DISCOVERY PROCESSES & THE ORGANIZATION OF INNOVATION

Gajendran Kandasamy

Submitted in total fulfilment of the requirements of
the degree of Doctor of Philosophy.

January, 2011

Innovation & Entrepreneurship Group,
Imperial College London Business School
South Kensington, London SW7 2AZ, United Kingdom.

Produced in LaTeX 2$_\varepsilon$

Abstract

The thesis comprises four key papers, which provide fresh perspectives pertaining to the key factors in the management of innovation: new ideas, people, transactions and institutions.

First, a model of discovery is proposed, highlighting the importance of problem reshaping and shifting in addition to usual problem solving approach. To illustrate how they can be incorporated within existing models, the conventional NK model is adapted in a novel way that not necessarily constrains agents to local optima nearby. The extended model is then used to study effects of curiosity and conditions under which analogy, recombination or local search would be effective. Building on this model, we show how satisficing behaviour of agents can be described by using cognitive constructs such as attention and stimulus, which moderate the gap between local (agent) and non-local (real-world) information.

Second, Innovation entails the interfacing of communities with different traditions and aspirations, in particular, the science and business domains. Through a quasi-experimental design, we explore the micro-foundations of the contact and conflict which define the science-business divide, strategies for mitigating discordance and exploit synergies are discussed.

Third, the attempt to understand innovation as intra-firm or inter-firm process from a consistent perspective within the existing theories of the firm has provoked a reconceptualization of the 'firm'. A reductionist approach at the level of actions and assets of the firm is found to achieve this reconciliation and also helps introduce the concepts of quasi-boundary to appreciate interaction of firms with the market and the institutions.

Third, the innovation process occasionally faces institutional impediments. One of the preeminent changes has been the involvement of the universities in innovation system, where its full commercial potential was realized over a century.

The historical observation of how multiple institutions were reformed provides new insights into the mechanism of institutional entrepreneurship.

Finally, consolidation of each of the factors requires acknowledgment that the innovation process exists in the context of each other, and are subject to evolution and extraneous influences. The conclusion is an attempt at synthesizing the four factors towards understanding the overarching dynamics in the innovation ecosystem. To leverage on the independent developments at each level, a proposal to build a consistent multi-level coherent framework for innovation is suggested.

Declaration

This is to certify that:

(i) the thesis comprises only my original work towards the PhD except where indicated,

(ii) due acknowledgement has been made in the text to all other material used,

(iii) the thesis is less than 100,000 words in length, inclusive of table, maps, bibliographies, appendices and footnotes.

I authorize the Dean of the Business School to make or have made a copy of this thesis to any person judged to have an acceptable reason for access to the information, i.e., for research, study or instruction.

Gajendran Kandasamy

Date, Place

Acknowledgements

Firstly I would like to express my appreciation to Gerry George, whose support has been essential in developing my ideas and finding my feet in the field. He has been an excellent host to new ideas, and there has been more opportunities than I could exploit. I was fortunate to work in an atmosphere of both accomplishment and humility.

Secondly I would like to thank Phanish Puranam of London Business School, whose regular meetings at LBS in 2008 was key in developing the model of discovery and ongoing collaboration on the science-business divide project. Out of the three reasons for my research (thesis, publication and learning), he considers third to be ideal. I hope I have gone in that direction.

I thank Magda Osman of University College London for supporting the science-business divide from an early stage and advise from the psychology perspective. Erkko Autio encouraged me to look into multi-level perspectives, which I have begun to explore in the synthesis chapter, and is bound to influence my future research orientation.

I wish to note many fruitful and some divergent conversations with fellow doctoral students. Gratitude is of course due, to my family for their patience and support throughout this period.

Contents

I INNOVATION - *THE FOUNDATIONS* **1**

1 Challenges Along the Innovation Spectrum:
A Foundational Focus **3**

1.1 Defining innovation 4
1.2 Central Factors in the Organization of Innovation 6
1.2.1 New Ideas 6
1.2.2 People 8
1.2.3 Transactions 10
1.2.4 Institutions 11
1.3 Methods, Data and Structure 12

