson	Josef Mašín saw the market potential in the electronic identification of livestock, concentrating on the Dutch project to identify pigs, not realizing that without an industry standard created by the key players or defined by the International Standards Organization (ISO), no real business was going to emerge. **Human Agency** To develop an inductive coupling transponder the size of a grain of rice and encapsulated in glass, Josef Mašín went to the consultants and engineers who were on the development team of Destron/IDI.	At a meeting at Sokymat in January 1991, Åke Gustafson demonstrated the direct connection method of terminating the wire ends of a microcoil directly to enlarged pads (gold bumps) on a silicon die. Åke Gustafson then patented the direct connection on February 25, 1991 (US 410), disregarding his Non Disclosure Agreement. Around April 1991, Gustafson made a quotation to Avid and Destron/IDI, thus disclosing the Trovan technology, without authorization from Joe or Trovan. EM Microelectronics Marin were moonlighting with Trovan's technology, as they reversed engineered the Trovan chip using the Orbit wafer mask set and created a standard RFID chip with the reference H 4001, and the Mega Bump invented by Trovan's engineers was used by Sokymat for their later date chips for automobile ignition immobilizers.	On August 23, 1989, Josef Mašín started negotiations with AEG Ulm, Germany (Dieter Deml) to manufacture exclusively passive transponders and readers for Trovan. Joe also discovered the innovative Swiss company Sokymat (Åke Gustafson) which had developed a technique for winding coils at high speed and being able to position the wire ends of a coil for interconnection. The RFID chip was first produced by Orbit Semiconductors in California, but at the request of AEG, EM Microelectronics Marin took over the volume manufacturing of silicon, because of their laser trimming and wafer bumping capabilities. Trovan developed not only the glass encapsulated transponder, but also industrial tags and contactless cards.

Tabulated Evidence from the Emerging RFID Industry

Company 18:	EM Microelectronic Marin, Switzerland	**Application & Technology**	Standard RFID chips for applications such as vehicle immobilizers, racing pigeon transponders and contactless smart cards
Year of Entrepreneurial Venture or Inventive Step:	1990	**Innovation**	EM reversed engineered the schematic circuitry of the Trovan RFID chip, creating a standard EM chip H7046 laser programmed Object Identification System (OIS) chip device (CMOS integrated circuit, 64 bits, Manchester or PSK coding) in June 1990, later released as a standard product known in the industry as H4001.
Interviewee:	Günther Meusburger		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
The market approach of EM Microelectronic Marin was opportunistic rather than strategic in setting out milestones to gain a foothold in the RFID industry. The sequence of events which led to success was serendipitous and could not have been foreseen. **"A new product comes from the gut, if it is in your head, it is too late"** Günther Meusburger	In 1990, EM Microelectronic Marin, a division of the watch making conglomerate SMH, was a semiconductor company supplying over 50% of its wafer fabrication capacity to the watch industry. The remaining capacity was filled with application specific integrated circuits for the medical, automotive and commercial industry. EM specialized in low voltage, low power CMOS devices with electrical erasable programmable read only memory (EEPROM). In addition, the company had extensive know-how and manufacturing capability in micro-packaging of silicon using a technique from the watch industry called "Tape Automated Bonding" (TAB). Using technology developed specifically for the watch industry, EM Microelectronic Marin was in the position to use the same silicon and micro-packaging technology for the RFID industry. **Social Interaction** Günther spent a lot of time discussing with Åke Gustafson of Sokymat, philosophizing on the techniques of manufacturing but also on the long term use of transponder technology.	EM Microelectronic took an opportunistic approach to the RFID industry, cherry picking application specific integrated circuit projects such as those for AEG/Trovan, Nedap and Chubb Lips. **Human Agency** Around the middle of 1990, Günther gave the Orbit chip design tape which he had received from AEG in Ulm to the East German Microelectronics Center (ZMD) in Dresden which reversed engineered the schematic circuitry of the Trovan RFID chip overnight. EM Microelectronic Marin did not use the design, but developed their own standard RFID chip (H7046).	When Günther left Eurosil Electronic in July 1984 to join EM Microelectronic Marin in Switzerland, he brought a vehicle identification project for the company Brown Boveri AG with him. The project was baptized "OIS" (in Bavarian dialect meaning "all is easy"), or in real world terms "Object Identification System." The knowledge gained in the development of application specific integrated circuits (ASICs) was used to create a standard range of RFID products, allowing newcomers to the RFID industry to compete with the pioneers.	A commonality between the watch and RFID industry is the requirement for low power, low voltage silicon. EM Microelectronics Marin, near Neuchâtel in Switzerland, a division of SMH and Eurosil Electronic GmbH, near Munich in Germany, a division of AEG Telefunken supplied semiconductor devices to the watch industry. Both these silicon vendors played a major role in the emergence of RFID, at first developing and supplying application specific integrated circuits (ASICs) to the pioneers, but later offering new entrants to the industry standard RFID chips.

Tabulated Evidence from the Emerging RFID Industry

Company 19:	Mikron, Austria	**Application & Technology**	Automatic fare collection in mass transit using an inductive high frequency contactless smart card
Year of Entrepreneurial Venture or Inventive Step:	1993	**Innovation**	Roland Koo recognizes the opportunity in automatic fare collection and sets about to develop a contactless smart card chip operating at 13.56 MHz, baptized "Mifare" as a replacement for tickets in mass transit.
Interviewee:	Roland Koo		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
The driving force for leaving AMI in 1986, during the recession period, was his discontentment with the conditions under which he had to work. His roots were in Graz and moving away from the area was not an option. To remain in Graz, he could either leave the semiconductor industry or become an entrepreneur and in some way remain connected to IC (integrated circuit) development.	In 1983, Roland Koo joined the semiconductor company AMI (Austrian Microsystems International, a joint venture between American Microsystems and an Austrian steel company), as a section manager of an engineering group, specializing in mixed signal design. He gained a wealth of experience in analog/digital design over the years that followed. **Social Interaction** Word got around that he was considering leaving AMI and a former sales person (Werner Hollig) of AMI in Germany who had taken up the position of sales director of Mikron in Eching, contacted him. Mikron was an IC design center and a silicon foundry customer of AMI.	Roland had six years background in analog/digital design, managing engineering projects. **Human Agency** In autumn of 1986, Roland met with the entrepreneur and managing director of Mikron, Elmar Zeising, who considered Roland's idea of a design center in Graz, close to AMI as a worthwhile strategy. Roland had six years background in mixed signal design, managing engineering projects, and this experience complemented the skill set at Mikron. Elmar Zeising had a feeling for people and was spontaneous in his decision making.	The engineers at Mikron Graz learned from the Siemens Automotive project and began to develop their own RFID product operating at a single frequency and having an etched antenna with a very minimum of external components.	From development of an RFID chip for Siemens Automotive in 1989, the strategic direction was set for Mikron in Graz. From the knowledge gained on the development of the RFID chip for the automotive application, Mikron developed in 1991 an RFID chip called "Midat" which became a standard in tool identification. In 1992, the next generation of RFID products under the name "Hitag" were released having additional technical features such anti-collision and encryption algorithms. With focus on customer problems, Roland recognized the opportunity in automatic fare collection and set about to develop a contactless smart card chip, baptized "Mifare" as a replacement for tickets in mass transit. Mikron Graz was sold to Philips Semiconductor in 1995 and Roland left in April 1996.

Tabulated Evidence from the Emerging RFID Industry

Company 20:	Motorola Indala, USA	**Application & Technology**	To replace barcode in item level tagging using capacitive coupling technology
Year of Entrepreneurial Venture or Inventive Step:	1995	**Innovation**	Theodore Geiszler invents the BiStatix technology, a radio frequency identification tag deriving power from an electrostatic field generated by a nearby reader.
Interviewees:	Noel Eberhardt & Victor Vega		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
The divisional manager of Motorola Indala, Fernando Reyes, was excited by the BiStatix project, but his boss François Dutray was more of an impediment. The project continued with little internal resources and Motorola was not willing to invest in a customized chip, manufactured at their own silicon foundry. Politics got in the way of progress. **Victor took BiStatix Personally**	BiStatix was a disruptive technology which could have displaced bar code in the retail environment, but also posed a serious threat to conventional transponder technology using inductive coupling, requiring a costly wire antenna for data communication. **Social Interaction** Noel made a presentation at the Media Lab to all sponsors of MIT (TTT – Things That Think consortium), demonstrating the simplicity of his antenna printing concept. A person from Procter & Gamble, Kevin Ashton was present at the seminar, who quickly met up with Noel to get a grip on the potential of the technology.	Motorola Indala management did not believe nor could be convinced barcode technology could be replaced with RFID. **Human Agency** The development of the BiStatix tag at Motorola Indala was done undercover as top management was not motivated by high volume, low margin, standardized, commodity products. Their focus was on proprietary solutions with high margins.	At the RFID show in Chicago, John Rolin, the chief engineer and instrumental in the design of the first BiStatix chip, living in Morgan Hill, was approached by Alien. John was aware that Motorola was disbanding RFID and shortly later left to join Alien.	The pioneers had a solution looking for a problem. Technology was pushed to the market with only early adopters using RFID in low volume, niche applications. The flip occurred in 1997 / 1998 when end users came looking for a technology to solve a problem. Two events kicked off the foundation of the MIT Auto-ID Center: Firstly Wal-Mart was thumping on the table to have their main suppliers make a decision on the technology for item-level tagging; Secondly while Wal-Mart was pressing their suppliers for a decision on technology, Noel Eberhardt was working on the continued development of the clandestine BiStatix technology, invented by Ted Geiszler. The beauty of the Bistatix technology was the simplicity of producing a printed antenna using a conventional inkjet printer and connecting a microchip to the antenna via an interposer.

Tabulated Evidence from the Emerging RFID Industry

Company 21:	Alien Technology, USA	**Application & Technology**	To replace barcode in item level tagging using radiative coupling technology
Year of Entrepreneurial Venture or Inventive Step:	2001	**Innovation**	Alien mounted silicon Ultra High Frequency silicon dice on substrates using Fluidic Self Assembly (FSA).
Interviewee:	Victor Vega		

Discontentment	Exposure to Opportunities	Alertness	Knowledge Spillover	Comments
Victor, who was extremely disappointed with the executive management at Motorola Indala, became the information conduit who brought Alien Technology to take an active interest in RFID. He demonstrated BiStatix to its senior management (President & CEO: Jeffrey Jay Jacobsen), and with Alien's proprietary manufacturing process in electronic assembly of micro devices (Fluidic Self Assembly), meant the technology fit with Motorola's BiStatix looked like a marriage in heaven.	The engineering staff at Motorola Indala was demotivated by an uncertain future and before Victor Vega jumped ship to join Alien, John Rolin recommended to Alien management that they acquire an RFID company. **Social Interaction** Before the acquisition of WaveID, John Rolin arranged a meeting between Victor and Tom Pounds CEO of WaveID, Curt Carrender CTO and John Price (director firmware and software) to discuss UHF technology (a black art) and how they could leverage the advantages of Alien's FSA process for RFID.	Alien management intended to discontinue their flat panel display business **Human Agency** The demise of the Bistatix technology at Motorola Indala gave rise to the emergence of the company Alien Technology. Victor Vega guided the management of Alien in the direction of RFID, at a time when he was still an employee of Motorola Indala.	In October 2001, Alien acquired WaveID, a company specialized in ultra high frequency tags. The founder of WaveID, Curt Carrender was originally Director of R&D for the Amtech System Division of Intermec Technologies, and would have had knowledge of the UHF chip technology developed by IBM and acquired by Intermec in 1997.	The opportunity was in item-level tagging and the initial project under the auspice of the Auto-ID Center was tracking consumer products at Wal-Mart.

Source: Author

6.3 Research Findings

The interviews yielded a database of codable statements or data fragments, each of which consisted of a word, phrase, sentence or a sequence of sentences conveying a coherent point. By comparing statements across informants, a re-occurring pattern of casual ideas, concepts and interlinking relationships emerged which allowed me to define categories and thereby identifying the dimensions which explain the pathway which leads to knowledge spillovers in the emergence of the RFID industry.

My qualitative analysis identified three critical dimensions: "discontentment", "human agency" and "social interaction" fostering the generation and propagation of knowledge during the emergence of the RFID industry. I found that it takes the "discontentment" dimension to act as a catalyst to initiate human agency and then social interaction which results in the knowledge spillover process.

The informant stories behind these three dimensions have been presented in the interview data section and are now represented schematically as data displays in figures I-III.

6.3.1 Findings: Discontentment Dimension

In my data, I found discontentment, stemming from three elements: internal company factors, uncontrollable external factors and the individual desire to change circumstances and pursue a particular entrepreneurial activity. I coded 21 statements into this category.