II IDEATION - *THE MICRO* **17**

2 The Problem-Solution Nexus:
Towards a Model of Discovery **18**

2.1 Introduction 19
2.2 Discovering Opportunities 20
2.3 Approaches To Modeling Discovery 21
2.4 A Discovery Case in Point 25
2.5 Modeling the Characteristics of Discovery 35
2.5.1 Alleviating Limitations of the NK Approach 35
2.5.2 Designing the Universal Landscape 41
2.5.3 Analogy and Recombination 46
2.5.4 Bridging Local and Non-local Information 51
2.6 Concluding Remarks 57

III PEOPLE - *THE MESO* **61**

3 Domain Specificity of Opportunity Coherence:
Exploring the Science-Business Divide **62**

3.1 Introduction . . . 63
3.2 Domain differences . . . 65
3.3 Quasi-experimental design and analysis . . . 72
3.3.1 Discuss aloud verbal protocols . . . 72
3.3.2 Repeated measures experiment . . . 75
3.3.3 Evidence based update experiment . . . 77
3.4 Discussion . . . 92
3.5 Appendices . . . 96
3.5.1 Administering the verbal protocols . . . 96
3.5.2 List of pitches (video clips) shown for experiment 1 . . . 97
3.5.3 Scenario related Questions . . . 99
3.5.4 Background Questions . . . 100

IV TRANSACTIONS - *THE MACRO* **102**

4 Reconceptualizing the (Innovative) Firm:
Actions, Assets & Quasi-boundaries **103**

4.1 Introduction . . . 104
4.2 Real Integration: Beyond TC And Capabilities . . . 106
4.3 Towards an Integrated Theory . . . 110
4.3.1 Existence of the firm . . . 113
4.3.2 Boundary decisions . . . 115
4.3.3 Internal organization . . . 119
4.4 Quasi-Boundaries . . . 121
4.5 Shaping The Ecosystem . . . 124
4.5.1 Shaping the Institutions: WARF 1924-2000 . . . 124
4.5.2 Shaped by the Market to Shape The Market: Symbian 1998-2009 . . . 130
4.6 Conclusion . . . 133

V INSTITUTIONS - *THE META* **135**

5 Realizing the Commercial Potential of University Research:
Multi-institutional Entrepreneurship & Partial Isomorphism **136**

5.1 Introduction 137
5.2 A Brief History of University Commercialization 138
5.2.1 Connecting the Milestones of University Commercialisation 142
5.3 Multi-institutional Change 145
5.4 Foundations of Isomorphism 149
5.5 Partial Isomorphism 151
5.6 Discussion 153
5.7 Appendix 156

VI SYNTHESIS - *THE INTERACTIONS* **158**

6 The Innovation Ecosystem:
Towards Multi-level Coherence **159**

6.1 Summary 160
6.2 Multi-level consolidation 162
6.3 Coherence in the Innovation Ecosystem 164

References **167**

List of Tables

1.1 A random sample run of the Kaufman model for N=3 and K=2 . 14

2.1 Review of approaches to study creativity and discovery 24

2.2 Coding of discovery interviews with scientists and entrepreneurs . 33

2.3 Comparative study of recombination, analogy and local search. ○: Inclusive search; ⋆: Exclusive search; ♢: Best { [analogy + local-search] , [local-search]} 48

3.1 Independent variables (responses to the pitch) and their description 71

3.2 Coding of discussions of four teams (two from each domain), each team comprising 3 each of science and business domain individuals. Other dimensions have not been presented due to lack of systematic variance. Values above 20% (equal weighting) are highlighted in blue and above 40% (double weighting) in red. 73

3.3 Variables in used in statistical model and their description 76

3.4 Fixed effects panel estimation for dependent variable - investment decision. Individuals (20) are the panel variable with variance is 0.2060842; when scenarios(15) is used as panel variable variance is .07620888. ⋆ - significant at the p=0.1 level; ⋆⋆ - significant at the p = .05 level; ⋆⋆⋆ - significant at the p = .01 level 78

3.5 Correlation between variables that scenario responses used in the fixed effects model in Table 3.4. 79

3.6 Description of the sequential stimuli presented for updating the beliefs of the respondent. 81

3.7 Autoregressive and latent trajectory estimation for the restricted models. Note that the columns referring to Science and Business do not denote sub-samples, rather they refer to dummies D^S and D^B respectively. Only intercepts (amplitudes of updates) and lagged variables (for persistence) are presented in this table (note that independent variables were included in the model according to Equations 3.2, 3.4, 3.6, 3.7). $\star$ - significant at the p=0.1 level; $\star\star$ - significant at the p = .05 level; $\star\star\star$ - significant at the p = .01 level. 84

3.8 Autoregressive and latent trajectory estimation for the fully specified model. $\star$ - significant at the p=0.1 level; $\star\star$ - significant at the p = .05 level; $\star\star\star$ - significant at the p = .01 level. 85

3.9 Unnormalized averages of the responses by the science and business sub samples for variables in Table 3.4, shown for both the repeated measures and evidence based update experiments. 91

3.10 Summary of the results for each of the hypothesis. 94

3.11 List of pitches (video clips) shown for Experiment 1 98

4.1 Stylised comparison between the three approaches 112

4.2 A reductionist perspective - actions and assets related to the firm, tabled to address the questions of the theory of the firm 120

4.3 Milestones in the evolution of WARF: comparative logic from transaction cost, capabilities and integrated approaches to the theory of the firm. 126

4.4 After inception, a firm's priority activities may relate to its size, nature and type. 129

5.1 Foundations of isomorphism, with university as an institutional example. 150

5.2 Contextualizing the concepts of institutional theory 155

List of Figures

1.1 An example of N=3, K=2 setting for the Kaufman model. 13

1.2 Ruggedness increased with complexity 15

1.3 Reproduction of plot in (Levinthal 1997). 15

2.1 Schematic flow chart of the main processes that led to the discovery of the catalytic properties of RNA. 27

2.2 A layered framework to contextualize problem solving, reshaping and shifting in relation to other cognitive-psychological constructs 34

2.3 (Left) Illustrative landscape for intuition and (Right) Payoffs accessible to 1dimensional agent: treading x while y=5 and y=1 . . 37

2.4 Performance of agents with access to different dimensions of the landscape 39

2.5 Effect of prior knowledge and curiosity (A2 is curious, K=2) . . . 44

2.6 Recombining domain commonality and performance (plotted at k=2) 50

2.7 Perceived gap as a function of actual gap, stimulus α and attention deficit β 55

3.1 Plotting the latent trajectories of the intercepts (λ) for different segments (model not specifying scenarios). 86

3.2 Plotting the trajectories of the unconditional intercepts (γ) and coefficient (ρ) of the lagged dependent variable for different segments for the all scenarios considered together. 87

3.3 Plotting the latent trajectories of the intercepts (λ) for different segments of scenario 1. 88

3.4 Plotting the trajectories of the unconditional intercepts (γ) and coefficient (ρ) of the lagged dependent variable for different segments of scenario 1. 88

3.5 Plotting the latent trajectories of the intercepts (λ) for different segments of scenario 2. 89

3.6 Plotting the trajectories of the unconditional intercepts (γ) and coefficient (ρ) of the lagged dependent variable for different segments of scenario 2. 90

3.7 Plotting the latent trajectories of the intercepts (λ) for different segments of scenario 3. 90

3.8 Plotting the trajectories of the unconditional intercepts (γ) and coefficient (ρ) of the lagged dependent variable for different segments of scenario 3. 92

3.9 Sample implementation of the slider scale. 100

4.1 The emphasized level of analysis in the three approaches, and the correspondence between the levels and integrated framework . . . 109

4.2 Illustrative schema of boundary decision and internal organization in the integrated perspective. 117

4.3 Schematic plot to illustrate the relationship between externalisation, priority given to the asset i and the effectiveness of getting it in the market. 118

4.4 Organizations pursuing complementary mode of capabilities: Technology Transfer Offices (eg. WARF, 1924) were formed with an external quasi-boundary, and Industrial Research Labs (eg. Philips Natuurkundig Laboratorium, 1914) via an internal quasi-boundary. 122

4.5 Comparison of the persistence of organizational boundaries: snapshots from 1925 and 2000 of Wiscoson Alumni Research Foundation (WARF) - University of Wisconsin (UW); and Research Corporation (RC) - partners. 127

4.6 Boundary evolution of Symbian Ltd. in a hyper competitive mobile devices market during the last decade. 132

5.1 Revenue, expenditure and investment of WARF (data courtesy WARF) 141

5.2 Seeking institutional change might entail interacting with multiple institutions 146

5.3 Multi-institutional entrepreneurship in action. Objective: Commercialization of university research 148

5.4 Partial isomorphism in action 154

5.5 Visualization of sphere, which is defined by a generator, dimensions, and a group 156

6.1 A multiple levels in the innovation ecosystem. Creativity decreases at higher levels, and impact decreases at lower levels. 165