At the individual level, "discontentment" and a "desire for change" are key drivers of entrepreneurial behavior. The "desire for change" also entails the emotion of "discontentment" during the start-up context, but it is a proactive rather than a reactive approach to a prevailing situation. It can be a desire for self realization, a need for achievement, a desire for independence or brought about through exposure to a market opportunity.

Negative forces internal to a firm have been shown to incite individual or collective "discontentment" arising from: a lack of recognition, a threat of unemployment, a departure of close colleagues, unfair treatment, a lack of management direction and attention, a change in strategic direction, internal restructuring, cost cutting initiatives, innovation stagnation, new management, financial stress, a lack of communication, customer complaints, deterioration of a company's image, a change in a company's culture, arrogance and politics.

Discontentment can also be triggered by uncontrollable factors such as a dramatic life change, economic melt down, change in market conditions and competitor threats.

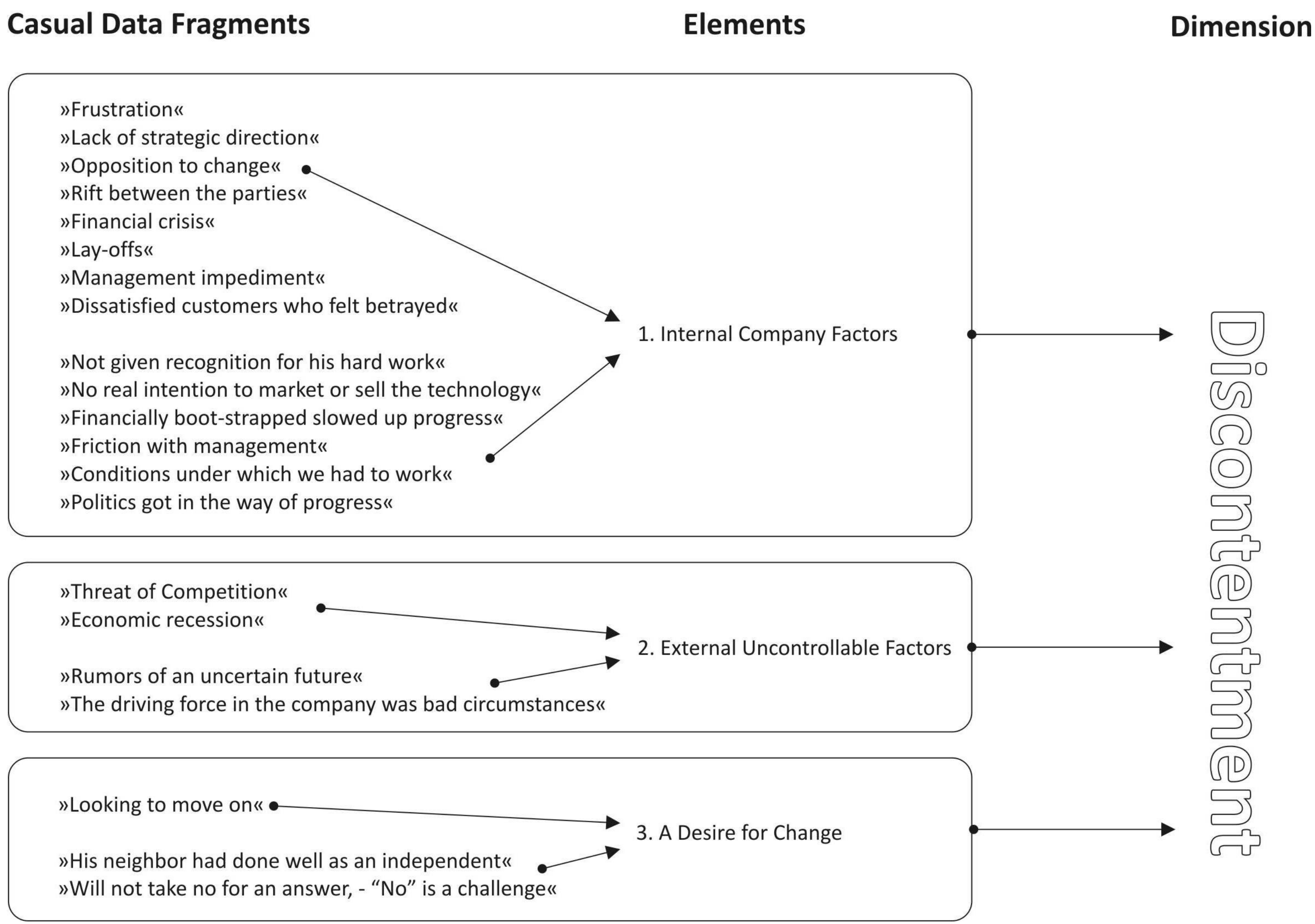
But perhaps the most poignant triggers of negative thoughts and mixed emotions leading to discontentment are jealousy and envy as well as the self serving desire for the pursuit of money, wealth, power and the glare of publicity which can lead to "questionable professional ethics" in a business environment.

Therefore, discontentment stems from negative forces which compel an individual to search for opportunities or assist an enterprising individual in a new venture. It is a trigger to push or pull an individual into an entrepreneurial process.

To counteract discontentment individuals must act or react; this brings into play the dimension of human agency.

I conclude by defining “discontentment” as a state of dissatisfaction with one’s circumstances, triggered by cognitive stimuli or external forces. In an entrepreneurial setting, discontentment can lead to a decision to take action, to positively or negatively influence a prevailing situation. This action may shape the entrepreneurial process.

FIGURE I
Exploratory Data Analysis of the Discontentment Dimension



6.3.2 *Findings: Human Agency Dimension*

The second dimension identified in my data was human agency, into which I coded 20 statements. Unlike the first dimension which is concerned with emotions and restlessness, the second dimension is concerned with action or reaction.

Human agency in the entrepreneurial process is the capacity to make a conscious or unconscious decision and to enact it. An unconscious decision is a metal process of human psyche influencing attitude and behavior which individuals make below the perceptual conscious mind. The psychological concept of the internal contradiction as an unconscious factor influencing human behavior was developed by Sigmund Freud (Geraskov, 1994). In the entrepreneurial process, unconscious decisions arise from discontentment and various social conflict situations directing individuals to react and settle unsolved problems.

In my data, I found human agency, in the form of 10 elements: consciously seeking to initiate a new venture, innovation, entrepreneurial persuasion, knowledge procurement, knowledge provision, knowledge protection, undercover activity, self-interest, discontentment provocation and unethical conduct. It is recognized that there are many possibilities in which human agency can be classified and the suggested elements are not exhaustive.

The first seven elements of the human agency dimension represent the incremental pathway from discovery to evaluation and eventual exploitation of an opportunity. They are the logical footprints to the diffusion of knowledge in an emerging industry. The later elements of self interest, discontentment provocation and unethical conduct are very subtle and difficult to capture in an interview.

During the data collection phase, egoism and selfishness were mentioned by those informants who experienced the blunt of self-interest in dealing with trusted associates on issues of financial engineering (e.g. retrenchment, selling the business, rights issue, launching an initial public offering), strategic direction, organizational design, power and percentage stake holding in the business.

Entrepreneurs are often referred to as "agents of change." In the ninth element, I observed "discontentment provocation" a process by which individuals or entrepreneurs 'molded' discontentment in a direction they deemed desirable for an entrepreneurial venture.

By inciting discontentment in others, they induce or influence them to alter their behavior or to act in a manner detrimental to their employer. Typically dissatisfaction was the outcome and in many cases individuals left their employer to join the 'inciting' entrepreneur's venture. An individual's discontentment can also spread to others.

The tenth element of human agency is unethical business conduct, raising its ugly head in the stories in the form of stealing of ideas (piracy), copying of intellectual property, bribery and deceitfulness.

According to the inventor and entrepreneur, Åke Gustafson, "unethical actions can also be the reason for economic progress in the industry".

I conclude by defining human agency (individual or collective) in the entrepreneurial process as the capacity to make a conscious or unconscious decision and to enact it, in particular, the decision to pass on information and knowledge (explicit or tacit) to another party, bringing into play a moral component (ethical or unethical) to influence subsequent events.