Part I

INNOVATION - *THE FOUNDATIONS*

Chapter 1

Challenges Along the Innovation Spectrum:

A Foundational Focus

Contents

1.1 Defining innovation 4

1.2 Central Factors in the Organization of Innovation . . 6

1.2.1 New Ideas 6

1.2.2 People 8

1.2.3 Transactions 10

1.2.4 Institutions 11

1.3 Methods, Data and Structure 12

Innovation has been increasingly a priority of organizations and businesses. A recent global survey (McKinsey 2010) shows 84 percent of executives say innovation is extremely or very important to their companies growth strategy. However the same survey also indicates that the core challenges facing the organization of innovation have not changed over the years. Innovation is the cornerstone of development or progress, and its prospects and challenges have motivated numerous institutions across the world to study its processes and underlying patterns and dynamics. This thesis is a contribution to this effort. In order to explicate the foundations that underpin innovation, I will pursue the following strategy:

- Define innovation in a way that allows focus on its general foundations.
- Identify the central factors involved in innovation.
- Address the foundational issues pertaining to the central factors.
- Synthesize the interactions among the central factors with the help of the insights on their foundations.

1.1 Defining innovation

They exists several definitions of innovation, of which a small selection is provided below to capture its essence: *"Change that creates a new dimension of performance"* (Hesselbein 1999). *"The introduction of new goods ..., new methods of production ..., the opening of new markets ..., the conquest of new sources of supply ... and the carrying out of a new organization of any industry..."* (Schumpeter 2000). *"Innovation is a new element introduced in the network which changes, even if momentarily, the costs of transactions between at least two actors, elements or nodes, in the network"* (Cabral 1998). *"Innovation is the sequence of activities by which a new element is introduced into a social unit, with the intention of benefiting the unit, some part of it, or the wider society. The element need not to be entirely novel or unfamiliar to members of the unit, but it must involve some discernable change or challenge of the status quo."* (West & Farr 1990). *"Five Stages of the Innovation Process: Recognition, Invention, Development, Implementation, Diffusion"* (Maidique 1980). *"Innovation cuts across a broad range of activities, institutions and time spans. If any part of the pipeline is broken or constricted, the flow of benefits is slowed."*(Botkin et al. 1986). *"Innovation is much more than invention the creation of a new idea and its reduction*

to practice and it includes all the activities required in the commercialization of new technologies" (Freeman & Soete 1997). *Essentially, innovation is the successful commercial exploitation of new ideas. It includes the scientific, technological, organizational, financial, and business activities leading to the commercial introduction of a new (or improved) product or service."* (Dodgson et al. 2008). *"Innovation is defined as the development and implementation of new ideas by people who over time engage in transactions with others within an institutional order. This definition focuses on four basic factors (new ideas, people, transactions, and institutional context)"* (Van de Ven 1986).

A definition is not meant to be all an encompassing elaboration of a phenomena, however discussions within academe give the sense that no single definition of innovation is complete, and choice is usually based on the emphasis required. The aim here is to draw from the various perspectives the core thrust of what is referred to as 'innovation'. And from the above, they are: Innovation is based on new ideas, involves commercial application, is strongly associated with successful or beneficial outcomes or change, engages people and their aggregation at all levels either as the subject or object of innovation, occurs in a institutional context, hence may have to overcome existing institutional barriers, is a process with a time dimension rather than an outcome. Based on these factors and with the focus on foundational research, I adopt definition of (Van de Ven 1986) with the following appendage:

Innovation is defined as the **successful** *development and implementation of new ideas by people who over time engage in* **commercial** *transactions with* **market entities in an accommodative** *institutional* **environment**.

The focus of this thesis is to delve deeper into these factors, which have been independently addressed in the literature, but not necessarily in relation to the unique features of innovation process. This thesis does not directly attempt to address the wide ranging research interests in innovation such as sectoral differences in innovation (Nelson & Winter 1977), national innovation system (Nelson 1993), various types of innovation such as radical-incremental innovations (Freeman 1974), continuous-discontinuous innovation (Tushman & Anderson 1986), innovation lifecycles and dominant designs (Abernathy & Utterback 1978), modular innovation (Henderson & Clark 1990), open innovation (Chesbrough et al. 2006). However the foundational contributions is expected to benefit a revisit of research questions in this space. With this disclaimer in place, in the following,

each of the factors identified in our adopted definition will be explored to seek important questions of foundational value pertaining to it.