FIGURE II
Exploratory Data Analysis of the Human Agency Dimension

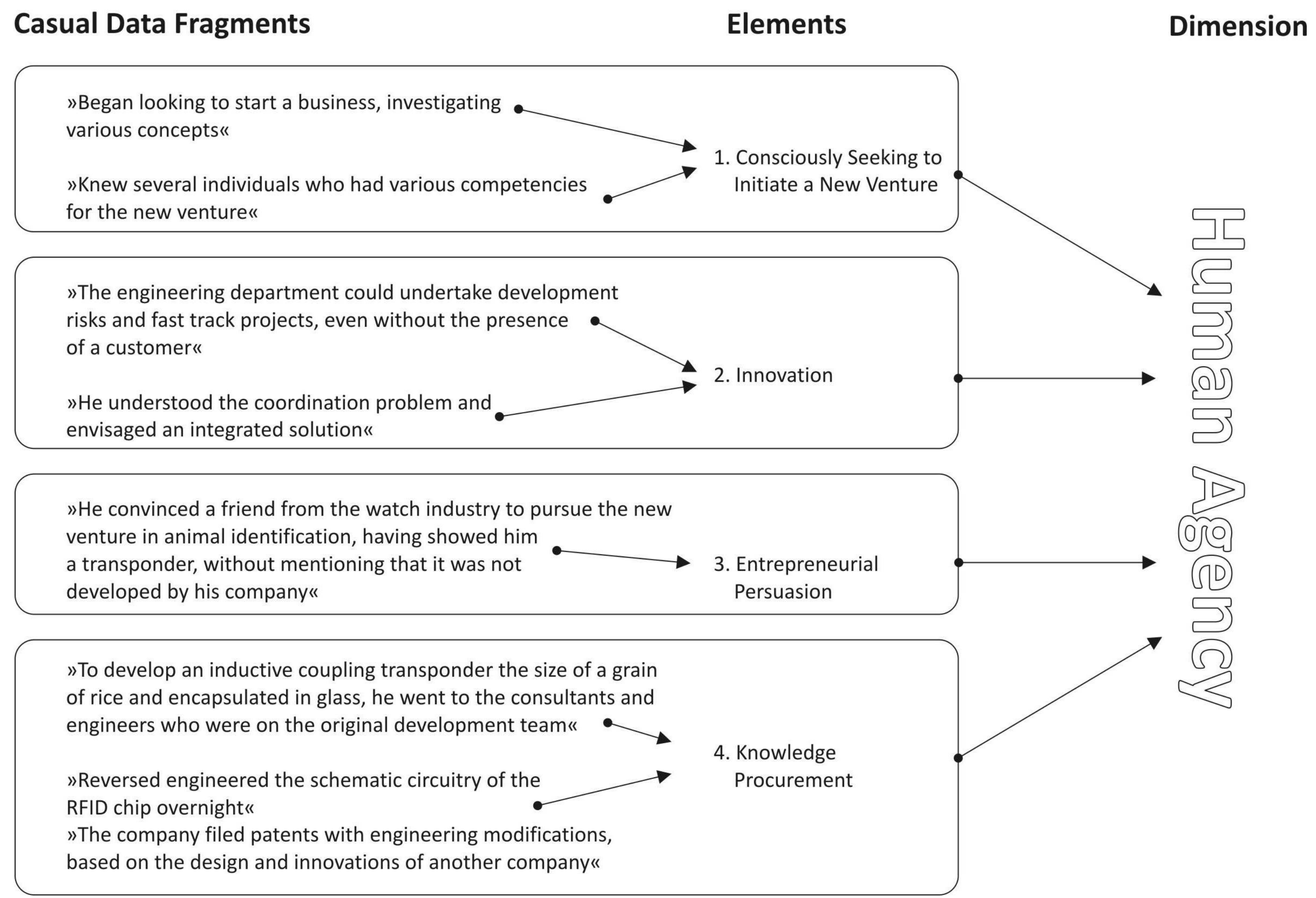


FIGURE II
Exploratory Data Analysis of the Human Agency Dimension

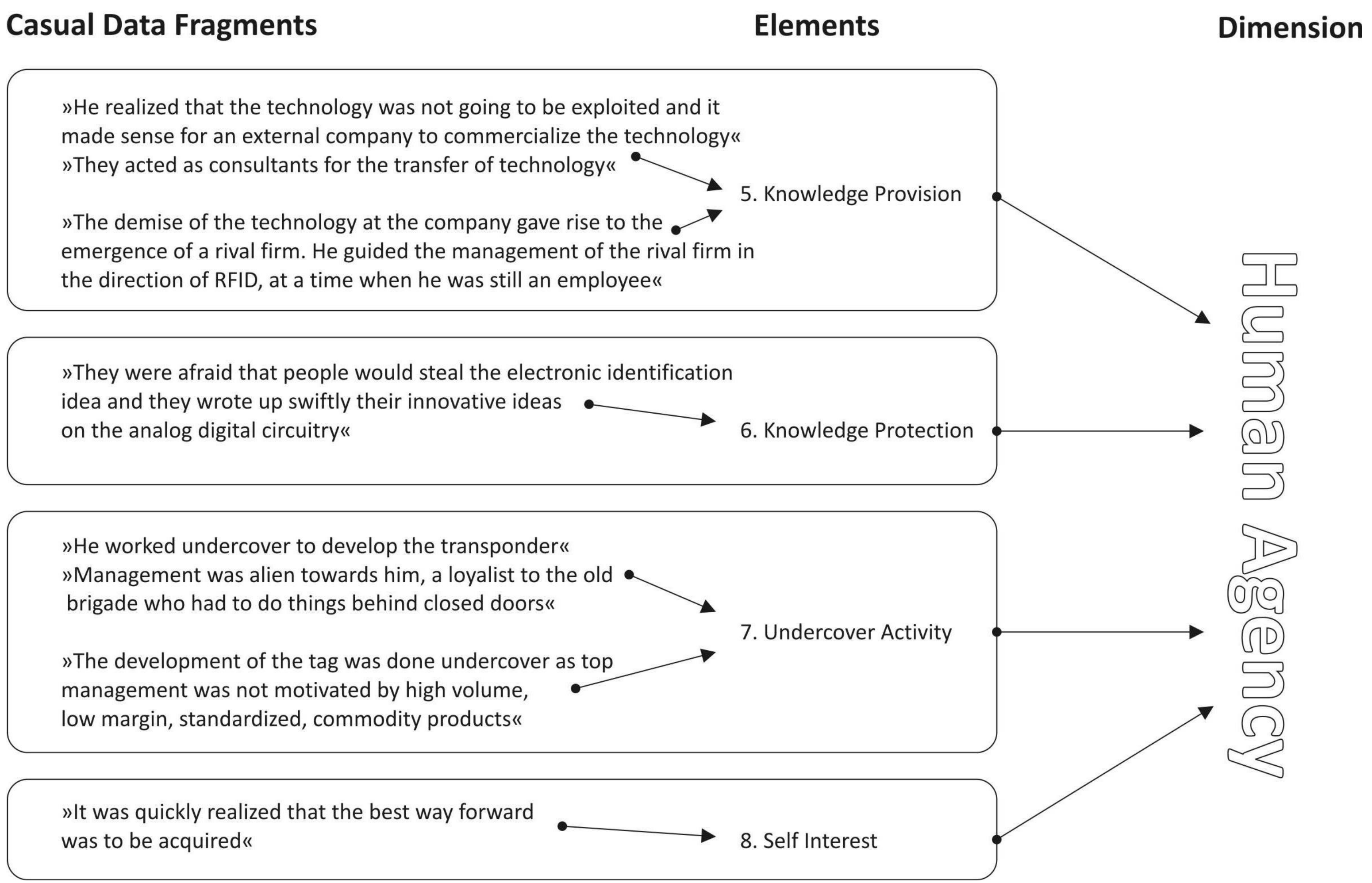
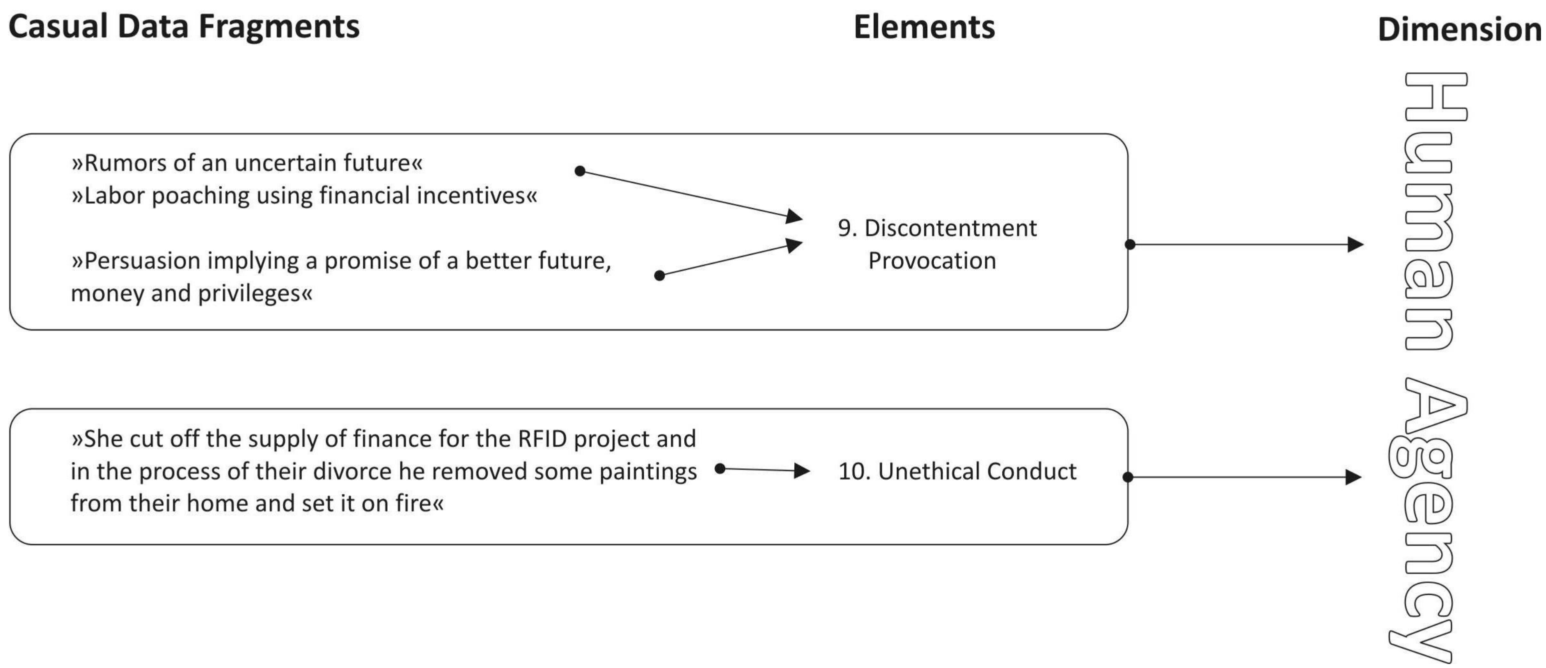


FIGURE II
Exploratory Data Analysis of the Human Agency Dimension



6.3.3 *Findings: Social Interaction Dimension*

The final dimension emerging from my data is social interaction, an event or a dynamic interactive process between individuals or a group of individuals with casual acquaintances, occupational colleagues, organizational members or community members. In the case of an event, there is learning or an influencing process in which emotion or information is conveyed which can give rise to new ideas, concepts and practices. In a dynamic interactive process individuals influence or modify their actions and reactions reciprocally, exchanging, sharing and interpreting information and knowledge. I coded 16 statements into this category.

My findings show that at the individual level, entrepreneurs influenced and motivated their collaborators through personal contact. Entrepreneurs were also the stimulus for other entrepreneurs to exploit opportunities, like a "magnet", they attracted others to the same opportunity. Serendipitous events also led to the discovery of opportunities.

In the concluding section of the "Time Series Analysis of Patent Applications", the evidence demonstrated that marketing, communication, information disclosure, litigation and technological advancements through creation or innovation, are all events involving human action and reaction. They form the basis for social interaction.

Similarly, the interactive processes at the firm, industry and community levels as outlined below confirm that social interaction is the mechanism that drives the diffusion (movement) of knowledge from an entrepreneurial firm to other firms and to the wider industry community.

Therefore, the social interaction dimension is the diffusion vector by which information and knowledge are transmitted and received.

I conclude by defining social interaction at the firm level as a dynamic interactive process of social actions between individuals or a group of individuals who modify their actions and reactions according to those of their occupational colleagues. At the industry level, social interaction is an event or a sequence of social actions between individuals or a group of individuals in a firm with other members of the community such as customers, material and equipment suppliers, consultants, research laboratories, test houses, universities, professional organizations and competitors which leads to the interpretation and sharing of information and knowledge.

FIGURE III
Exploratory Data Analysis of the Social Interaction Dimension

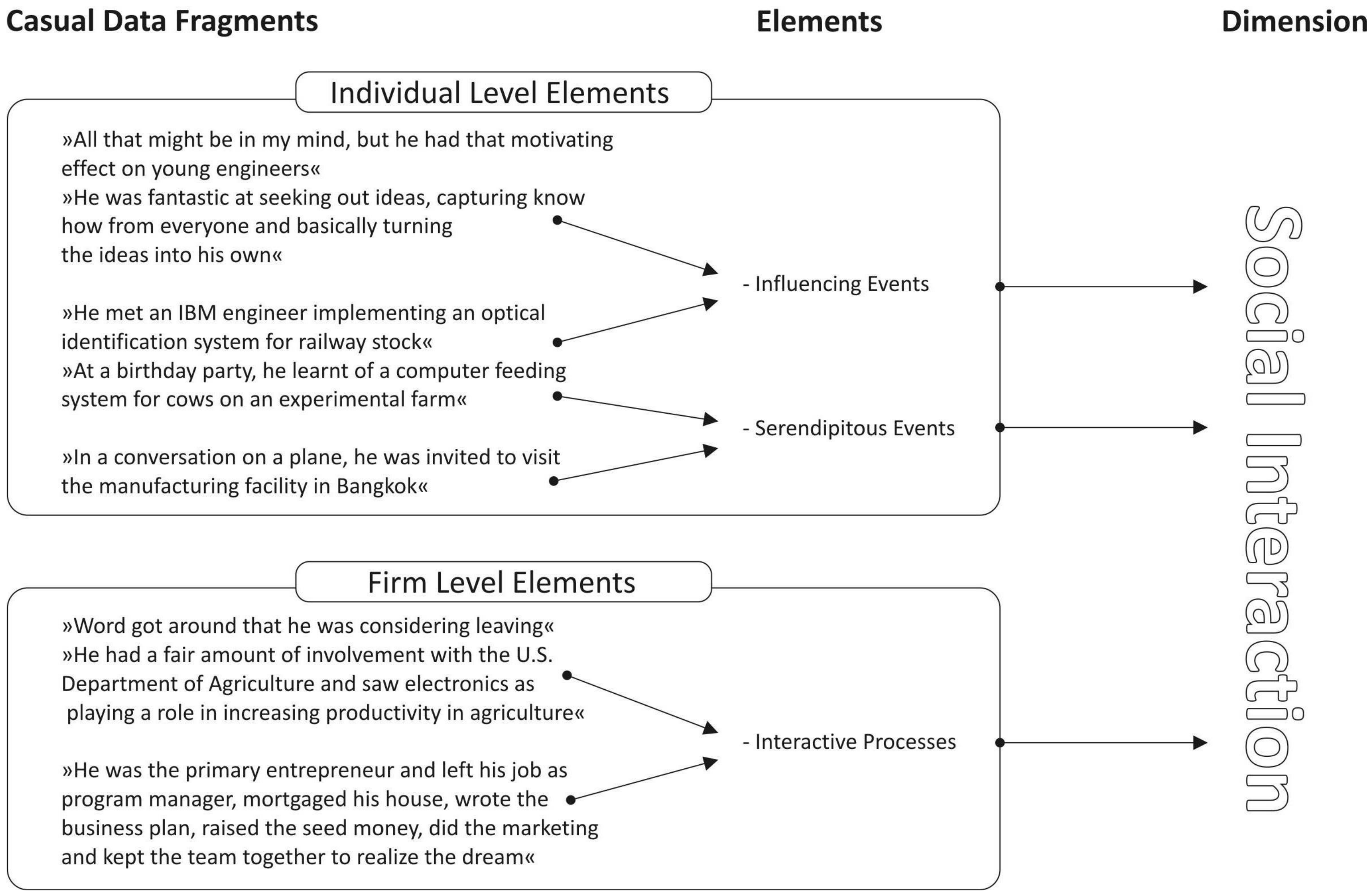
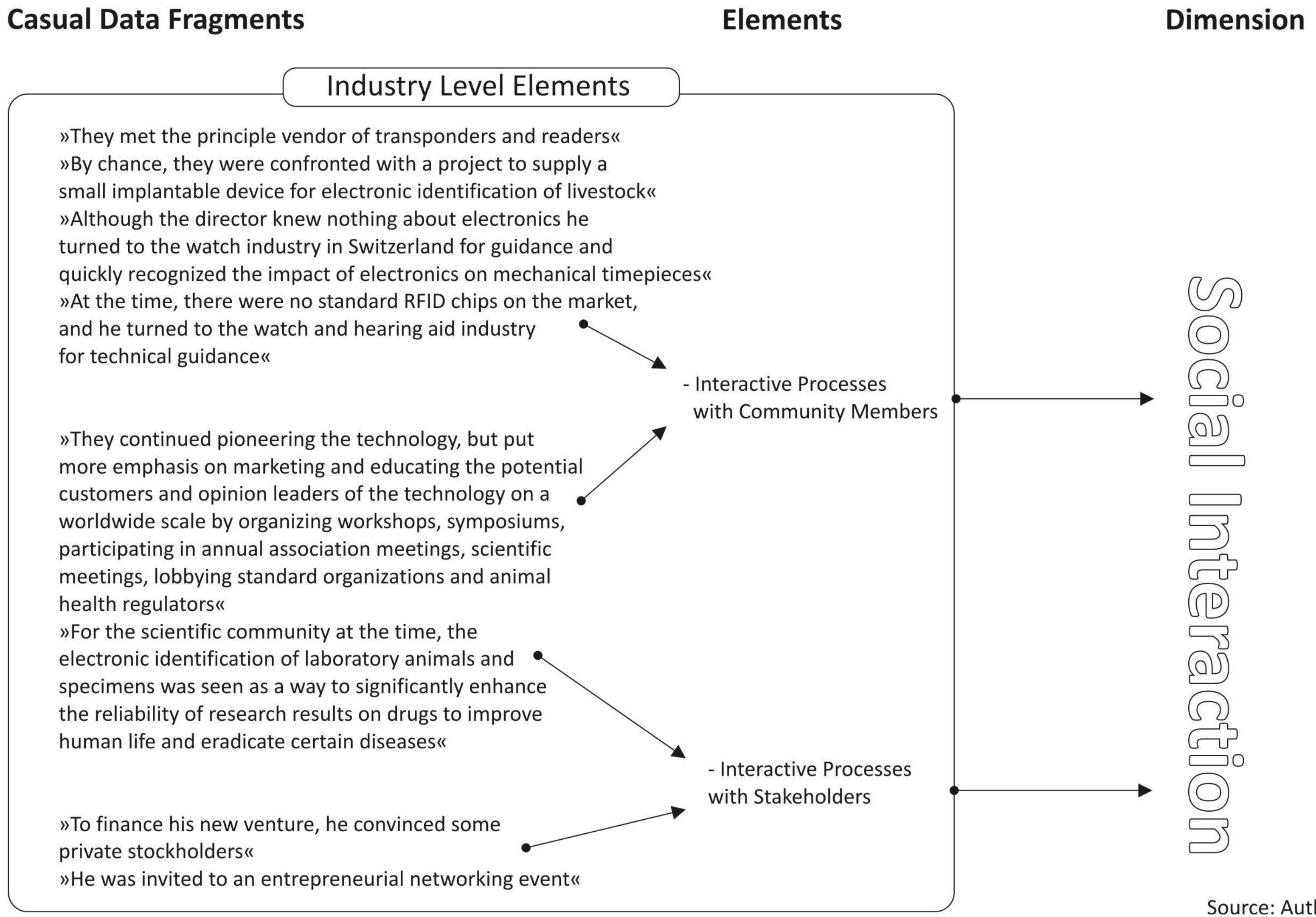


FIGURE III
Exploratory Data Analysis of the Social Interaction Dimension



Source: Author

6.4 Concluding

In this section, I found that the feeling of discontentment, originating from negative or positive circumstances, was the precursor to individuals sharing knowledge or to exploiting knowledge through new venture creation. I found that knowledge spillovers were a consequence of the human agency, or action, of discontented individuals. And I found that during the emergence of the RFID industry, the discovery, evaluation and exploitation of opportunities by individuals were the result of knowledge spillovers that resulted from extensive social interactions.

The three dimensions of discontentment, human agency and social interaction describe the pathway to knowledge spillovers during the emergence of the RFID industry.

In summary, the emotion of discontentment triggered by negative forces acts as a catalyst to human agency, in particular, the decision to pass on knowledge to another party. Discontented individuals were the knowledge conduits who diffused knowledge to entrepreneurs and their collaborators through social interaction.

In the next chapter, I bring together the key findings at the individual, firm and industry level, before presenting propositions formulated to describe the nature and consequences of knowledge spillovers in the emergence of the RFID industry.

CHAPTER 7 – DISCUSSION AND CONCLUSION

7.0 Introduction

In this chapter I will revisit the question that guided this study: "Why, when and how do knowledge spillovers occur in an emerging industry?" To do this I will first briefly present the evolution of the RFID industry and a summary description of the industry process. I then explore the evolution of the industry from the perspective of the four research questions that directed the data collection:

1. How do individuals identify opportunities in an emerging high-tech sector?

2. What triggers individuals to act on an entrepreneurial opportunity?

3. What is the extent and nature of innovation during the emergence of a knowledge based industry?

4. What facilitates knowledge spillovers in an emerging high-tech industry?

I will then present a summary of key research findings from the analysis of the interview data, the patent analysis, and my description of the evolution of the industry. I then state the five propositions that emerged from this study.

The chapter then seeks to integrate my findings with existing literature. I explore two themes from the literature in the light of the findings of my study of the RFID industry. And I present a model on Entrepreneurial Emotion, Cognition, Motivation, Human Agency and Social Interaction (Fig. V).

The two themes from the literature are:

- Triggering Events and Shane's et al. (2003) Model of Entrepreneurial Motivation and the Entrepreneurship Process
- Knowledge Spillovers

7.1 The Evolution of the RFID Industry

RFID invention occurred on the heels of radar development during the Second World War. Early explorations of RFID occurred in the early seventies in government research laboratories and academic institutions. The transfer of technology from the scientists and academics to commercial industry was impeded by bureaucracy.

Several inventors, scientists, and engineers pioneered RFID in the late seventies and eighties with a shift in technology from radiative to inductive coupling transponder systems. In the mid eighties, the transition from ground breaking to incremental innovation began as a result of knowledge spillover becoming rampant among the players of the emerging RFID community.

In the case of animal identification, entrepreneurs turned to the Swiss watch industry for manufacturing ideas on coil winding, miniaturization and encapsulation. In doing so, the innovative entrepreneurs in RFID alerted entrepreneurs in the watch industry to the potential of this technology.

Not all entrepreneurs were engineers, many were individuals who just understood the opportunity and assembled key people around them who gave credibility to their business.

However, the pioneers of RFID were ahead of their time with a “solution” looking for a “problem”. Many of the innovative companies had developed application specific integrated circuits (ASICs) with design houses and semiconductor companies, and their tacit knowledge of RFID technology was codified in the layout of their customized silicon chips.

Many companies patented their innovations, describing their inventive steps in patent claims like a recipe in a cook book, for rival companies to circumvent and improve upon.

The players in the industry were small innovative companies operating on a shoestring budget and constantly seeking funds to fuel product and process development and to market to the world a product yet to be accepted. The knowledge created within the innovative companies diffused with the departure of employees and provided knowledge spillover benefits for others to exploit.

In the early nineties, RFID was considered the panacea for all identification problems, though disagreement on communication standards and operating frequency for any given application, resulted in a slowing of growth.

Semiconductor companies like Hughes Semiconductor, Eurosil Electronic, Texas Instruments, EM Microelectronics, Philips Semiconductors, Siemens and Motorola entered the market.

The technical knowledge which the semiconductor companies had acquired through the development of customized integrated circuits for the pioneering companies of the eighties and early nineties was used to develop standard RFID chips.

By the mid nineties, an RFID community had formed made up of engaging specialized companies competing along the value chain. With the decline in product innovation, process innovation began with the arrival of a "dominant design" in the manufacture of companion animal tags and contactless smart cards.

Only those companies who recognized RFID as a tool to provide a service and concentrated on a niche market became profitable. The rest were focused on too many applications and gaining economy of scale in the production of tags was a near impossibility. Financial stress put extreme pressure on the entrepreneurs and constant improvisation to survive put a strain on employee moral.

The burst of the IPO bubble in 2000 and the terrorist attack on the Twin Towers in New York on September 11, 2001, was a shock to all markets causing a freeze on investment around the world, and ultimately resulting in the sudden death of many RFID companies. In this shakeout phase, many small RFID companies were acquired and merged with large corporations. Those who survived the turbulent period enjoyed rapid growth in the years that followed, especially in the security sector. The survivors picked up the pieces of the insolvent competitors and acquired their tangible and intangible assets cheaply.

At each stage in the emergence of RFID technology, the scientists, inventors, entrepreneurs and the innovative firms provided benefits to the industry that outlasted their existence.

7.1.1 Summary Description of the Industry Evolution Process

Conventional wisdom holds that knowledge spillovers tend to be localized within countries and regions (Jaffe et al., 1993). The example of the "syringe-implantable transponder for animal identification" has demonstrated to the contrary that knowledge spillovers in the emergence of a new industry diffuse rapidly, when the customer and supplier base are global.

After the ground breaking era of innovation during the fifties and sixties, and to some degree in the seventies and early eighties, came an era of incremental innovation by the players in the RFID industry. The knowledge input for this innovation came from the external acquisition of technological knowledge to leverage internal development by using technical clues to overcome engineering hurdles, and ultimately accelerating product and process development, reducing R&D expenditure and bringing new products faster to market.

From the above evolution analysis, the determinants underlying the change process by which the RFID industry emerged and grew are: entrepreneurial activity and financial investment, technological progress, the transition from ground breaking to incremental innovation, globalization, fragmentation and specialization along the value chain, standardization of transponder operating frequencies and communication protocols for specific applications, the shift from market creation to market demand, and knowledge spillovers from innovative small and medium size enterprises to rival firms of similar size.

Entrepreneurial actions and reactions at the individual level link to the aggregate level of the industry through the dynamic mechanisms of technological progress and knowledge spillover.

7.1.2 RFID Industry Evolution in terms of the Four Research Questions

Question 1

> How do entrepreneurs identify opportunities in an emerging high-tech sector?

The answer to this question is found in the category "exposure to opportunities." All of the entrepreneurs from the 21 firms were confronted with an opportunity through employment, social interaction with other entrepreneurs, a serendipitous incident or had prior knowledge of the opportunity.

The category "alertness to opportunities" is closely linked to exposure, especially in the technology field where engineers and inventors are confronted with many technical issues which give them prior knowledge of an opportunity. The data did not reveal that entrepreneurs were in a constant state of alertness and could recognize an opportunity before being exposed to information or knowledge on the opportunity.

From the data collected in the RFID industry, exposure and alertness to opportunities are different sides of the same coin: prior stocks of knowledge and preferential access to or ability to recognize information about an opportunity are a prerequisite for cognitive alertness. There is a gathering of information, an interruption and a learning process before the intuitive spark of entrepreneurial behavior. The idiom "seeing is believing" best explains the narrow interface between exposure and alertness.

Therefore, entrepreneurs discovered opportunities in the emerging RFID industry, through prior knowledge of the business and or through social interaction with other entrepreneurs.

Entrepreneurial spirit is contagious, a phenomenon attracting other entrepreneurs to the same opportunity which I labeled "entrepreneurial magnetism." Enthusiastic entrepreneurs exude information and knowledge about an opportunity in conversation with suppliers, customers and often with potential competitors. I refer to this discharge or flow of information and knowledge as "entrepreneurial flux."

Question 2

> What triggers individuals to act on an entrepreneurial opportunity?

19 entrepreneurs from 21 firms who pioneered the RFID industry in the period between 1970 and 2000 described their frame of mind prior to launching an entrepreneurial venture as being in a state of "discontentment."

They expressed their dissatisfaction of their situation, by using such words as: frustrated, worried and disappointed; and phrases such as: not given recognition, undermined his position, no real intention, felt betrayed, bad circumstances forced creativity and rumors of an uncertain future, before taking action to change their circumstances.

The state of discontentment was the impetus driving the individual to trigger change, whether positive or negative change.

Discontentment does not only trigger change in entrepreneurs, but it also triggers change in individuals associated with a potential or existing entrepreneurial venture. In several cases, discontented engineers working for an RFID company assisted an external entrepreneur or entrepreneurial company with information and knowledge on technical and market issues.

These discontented individuals were the knowledge conduits which helped give rise to rival firms, either through replicating the existing technology of their former employer or innovating having recognized a new opportunity.

Question 3

What is the extent and nature of innovation during the emergence of a knowledge based industry?

Early explorations of RFID prior to the 1970s (refer to table 1 “RFID Timeline”) were ground breaking inventions which gave birth to radar, airborne Identification Friend or Foe (IFF) systems and microwave transponder technology. Most of the inventions were developed under the shroud of military secrets.

In 1975, the scientists at Los Alamos Scientific Laboratory (LASL) developed an animal identification tag using modulated backscatter, but only a decade later did the technology become commercially available when the scientists took a leap of faith and developed the technology further for electronic toll collection and railway stock identification.

RFID was developed 60 years ago by Harry Stockman in 1948, but its implementation awaited a host of other technical developments such as low voltage, low power complementary metal oxide semiconductors (CMOS), electrically erasable programmable read-only memory (EEPROM), microprocessors and the personal computer, as well as advances in radio technology, application software, and communication networks.

Between the mid eighties and early nineties, a number of enterprising individuals (Vern Taylor, Theodore Geiszler, Åke Gustafson, Joseph Mašín, Roland Koo, to name a few) entered the RFID industry developing innovative technology based on the inventions of their peers.

Their innovations were incremental, rather than ground breaking inventions and their technology was replicated by many in the years that followed.

By the late nineties there was a shift from market creation to market demand, when transportation authorities, financial institutes, government agencies and retailers were looking for "a solution to a problem."

Today, paper tickets in mass transit applications in Hong Kong and Seoul are replaced by contactless smart cards; RFID enabled payment cards (debit and credit) are used to make micro-payments at fast food restaurants in the United States to enhance consumer convenience and flexibility; post 9/11 electronic passports are becoming mandatory for all travelers visiting the US from countries under the Visa Waiver program, and to improve merchandise management and on-shelf availability of products at Wal-Mart, RFID tags are used to track products in the supply chain.

Question 4

> What facilitates knowledge spillovers in an emerging high-tech industry?

After the ground breaking era of innovation during the fifties and sixties, and to some extent in the seventies and early eighties (refer to table 1), came an era of incremental innovation giving rise to rampant knowledge spillover among the members of the RFID community. Knowledge spillovers were a prerequisite for growth in the emergence of this industry. The nature of knowledge spillovers was through marketing activity and social interaction of individuals working in firms along the value chain.

The social interaction of entrepreneurs is particularly poignant in the RFID industry, by way of example, the company Identification Devices Inc. (IDI) in Boulder, Colorado established by Vern Taylor developed in 1985 the first syringe implantable glass encapsulated transponder for animal identification, and within a very short period of time the technology was replicated by three American and three European companies.

Vern Taylor was not an engineer, but he was an astute entrepreneur who surrounded himself with people who could turn his vision into reality.

Vern looked at ways to identify horses after a family mare was stolen in 1971. His first identification company was Equine Services, Inc. of Broomfield, Colorado which developed and marketed an electronic scanning device that could positively identify any horse by its knuckles, those calluses on the inside of a horse's legs. He sold his interest in Equine Services and used the money to start "Identification Devices Inc." in 1980.

Vern was exposed to the opportunity of animal identification and certainly alert to any technical solution, but the idea of a syringe implantable transponder came from a telephone conversation he had with Michael Beigel from the company International Identification Inc. (Triple I) on the morning of August 12, 1980.

Thaine Clark, an entrepreneur and founding member of Triple I, visited Vern Taylor in Denver during the summer of 1981 in an attempt to sell the technology developed by Michael Beigel. Vern saw Beigel's tiny encapsulated transponders, an injectable device and a reader. Vern would have also been aware of the Beigel patent (U.S. 4,333,072) filed August 6, 1979 and granted June 1, 1982.

In 1980, Vern Taylor made contact with Dr. Ralph C. Knowles, the Chief Staff Veterinarian for equine diseases at the National Headquarters of the United States Department of Agriculture (USDA) in Washington DC. Vern was focused on methods of identification and in numerous telephone conversations he would pick Ralph's brain.

Ralph had 27 years service behind him with USDA, of which 18 years was in the same position. The money was good, but the job satisfaction had declined and at the latter stage of his career at USDA, he was assigned an unpalatable task.

Vern Taylor recognized Ralph's "discontentment" and used the opportunity to engage Ralph to work as a full time consultant for IDI in order to legitimize Vern's business.

In 1982, Vern engaged Thomas Milheiser, a senior electronics engineer from Martin Marietta, to develop the IDI transponder. His invention was patented in February 1984 (U.S. 5,166,676) citing Beigel's patent as prior art.

In the 1983 IDI business plan, Vern Taylor used a mocked up version of an RFID reader, transponders and a syringe injectable device based on what he had been shown to him by Thaine Clark.

Initially, the development at IDI followed the same engineering steps as those taken by Michael Beigel, encapsulating the electronics of the transponder device with resin, but unknown to the engineers at IDI the plastic encapsulation developed micro holes which left the device highly hydroscopic. Because of the dynamic movement of animals, especially rodents, moisture seeped into the holes over time resulting in corrosion and eventual transponder failure.

The breakthrough in syringe implantable transponder technology came in 1985, through engineering discussions with IDI's customer Bio Medic Data Systems (BMDS) who identified the leakage problem, and an external consultant Dr. Gerald E. Loeb who recommended packaging the electronics in miniature glass tubes. The customer BMDS later replicated the technology with the help of a former IDI employee, Donald Urbas, who established the company UMG in Evergreen Colorado in competition with IDI.

Using glass as the packaging solution for syringe implantable transponders, suppliers, distributors and customers soon became competitors as the market grew for companion and laboratory animal identification. Knowledge spillovers were not geographically bound and the pioneering company IDI, later Destron/IDI were forced to sell the access control part of their business to their silicon vendor (a division of Hughes Aircraft), in order to survive.

Under the category “knowledge Spillover”, all 21 firms either used knowledge spillovers to start their entrepreneurial venture, to redirect their engineering efforts or were the victims of knowledge spillover resulting in rival firms taking market share without having to pay for the development.

In answering the research questions based on the data collected, the dimensions “discontentment”, “human agency”, and “social interaction” have been shown to influence the outcome of events in the discovery, evaluation and exploration stage of an opportunity.

7.2 Key Findings and Emerging Propositions

At the individual Level

The dimension “Discontentment” is intended to fill a gap in the research stream that links human agency, social interaction and knowledge spillover in the discovery, evaluation and exploitation stage of an opportunity.

Discontentment is a driving force for entrepreneurial activity, triggered by cognitive stimuli and/or negative forces. Individual discontentment can arise from destructive criticism, a lack of recognition, a threat of unemployment, a change in strategic direction, disgruntle customers, conflict or just plain boredom and can also be a self serving bias inciting discontentment in other individuals.

Entrepreneurs recognize discontentment and can manipulate it, polarizing individuals to act in a negative manner to the detriment of their employer (human agency). Dissatisfaction ultimately results in these individuals leaving their former employer and joining the entrepreneur’s new venture.

The dimension “discontentment” is not a state of mind attributed to entrepreneurs in their effort to change their circumstances, but rather it applies to all individuals who are on the verge of change. Researchers, engineers, inventors and business managers in contact with the outside world of an organization are potential knowledge conduits when an opportunity arises.

To counteract the emotions or restlessness of discontentment, individuals must act or react which brings into play the dimension of human agency.

At the Firm Level

In the early emergence of RFID, research and development at Los Alamos Scientific Laboratory (LASL) in Albuquerque, New Mexico, and the entrepreneurial efforts of William Parks III (1970), Charles Walton (1972) and Michael Beigel (1979) resulted in the introduction of creative technical products for new and existing applications. However, for the most part, innovations in the RFID industry were replications or modifications of existing products and services.

The process flow in the discovery, evaluation and exploitation stage of an opportunity should differ between ground breaking and less innovative, incremental opportunities. From the evidence collected in the RFID industry, incremental innovations prevailed over ground breaking innovations. Prior to 1985, universities and government research labs were an important source of technology creation, thereafter most of the innovation came from small and medium size firms within the value chain.

The waves of innovation in the RFID industry in the period between 1985 and 2000 were incremental steps of technological integration (e.g. packing discrete components into a single chip solution, reducing the footprint of the silicon and/or adding functionality) which ultimately brought down the cost.

At the Industry Level

Before information and knowledge can transmit, there must be social interaction. The term "interaction" can be a static event or demonstration in which ideas and concepts are picked up by sheer direct observation, or alternatively can be a dynamic interpersonal process of communication between individuals or a group of individuals with interpersonal networks or interacting members of a social community.

Social interaction is the mechanism that drives the diffusion of knowledge from an entrepreneurial firm to other firms and to the wider industry community.

Entrepreneurial magnetism is a facet of social interaction in which entrepreneurs draw the attention of other entrepreneurs to a specific opportunity.

Knowledge spillovers are a central tenant of the entrepreneurial process. Entrepreneurs, collaborators, professionals and interfacing agents along the value chain (communities and networks of practice) are the creators and carriers of information and knowledge sparking off rival activity.

The mechanism for knowledge spillovers I observed from my data is as follows:

Entrepreneurs in this emerging industry needed to share knowledge as a way of building credibility and legitimacy. Transfer of new ideas and knowledge to competitors was facilitated through external relationships with customers, suppliers and alliance partners. The main source of knowledge spillovers was from innovative small and medium size enterprises to rival firms of similar size.

Patents (applying mainly to inventions embodied in a process or an apparatus) facilitate knowledge disclosure through the publication of patent applications, but they are weak mechanisms of protection for the fast moving technology in the emerging RFID industry characterized by small to medium size companies.

While patents offered some protection in developed market economies for small entrepreneurial RFID firms, defending patent rights is an expensive judicial process with an unknown outcome.

Litigation is also common place in the RFID industry, a weapon of business aggression in which rival companies or arch enemies are rendered lame in the marketplace or financially destroyed by their opponents.

Finally, geographical boundaries are not a hindrance in the knowledge-based industry of RFID and innovative companies can be easily targeted by imitative entrepreneurs by sourcing their primary intellectual capital asset, namely human capital, through shrewd tactics, interpersonal chemistry and financial incentives. For the imitative entrepreneur, it is only a question of selecting the right individual or group of individuals to mobilize the resources for replication of an existing process, product or service.

Determinants of Industry Growth

The key factors influencing economic growth during the emergence of the RFID industry include vibrant entrepreneurial activity, capital investment, technological change, the transition from ground breaking to incremental innovation, globalization, specialization, value chain fragmentation, standardization, the shift from market creation to market demand, and knowledge spillovers from innovative small and medium size enterprises to third-party firms.

Emerging Propositions

What follows is a theoretical statement presented in the form of five propositions which emerged in the course of the iterative process of data gathering and analysis.

First Proposition

Discontentment, originating from negative forces, acts as a catalyst to kick-start the process of human agency, and human agency can drive the entrepreneurial process.

Second Proposition

Human agency, the capacity to make decisions and enact them, can lead to the diffusion of information and knowledge through social interaction of individuals or groups of individuals.

Third Proposition

The underlying mechanism which connects the individual or a group of individuals to a community of practice in the discovery, evaluation and exploitation stage of an opportunity is social interaction.

Fourth Proposition

The three components of "discontentment", "human agency" and "social interaction" explain the pathway leading to knowledge spillovers in an emerging industry.

Fifth Proposition

The pace of industry growth during the emergence of a knowledge-based industry is dependent on technological progress and knowledge spillovers.

The emerging construct from the above propositions is that "knowledge spillovers" are an integral part of the evolutionary process in the growth of an industry.

7.3 Enfolding Literature and Emerging Model

An essential feature of theory building is comparison of the emergent concepts and propositions with extant literature in order to highlight divergent and congruent views.

The literature reviewed to-date focuses on: the entrepreneur in terms of behavioral, cognitive and emotional complexities influencing the entrepreneurial process at each of its stages; on the firm in terms of the innovation process of knowledge creation or replication to provide a new form of process, product or service and the individual-opportunity nexus of entrepreneurship in defining a framework for the discovery, evaluation and exploitation stage of an opportunity; and on the industry as a collective process of engaging companies along the value chain (community perspective). As a subset of the community perspective, knowledge spillovers have been investigated with the literature revealing that knowledge diffuses from innovative companies to imitators through the key mechanisms of employee mobility, information exchange through interpersonal networks and the disclosure of patents.

I will now describe the sequence in which the three dimensions "Discontentment", "Human Agency" and "Social Interaction" come together to influence the process of "knowledge Spillover" using the key findings from the RFID industry, the propositions and drawing on additional literature for direction.

I will look at two areas of literature: triggering events and knowledge spillovers.

7.3.1 Triggering Events and Shane's et al. (2003) Model of Entrepreneurial Motivation and the Entrepreneurship Process

A fundamental question on knowledge spillover that has received relatively little empirical attention in the literature concerns the triggering factor(s) which initiate(s) the process.

Morris, Zahra and Schindehutte (2000) suggest factors that trigger entrepreneurial behavior. An array of triggers is identified ranging from the quest for survival to a deliberate search for opportunities (Zahra, 1991) brought on by negative or positive factors in an individual's life. Negative forces are adverse or unfavorable conditions that compel entrepreneurs to seek opportunities to counteract a potential loss while positive forces foster proactive behavior.

There are many possibilities that trigger entrepreneurial action and even diversity among those possibilities. A number of possible triggers that pressure or encourage an entrepreneur to act include job dissatisfaction, unemployment, dramatic life changes, deliberate search, boredom, a desire for a fresh start or confrontation with a market opportunity (Morris, Zahra and Schindehutte, 2000).

Morris et al. speculate that the start-up triggers are associated almost exclusively with developments in the personal life of the entrepreneur.

To some degree the observations made by Morris et al. concerning specific triggers encouraging particular entrepreneurial initiatives in companies fill a void in the literature, but their study fails to highlight the individual triggers which ignite the spark of entrepreneurial activity in a knowledge based industry.

Evidence in the RFID industry shows that discontentment leads individuals or a group of individuals to pursue a particular entrepreneurial activity, often in competition with their former employer. Discontentment can trigger positive or negative actions. In the case of an entrepreneurial person, discontentment from job dissatisfaction, may give rise to that person pursuing a perceived market opportunity. Or a discontented individual may consciously or unconsciously divulge information and knowledge to a third party, aiding the emergence of a rival firm. Alternatively, an entrepreneurial person may incite or recognize discontentment in an individual and use it to guide the individual in a particular direction.

Entrepreneurs in the technology sector make decisions under uncertainty and therefore the acquisition of information and knowledge from other parties increases decision accuracy.

In the discovery stage of an opportunity, the entrepreneur can mine a rich seam of discontentment in potential collaborators or recognize discontentment in individuals. Discontentment is also contagious and can spread like an epidemic. Human agency takes over and knowledge flows in diverse directions.

The outcome of discontentment is to invest a moral component into an entrepreneurial process. Knowledge spillovers are the consequence of human decision making, resulting in the diffusion of information and knowledge.

This observation suggests that “discontentment” and “human agency” are both concepts that require concomitant consideration in evaluating knowledge spillovers in an emerging high-tech industry.

Therefore, mental processes - the cognitive mechanisms through which we acquire, store, transform, and use information - influence entrepreneurs and their role in the entrepreneurial process (Baron, 2004).

Baron (2008) suggests that the feelings and moods entrepreneurs experience influence several aspects of their cognition and, hence, important elements of the entrepreneurial process.

Entrepreneurial Motivation

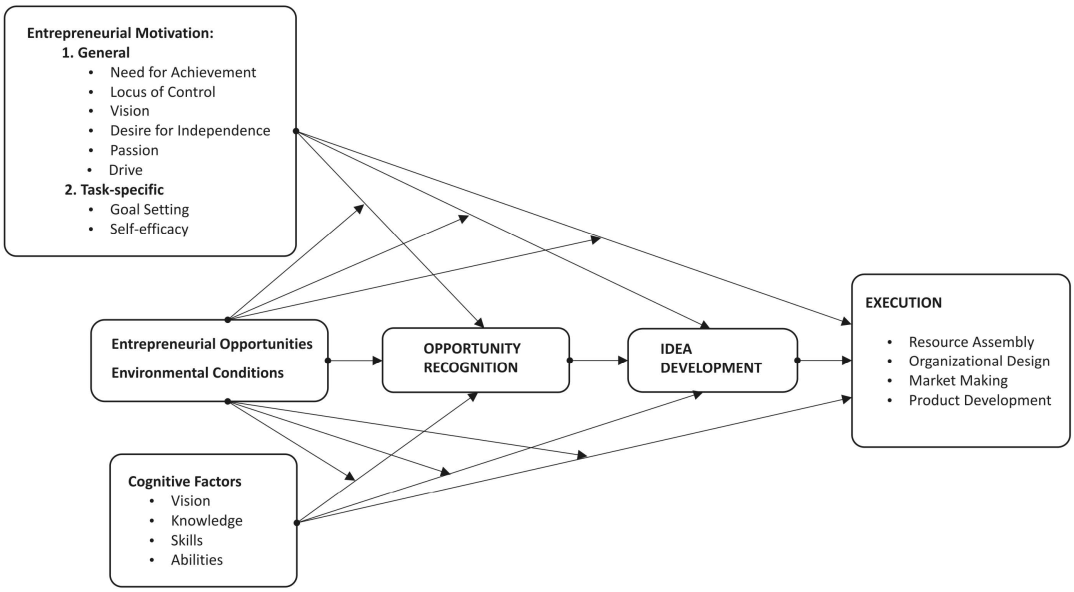
> "There can be no knowledge without emotion. We may be aware of a truth, yet until we have felt its force, it is not ours. To the cognition of the brain must be added the experience of the soul"
>
> Arnold Bennett 1954

Shane et al. (2003) suggest that recent research on entrepreneurship has ignored the role of human agency and that the attributes of the decision makers in a new venture influence the entrepreneurial process. Also the motivations of the decision makers might influence the entrepreneurial process at each of its stages, and in concert with cognitions, opportunities and environmental forces.

In the arguments of Shane et al. they explicitly assume that all human action is the result of the combination or integration of motivation and cognition, the latter including ability, intelligence, and skills (Locke, 2000), which drive the entrepreneurial process.

Shane et al. (2003: pp. 274) propose the model of entrepreneurial motivation (described below) as a stepping stone in defining entrepreneurship as a process that begins with the recognition of an entrepreneurial opportunity and is followed by the development of an idea for how to pursue that opportunity, the evaluation of the feasibility of the opportunity, the development of the product or service that will be provided to customers, assembly of human and financial resources, organizational design, and the pursuit of customers.

Figure IV Model of entrepreneurial motivation and the entrepreneurship process



Source: Shane, S., Locke, E.A. and Collins, J.C. (2003). "Entrepreneurial motivation", Human Resource Management Review, Vol. 13 (2): pp. 257-279.

The model synthesizes motivation and cognitive perspectives to highlight entrepreneurial decision making from opportunity recognition to execution. Human motivations influence not only the incremental decision making steps after the discovery of an opportunity, but how people undertake the entrepreneurial process. Therefore, the motivational attributes of people making decisions about an entrepreneurial process influence the decisions and actions that they make.

Shane et al. (2003) link motivation to human agency in the entrepreneurial process and thereby provide a road map to guide future scientific inquiry.

From the evidence collected in the RFID industry, it is possible to expand this model and develop explanations for how human motivation and action influence the entrepreneurial process.

However, there are several shortcomings in the model which need to be addressed. Firstly, Shane believes that individuals, and not groups or firms, discover entrepreneurial opportunities (Shane, 2003). Secondly, the model does not consider the acquisition and passage of information and knowledge through social interaction during the discovery, evaluation and exploitation stage of an opportunity. And thirdly, the role of discontentment as a motivation for human agency has not been considered.

These shortcomings in the model of entrepreneurial motivation proposed by Shane et al. can be further explored in terms of the five following headings:

1. The Individual and the Opportunity
2. Motivation
3. Knowledge Spillovers through Social Interaction
4. Cognitive Process
5. Human Agency

1. - The Individual and the Opportunity

It is true that an entrepreneur identifies and pursues an opportunity, but in the technology sector it requires more than one individual to recognize the complete picture. The cognitive process is a collective act in the discovery stage, exchanging information and knowledge before evaluation and exploitation.

Most conceptual accounts of the entrepreneur are usually embodied in a single person, but entrepreneurship is not the result of what single individuals do; it is the consequence of collective organizing and social interaction (Lindgren and Packendorff, 2002).

I also echo the sentiments of Mezias and Kuperman (2001) who argue that successful entrepreneurship is not the result of solitary individuals acting in isolation; entrepreneurs exist as part of larger collectives.

2. - Motivation

The motivations of people making entrepreneurial decisions in progressing from opportunity recognition to resource assembly include the need for achievement, locus of control, vision, desire for independence, passion, tenacity and drive. Not captured in the Shane et al. model are the human triggers that motivate an individual to seek change, before engaging in entrepreneurial behavior. As discussed in the previous section, negative or positive factors in an individual's life can initiate a deliberate search for opportunities. Certain human triggers, such as discontentment, conflict or strategic disagreement, predispose people to take action prior to the discovery of an opportunity. Therefore, these specific motivational triggers influence the human psychic before the discovery and evaluation stage of an opportunity. They provide the impetus and energy for certain individuals to implement change.

3. - Knowledge Spillovers through Social Interaction

In a knowledge intensive industry, spillovers take place through social exchanges during different steps of the entrepreneurial process (Ulhøi, 2005). Drakopoulou Dodd et al. (2006) argue that entrepreneurship may perhaps be best understood as a set of interrelations and interactions within the opportunity and constraint structures of specific environments. Therefore, the logical consequence of social interaction in an entrepreneurial context is the acquisition or provision of information and knowledge.

4. - Cognitive Process

The heart of the cognitive process of entrepreneurship in the knowledge based industry of RFID is discovering, deciding, forming ideas and acting on the opportunity. In my judgment, feelings and emotions are part of the cognitive process as they contain built-in action tendencies, for example, to approach objects appraised as favorable and to avoid or destroy those appraised as harmful (Arnold, 1960). In the case of the RFID industry, we have seen that the emotion or motive of discontentment can lead to a decision to take action, to positively or negatively influence a prevailing situation.

5. - Human Agency

Societies neither determine entrepreneurs, nor do entrepreneurs determine society, but they may have considerable impact on each other. Social structures are both the medium and the outcome of social interactions, both constraining and facilitating human action (Giddens, 1984). Giddens accords structure a formative position in social action, but also recognizes the agents' freedom within the social structure, a freedom to modify the structure (Drakopoulou Dodd and Anderson, 2007).

By applying this theoretical orientation to entrepreneurship, it holds that all entrepreneurial action is performed within the context of a pre-existing social structure, and the entrepreneurial agent may be shaped by it, or employs his or her agency to change the structure (Drakopoulou Dodd and Anderson, 2007). Therefore, entrepreneurial progress arises from human agency (decision, action or reaction) and social interaction of individuals.

The entrepreneurial model proposed by Shane et al. in Fig. IV graphically brings together the main ideas from such theorists as Bandura (self-efficacy), Brockhaus (risk-taking propensity), Gartner (new venture creation), Kirzner (entrepreneurial discovery), McClelland (need for achievement), Palich and Bagby (cognitive theory) and Rotter (locus of control), to name just a few. The shortcomings of this model have been discussed in depth above.

7.3.2 An Emerging Model of Entrepreneurial Emotion, Cognition, Motivation, Human Agency and Social Interaction

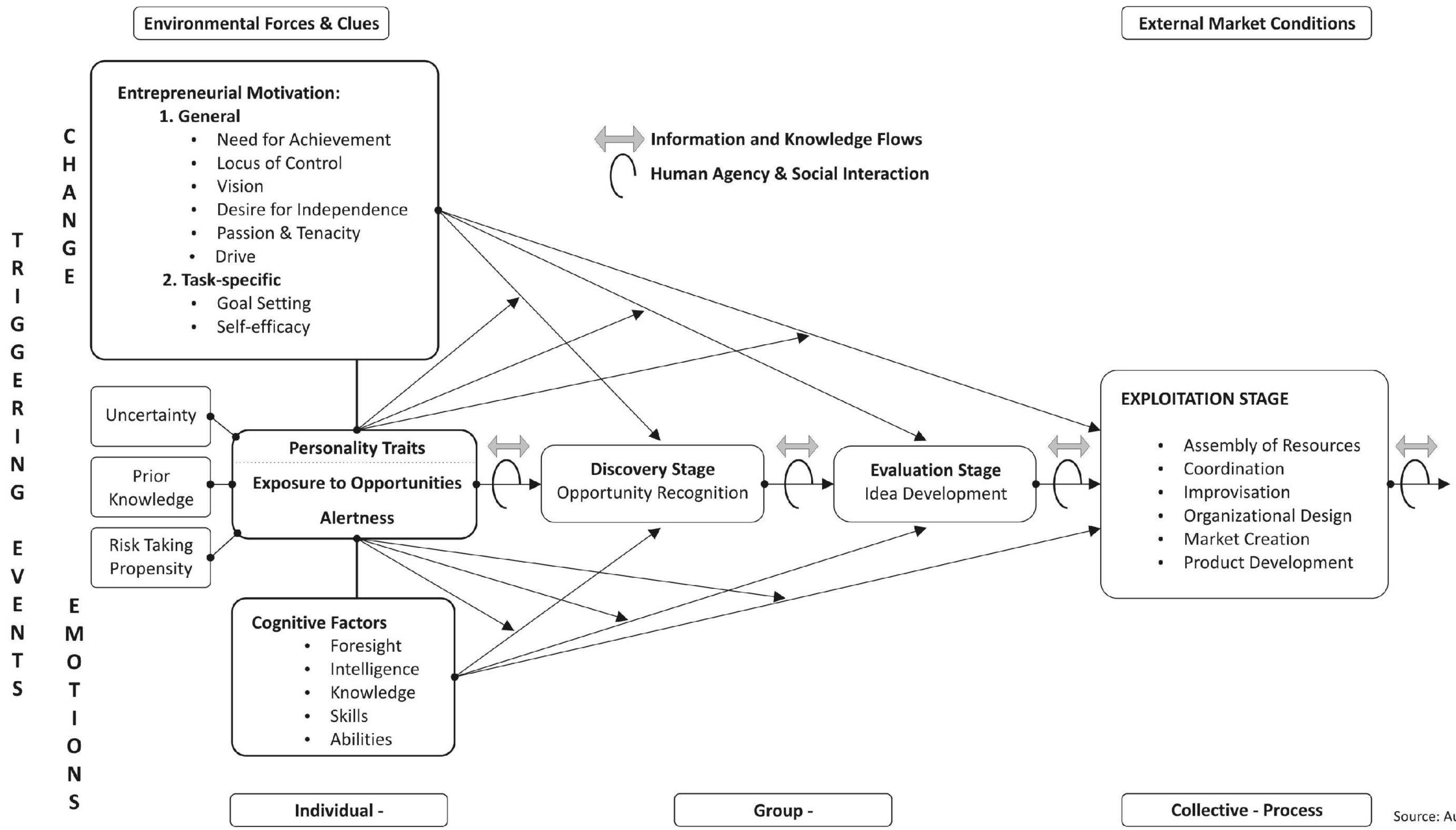
In my conceptual model Fig. V, leaning on the work of Shane at al, I also synthesize the ideas of the founding theorists, building a bridge from the triggering events that result in entrepreneurial activity, the environmental forces and individual factors which shape the discovery of an opportunity, the interaction of the entrepreneur with collaborators in the evaluation stage, the collective process of execution, to a community of practice in a knowledge based industry.

Fig. V illustrates the key stages of an entrepreneurial process and its progress is determined by human agency and social interaction.

It is my firm belief that further research on the proposed relationships between cognition, motivation, human agency and social interaction in figure V will deepen our understanding of the entrepreneurial process.

Figure V

Model of Entrepreneurial Emotion, Cognition, Motivation, Human Agency & Social Interaction



Source: Author

7.3.3 Knowledge Spillovers

As discussed, individuals and firms can acquire information and knowledge created by others through many diffusion mechanisms, and thereby facilitate the creation of even more knowledge. The mobility of highly skilled personnel between rival firms represents another vehicle for the spread of implicit and explicit knowledge.

As Arrow suggests, some information may be conveyed simply by inspection of a product that has been produced with a new technology, or by observation of the actions that the creators take to exploit their knowledge. Other information may be publicly disclosed by inventors through the publication of patents (1962).

Patent publications facilitate knowledge disclosure (Arrow, 1962), but it is evident in the RFID industry that knowledge spillovers occur before patent publication.

The mechanism by which knowledge transferred in the RFID industry contrasts with some prior research on knowledge spillovers. For example, it has been argued that knowledge spillovers originate from R&D activity in large corporations, research institutions, universities and research laboratories (Acs, Audretsch and Feldman, 1994; Acs, 2002); that knowledge is geographically bounded (Jaffe, 1989; Audretsch and Feldman, 1996; Audretsch and Stephan, 1996; Cooper and Folta, 2000); and that patents create barriers to entry for competitors (Porter, 1980) and signal a firm’s technological capabilities (Deeds et al., 1997). The mechanisms I observed are contrary to these findings.

But perhaps, the most powerful source of knowledge spillover concerning technology in the RFID industry is the constant urge of technicians, engineers, scientists and inventors in dialogue with colleagues and other members of the community to tell the world of their latest creation or innovation.

Their creation (invention) or innovation (introduction of a new product or process) over existing prior art provides direction, guidance and knowledge inputs for other members to follow and adapt in developing the next innovation step.

This search for recognition engenders motivation and satisfaction in individuals if accompanied by positive feedback, but a lack of recognition or respect can result in dissatisfaction or disgruntled behavior. Dissatisfaction in the workplace is contagious, spreading negative sentiments throughout an organization.

Many mechanisms exist for the propagation of knowledge spillover in a knowledge based industry, but individual dissatisfaction is very similar in nature to distrust.

> Because trust has a strong "upside," it is not surprising to learn that distrust has opposite effects. In fact, basic distrust between individuals or groups is a key cause of angry conflicts between them. Another and closely related cause is pre-existing grudges. (Thompson, 1998)

In the case of dissatisfaction, it may result in anger and resentment, but initially, action takes the form of knowledge spillover.

7.4 Conclusions

This thesis makes several contributions to the body of knowledge in the field of entrepreneurship.

First, the research presented here is a systematic and rigorous documentation and study of the evolution of the RFID (Radio Frequency Identification) industry, collecting data from multiple sources and at multiple levels (individuals, firms, industry).

Second, the research advances our understanding of the mechanisms which facilitate knowledge spillovers during the emergence of a knowledge based industry.

Third, it provides in particular a comprehensive description of the emergence of the RFID industry in the United States and Europe with a focus on patent activity surrounding specific innovations and the nature of information flows between firms in the value chain.

Fourth, core findings are that the discovery, evaluation and exploitation of opportunities by individuals in the RFID industry were the result of knowledge spillovers that resulted from extensive social interactions; that knowledge spillovers can be instigated by entrepreneurs or their collaborators by molding or recognizing discontentment in potential knowledge workers, a process which is described as “discontentment provocation”; and that a core generative process to the emergence of a new industry is knowledge spillover. Contrary to existing literature, patents played a relatively insignificant role in knowledge spillovers relative to social interaction in the emerging RFID industry. Furthermore, knowledge spillovers were not geographically bound and localized within spatial proximity to the knowledge source.

Fifth, the analysis of the empirical data identifies the dimensions "discontentment", "human agency" and "social interaction" as underpinning the process that fostered the generation and propagation of knowledge during the emergence of this industry. The discontentment dimension, originating from negative forces, acts as a catalyst to trigger the process of human agency, the decision to pass on information and knowledge to another party. Human agency then leads seamlessly into social interaction, resulting in the acquisition, interpretation and/or sharing of information and knowledge. Discontented individuals were the knowledge conduits who diffused information and knowledge to entrepreneurs and their collaborators through social interaction.

These are developed in a number of propositions. These five propositions emerged in the course of the iterative process of data gathering and analysis.

> *Discontentment, originating from negative forces, acts as a catalyst to kick-start the process of human agency, and human agency can drive the entrepreneurial process.*

> *Human agency, the capacity to make decisions and enact them, can lead to the diffusion of information and knowledge through social interaction of individuals or groups of individuals.*

> *The underlying mechanism which connects the individual or a group of individuals to a community of practice in the discovery, evaluation and exploitation stage of an opportunity is social interaction.*

> *The three components of "discontentment", "human agency" and "social interaction" explain the pathway leading to knowledge spillovers in an emerging industry.*

The pace of industry growth during the emergence of a knowledge-based industry is dependent on technological progress and knowledge spillovers.

Sixth, this thesis also advances the theory of knowledge spillovers in an emerging knowledge intensive industry by expanding upon the "Entrepreneurial Motivational Model" proposed by Shane et al. (2003). It introduces the triggering events that motivate an individual to seek change prior to the discovery of an opportunity and the social exchanges which take place during different steps of the entrepreneurial process. Based on this a model of entrepreneurial process is presented. This model integrates entrepreneurial emotion, cognition, motivation, human agency and social interactions, to explain the key stages of the entrepreneurial process.

To summarize, this thesis sought to answer the overarching question of "Why, when and how do knowledge spillovers occur in an emerging industry?" In this process, this thesis has demonstrated that the emotion of discontentment triggered by negative forces acts as a catalyst in kick-starting the process of human agency, the capacity to make decisions and enact them, in particular, the decision to pass on information and knowledge to another party. The entrepreneurs in this industry made decisions under uncertainty, thus the acquisition of information and knowledge to increase decision accuracy was paramount. Discontented individuals were the knowledge conduits who diffused information and knowledge to entrepreneurs and their collaborators through social interaction. Entrepreneurial magnetism is also a facet of social interaction in which entrepreneurs attracted other entrepreneurs to the same or similar opportunity. Therefore the three dimensions "discontentment", "human agency" and "social interaction" are the diffusion vectors by which information and knowledge are transmitted and received.

As with all research, this thesis is subject to certain limitations. First, it collected qualitative data from 57 interviews representing 21 firms in the RFID industry to study knowledge spillovers, which from a statistical standpoint is insufficient to employ a mathematical model to measure variables in the theory of knowledge spillover.

Second, I acknowledge that my focus on the RFID industry raises questions about the generalizability of my study beyond this industry.

The managerial implications of this research are that entrepreneurs in knowledge driven industries need to think differently about the mechanisms which lead to knowledge spillovers and the challenges of managing people and business relationships in an emerging industry. In contexts characterized by high levels of technological, market and organizational uncertainty, a strategic and tactical imperative facing entrepreneurs is to build credibility and legitimacy with various internal and external stakeholders. This activity, by its very nature, leads to knowledge spillovers. Such spillovers can be positive for the new firm by, for example, attracting resources, including customers, to the industry, or it may lead to convergence of the technology around a dominant design. Yet, the dilemma facing entrepreneurs is that the very same processes can alert others to the same opportunities, thus increasing competition for the emerging, and often struggling, organization.

This research has also important implications for public policy in leveraging research and development efforts in universities and national laboratories into commercial activities. Governments must devise programs that address the spillover of knowledge created and accumulated by these institutes to effectively bolster the performance and competitive position of indigenous industry.

GLOSSARY OF TERMS

RFID (Radio Frequency Identification) is a term that describes any identification system wherein an electronic device (tag) uses radio frequency, capacitive or magnetic field variations to communicate with an interrogator (reader).

Knowledge in the context of the RFID industry is scientific and technical expertise and skills acquired through work experience and/or education; the accumulation of process and product innovation and the assimilation of information to create new innovation; the theoretical and practical understanding of the market and how it operates; a human understanding of collaborators with the ability to motivate or manipulate them to perform a particular task and knowing where to find information, ideas and concepts on a subject matter.

Knowledge spillover is the unidirectional or bidirectional spread of information and knowledge to members or potential members of a community. Entrepreneurs, collaborators, professionals and interfacing members along the value chain (communities and networks of practice) are the creators and carriers of information and knowledge who through social interaction spark off rival activity.

Discontentment, triggered by cognitive stimuli or external forces, is a state of dissatisfaction with one’s circumstances. In an entrepreneurial setting, discontentment can lead to a decision to take action, to positively or negatively influence a prevailing situation. This action may shape the entrepreneurial process.

Human agency (individual or collective) in the entrepreneurial process is the capacity to make a conscious or unconscious decision and to enact it, in particular, the decision to pass on information and knowledge (explicit or tacit) to another party, bringing into play a moral component (ethical or unethical) to influence subsequent events.

Social interaction at the firm level is a dynamic interactive process of social actions between individuals or a group of individuals who modify their actions and reactions according to those of their occupational colleagues. At the industry level, social interaction is an event or a sequence of social actions between individuals or a group of individuals in a firm with other members of the community such as customers, material and equipment suppliers, consultants, research laboratories, test houses, universities, professional organizations and competitors which leads to the interpretation and sharing of information and knowledge.

Entrepreneurial Magnetism conveys the notion that entrepreneurs and their collaborators alert other entrepreneurs in the value chain to the same or similar opportunity in an emerging industry.

Entrepreneurial flux describes the induction process of information and knowledge flow from entrepreneurs to other individuals during the discovery, evaluation and exploitation stage of an opportunity.

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APPENDIX A

A detailed description of the various RFID technologies is presented.

RFID Technologies

From the history of RFID presented in Chapter 3, there are a variety of technologies which can be used for identification. Basic approaches can be described by two classes: CMOS and non-CMOS.

Non-CMOS based RFID:

Non-CMOS-based RFID refers to those RFID systems using physical phenomenon that can be detected remotely using radio waves without the use of CMOS circuitry in the tag.

Non-CMOS tags can be constructed using elements that have a unique response at a particular frequency (or frequencies):

- Tuned circuits
- Surface Acoustic Wave (SAW) resonators
- Magnetic materials
- Harmonic generation

Tuned Circuits

The tag containing inductors and capacitors connected to an antenna, causes a perturbation of the field generated by a reader transmitting a signal that is sweeping past the frequency (or frequencies) of resonance of the tuned circuit of the tag. The reader detects the presence or absence of the tag by detecting the presence or absence of the field perturbation. Electronic article surveillance systems (EAS) can use this technique. The resonators can also be tuned cavities or resonant wire filaments tuned to resonate at specific frequencies. If a tag contains several circuits or filaments tuned to different frequencies, the tag can be used to convey a small amount of data.

SAW Resonators

RFID tags have also been constructed using surface acoustic wave (SAW) materials. SAW materials are piezoelectric. An antenna connected to a SAW crystal excites the crystal at the frequency of the radio wave. An acoustic wave at the same frequency as the radio wave is launched in the SAW crystal. Lithographic techniques are used to construct resonators or delay lines on the crystal. The presence or absence of a resonator tuned to a particular RF frequency (or at a particular delay) is used to code a binary '1' or '0'.

The reader transmits a pulsed radio wave that is received by the tag and converted into a pulsed acoustic wave. The presence or absence of delayed pulses at particular delay times is used to code zeros and ones. The delayed pulses are reradiated by the tag antenna and detected by the reader. Alternately, a swept radio signal can be used to excite resonators on the SAW crystal, and the presence or absence of a response at a given frequency is used to denote binary information.

Magnetic Materials

Another class of devices exploits properties of magnetic material. Some magnetic material, when properly biased with a static magnetic field, produces a response to a pulsed magnetic field which can be detected and used for EAS applications. Some of these types of systems operate in the 100 kHz region of the radio spectrum and the waves can penetrate the body and other conductive material. This property of low frequency radio waves is used to make robust EAS systems that are difficult to defeat. A variety of other magnetic properties of materials can be used for EAS and RFID systems.

Harmonic Generation

Diodes attached to antennas can be used to produce harmonics of an impinging radio wave. EAS systems can use this phenomenon to build simple tags whose presence is detected by detecting harmonics of the transmitted radio signal. (Of note is that this phenomenon can also be used with a CMOS RFID tag to transmit data at the harmonic of the signal sent by the reader).

Other physical properties can also be used to construct a device (tag) that can be detected remotely. In general, tags using these techniques have limited anti-collision capability, limited data capacity, are read only and programmed at manufacture if they contain more than a single bit.

CMOS-based RFID

CMOS-based RFID refers to those RFID systems using tags built with CMOS circuitry to store information, provide coding and modulation, and control tag function. CMOS is the semiconductor technology of choice because of its high impedance, low power demands, low voltage operation and ease of economical fabrication. Occasionally, other semiconductor technologies are used to supplement the capabilities of CMOS with the attendant increase in tag complexity and cost. Gallium arsenide (GaAs) can be used in high-performance tags in the microwave spectrum as the technology for the RF front end of tags. Bi-polar circuitry can also be used, usually for high-speed analog functions. Other microwave devices can also be used such as microwave diodes, field effect transistors, PIN diodes, and similar devices. These are used in conjunction with CMOS circuitry for digital logic and data storage.

CMOS RFID Techniques

CMOS-based tags need several elements for operation: power, memory, a data clock, control of operation, coding (ones and zeros are always coded), modulation, and optionally a receiver, transmitter (for RF-active tags), external connections at the tag (for other functions such as sensing or transfer of data) and similar items.

In addition to differences in implementation of these elements, systems can operate at various radio frequencies and use a variety of parameters for the physical layer, data layer and application layer.

Source of Information

Landt, Jeremy (1999) “RFID Tutorial AutoID ’99”, IEEE Workshop on Automatic Identification Advanced Technologies, Summit, New Jersey, pp. 1 – 14.

Types of CMOS RFID Systems

There are basically four types of CMOS transponder systems:

1. A system operating on the same principle as the Identification Friend or Foe (IFF), which uses a receiver to sense the interrogating signal and a separate transmitter to send back the responding signal. A version of this system developed by William Parks III, used energy from the interrogating beam to power the transponder and featured a rewritable memory for the ID number. It is the basis of the 1970 Cardullo/Parks patent, 3,713,148. Bill Parks can be credited with the technical aspects of this invention, and he was also ahead of his time with a "writable memory" in the transponder. This technique is used today in the "Easy Pass" toll road system deployed in the Northwest of the United States.

2. Radiative (UHF) or electromagnetic coupling, an example of which was developed in 1973 at the Los Alamos Scientific Laboratory, Albuquerque, New Mexico. Steven W. Depp was the initial leader of the Los Alamos team that at the request of the U.S. Department of Agriculture developed a radiative backscatter UHF system running at 915 MHz to track cattle. The backscattered signal is modulated by the transponder to produce a sub carrier, and the coding is provided by modulating the sub carrier with a serial code. The development is the basis of the 1978 patent, 4,075,632. Today, the technique is used for inventory control by Wal-Mart and the US Department of Defense, for railroad car identification, and for toll road systems like Florida's E-Pass.

3. Inductive coupling where the interrogator and transponder are coupled by a magnetic field and which finds its origins in the grid dip meter. Using this principle, Harm J. Kip and Tallienco Wieand Harm Fockens of Nedap developed an electronic collar to identify cattle before feeding and patented the idea in 1976 (U.S. 4,196,418). The first concept of an injectable transponder the size of a grain of rice can be attributed to Michael Beigel who developed a miniaturized read/write transponder in 1979 (U.S. 4,333,072). A variation of inductive coupling involves sweeping the frequency. Charles Walton is the key inventor behind this technique and it is used for short range applications like non-contact credit card and key systems. Today, animal tags, proximity cards, contactless smart cards for payment & ticketing, and electronic passports operate on the principle of induction.

4. Capacitive coupling where the interrogator and transponder are coupled by an electric field. This system was invented by Theodore Geiszler et al., and developed by Motorola as the BiStatix tag. The technique was aimed at very low cost applications but it had a short range and performance issues; Motorola abandoned it in 2001.

APPENDIX B

Index of subjects interviewed

1. Mario William Cardullo (Year 1970 - Communications Services & Telserv, Rockville, USA) at his home in Alexandria on 23 October 2007
2. William L. Parks, III (Year 1970 - Communications Services & Telserv, Rockville, USA) at the Olive Garden Restaurant in White Marsh, Baltimore on 3 February 2008
3. Charles A. Walton (Year 1972 - Proximity Devices, Sunnyvale, California, USA) at his home in Los Gatos, California on 21 September 2007 and 26 October 2007
4. Steven W. Depp (Year 1973 - Los Alamos Scientific Laboratory in Albuquerque, New Mexico, USA) at his home in Katonah, New York on 6 February 2008
5. Harm J. Kip and Tallienco Wieand Harm (T.W.H.) Fockens (Year 1976 - Nederlandsche Apparatenfabriek in Groenlo, Netherlands) at the offices of NEDAP, Netherlands on 17 April 2008
6. Dr. Edward E. Tindall (Year 1979 - International Identification Inc. (Triple I) in Rosemont, New Jersey, USA) at his home in Stockton, New Jersey on 17 September 2007 and 2 February 2008
7. Michael L. Beigel (Year 1979 - International Identification Inc. (Triple I) in Rosemont, New Jersey, USA) at his home in Encinitas, California on 20 April, 25 September and 27 October 2007
8. Jennifer P. Ellsworth (Year 1979 - International Identification Inc. (Triple I) in Rosemont, New Jersey, USA) at her home at Point Pleasant on 2 February 2008
9. Dr. France Rode (Year 1980 - Sielox Systems, Cupertino, California, USA) at a restaurant in Cupertino, California on 25 October 2007
10. Gary Carroll (Year 1981 - BI & GnuCo Technology, Boulder, Colorado, USA) in Boulder Colorado at the offices of GnuCo in Boulder on 20 October 2006 and 20 September 2007
11. Dominick Alston (Year 1980 - Identification Devices, Inc. (IDI) Westminster, Colorado, USA) at the St Julien Hotel in Boulder, Colorado on 19 April 2007
12. B. W. (Ben) Polzkill (Year 1980 - Identification Devices, Inc. (IDI) Westminster, Colorado, USA) at Adam's Mark Hotel in Denver Colorado on 7 February 2007
13. Thomas Milheiser (Year 1980 - Identification Devices, Inc. (IDI) Westminster, Colorado, USA) at Starbucks cafe in Denver, Colorado on 20 October 2006

14. Donald J. Urbas (Year 1983 - Identification Devices, Inc. (IDI) Westminster, Colorado, USA) at the offices of UMG in Evergreen, Colorado on 19 September 2007
15. Whitney Patten (Year 1983 - Identification Devices, Inc. (IDI) Westminster, Colorado, USA) at the St Julien Hotel in Boulder, Colorado on 19 April 2007
16. John Bradin (Year 1983 - Identification Devices, Inc. (IDI) Westminster, Colorado, USA) at the offices of HID in Denver, Colorado on 20 October 2006
17. Dr. Ralph C. Knowles D.V.M (Year 1984 - Veterinary Consultant to Identification Devices Inc.) at the Holiday Inn Hotel and at the Northern Trust Bank of Florida, Vero Beach, Florida on 1 February 2008
18. Dr. Jeremy A. Landt (Year 1984 - Amtech, Albuquerque, USA) at the offices of Transcore in Albuquerque, New Mexico on 7 February 2008
19. Thomas W. Payne (Year 1984 - Identification Devices, Inc. (IDI) Westminster, Colorado, USA) at his home in Scaly Mountain, North Carolina on 4 February 2008
20. Dieter Heidrich (Year 1985 - Identification Devices, Inc. (IDI) Westminster, Colorado, USA) at the St Julien Hotel in Boulder, Colorado on 17 April 2007
21. Charles Cushing (Year 1985 - Identification Devices, Inc. (IDI) Westminster, Colorado, USA) in Bangkok, Thailand on 27 April 2007
22. Michael M. Malmer (Year 1985 - Identification Devices, Inc. (IDI) Westminster, Colorado, USA) at the St Julien Hotel in Boulder, Colorado on 17 April 2007
23. Dr. Flavio Audemars (Year 1986 - Audemars, Lugano, Switzerland) at the offices of Audemars Holding in Lugano, Switzerland on 26 November 2007
24. Theodore D. Geiszler (Year 1986 - Indala Corporation, San Jose, California, USA) at his home in Monte Sereno, California on 25 & 26 October 2007, and at his holiday home in Indian Wells on 8 February 2008
25. Daryl F. Yurek (Year 1987 - Destron/IDI, Boulder, Colorado, USA) in downtown Denver on 18 April 2007 and 20 September 2007
26. Neil E. Campbell (Year 1987 - Bio Medic Data Systems) at the offices of Bio Medic Data Systems, Seaford, Delaware on 17 September 2007
27. Douglas Hull (Year 1987 - AVID Identification Systems, Norco, California, USA) at the Century Park Hotel in Bangkok, Thailand on 26 April 2007
28. Josef Schuermann (Year 1987 - Texas Instruments (TIRIS), Freising, Germany) at his home in Oberhummel in Germany on 15 August 2007
29. Parvis Hassan-Zade (Year 1988 – Datamars, Lugano, Switzerland) at Hotel Lugano Dante in Lugano, Switzerland on 3 April 2007 and 26 November 2007

30. Åke Gustafson (Year 1988 – Sokymat, Granges, Switzerland) at his summer house in Torp Senoren, Ramdala, near Karlskrona in Sweden on 15 May 2007
31. Josef Mašín (Year 1989 - Trovan, Isle of Man, Great Britain & EID, Santa Barbara, USA) at the Hilton Hotel in Los Angeles on 21 October 2006 & 4 February 2007 and in Santa Barbara on 26 October 2007
32. Ulrich M. Usling (Year 1989 - Euro ID Usling, Euskirchen, Germany) at the Parkhotel in Euskirchen Germany on 25 and 26 January 2007
33. Glen Zirbes (Year 1989 - Cross Technology, Minneapolis, Minnesota, USA) at the offices of HEI in Chanhasson, Minneapolis, Minnesota on 16 April 2007
34. Duncan McCannel (Year 1989 – Travel Tag, Minneapolis, Minnesota, USA) at the Holiday Inn in Bloomington, Minneapolis, Minnesota on 18 September 2007
35. Dieter Deml (Year 1989 - AEG, Ulm, Germany) at his home in Babenhausen, Germany on 13 February 2007
36. Günther Meusburger (Year 1990 - EM Microelectronics Marin, Marin, Switzerland) at his home in Vinelz, Switzerland on 25 November 2007
37. Roland Koo (Year 1990 - Mikron, Graz, Austria) at his home in Eggersdorf – Graz, Austria on 23 August 2007
38. Wim O. de Jong (Year 1991 - NEDAP in Groenlo, Netherlands) at his home in Winterswyk, Netherlands on 28 April 2007
39. Peter R. Lowe (Year 1991 - Hughes Identification, Boulder, Colorado, USA) at a restaurant in Bloomington, Minneapolis, Minnesota on 19 October 2006
40. Don Small (Year 1992 - Hughes Identification, Boulder, Colorado, USA) at the Ontario Hilton Hotel in Ontario California on 19 April 2007
41. Randolph Geissler (Year 1993 - Destron Fearing, St Paul, Minnesota, USA) at a restaurant in St. Paul, Minnesota on 18 & 19 October 2006
42. Mikael Blomqvist (Year 1993 – Metget, Ronneby, Sweden) in Karlskrona in Sweden on 16 May 2007
43. Noel Eberhardt (Year 1993 - Motorola Indala, San Jose, California, USA) at his home in Cupertino on 25 October 2007
44. Victor Vega (Year 2001 - Alien Technology Corporation, Morgan Hill, California, USA) at the offices of Alien Technology Corporation on 8 May 2008
45. Vik Pavate (Year 2001 - Kovio, Inc., Milpitas, California, USA) at the offices of Kovio on 8 May 2008