1.2 Central Factors in the Organization of Innovation

The four central factors in the definition typically engage the manager involved in the innovation process, hence has applied relevance, despite the foundational research focus. *"From a managerial viewpoint, to understand the process of innovation is to be able to answer three questions: How do innovations develop over time? What kinds of problems will most likely be encountered as the innovation process unfolds? What responses are appropriate for managing these problems? Partial answers to these questions can be obtained by undertaking longitudinal research which systematically examines the innovation process, problems, and outcomes over time."*(Van de Ven 1986). Van de Ven suggests that partial answers to these questions could be found through longitudinal research that systematically observes the innovation process, its outcomes and its challenges. His efforts in pursuing this method culminated in interesting observations (Van de Ven & Poole 1990), but did not sufficiently address the questions set out, in particular the third question of appropriate measures that can be taken to organize innovation. This is not surprising given the nature of innovation, which does not proffer trivial a priori patterns. Understanding these patterns would require deeper theoretical work corroborated by a variety of methodologies. Taking one factor at a time, attention is focused on existing theory and wisdom that are not fully compatible with the phenomena of innovation.

1.2.1 New Ideas

New ideas is a result of discovery, which is central to all human achievements, including entrepreneurial activities in science and business. Despite the attention given to mind and discovery since before Socrates, a model of discovery remains inadequate in describing the essential features of the phenomena. Unravelling mechanisms of cognition, creativity and discovery are perhaps the most intriguing topics that can be under research. The topic spawns itself, and looks for an answer that characterizes humanness and its achievements. Discovery expands

rationality and underpins innovation, Innovation gives rise to change, and possibility for change gives hope in any area.

Discovery plays a crucial role in entrepreneurship (Kirzner 1997, Shane 2000), and strategy literature has also shown considerable interest in knowledge creation (Nonaka 1994) followed by a stream of literature on the knowledge based view of the firm (Grant 1996), popular interest in knowledge management (Prusak 2001) and recently integrative thinking (Martin 2007). Disagreements on discovery processes lie at the heart of debates in entrepreneurship, economics and strategy.

Management scholars have noted that it is an aphorism that a regulated environment does not bode well for discovery (Pavitt 1999). The principle paradox in defining a method for originality lies in that fact that do so would be tantamount to an oxymoron, as any creative action defined so, would thence be unoriginal. Following a similar argument, the physicist David Bohm concludes his chapter 'On Creativity' (Bohm 1996): *...it is up to each person to make the first step for himself, without following another, or setting up another as his authority for the definition of what creativity is and for advise on how it is to be obtained. Unless he starts to discover this for himself, rather than try to achieve the apparent security of a well-laid-out pattern of action, he will just be deluding himself and thus wasting his efforts. ... to determine the order in which one functions psychologically by following some kind of pattern, is the very essence of what it means to be mediocre and mechanical. ... Certain kinds of things can be achieved by techniques and formulae but originality and creativity are not among these.*

Discovery is often associated with a flash of insight or reduced to computable problem solving - unhelpful descriptions of arguably one of most complex processes. Despite having titled his seminal book "Logic of Discovery", Popper disclaims that there is any logic to discovery (Popper 1959, p. 31): *... my view of the matter, for what its is worth, is that there is no such thing as a logical method of having new ideas, or a logical reconstruction of this process. My view may be expressed by saying that every discovery contains 'an irrational element', or a 'creative intuition'* .... Einstein held similar views (Einstein 1918): *No logical path leads to these elementary laws; it is instead just the intuition that rests on an empathic understanding of experience.*. Others reflected on its hidden nature and the difficulty to unravel the mechanisms of mere understanding, of which our current topic on discovery is the pinnacle (Kant 1988 edn., p. 118): *The schematism of our understanding in regard to phenomena and their mere form, is an art, hidden in the depths of the human*

soul, whose true modes of action we shall only with difficulty discover and unveil.

Yet others (Simon 1977) were optimistic on the other end of the spectrum, claiming not only that computers could replicate thinking and discovery but also that no significantly additional theoretical apparatus from those that they were utilizing would be required for realizing it. *"The processes of discovery are just applications of the process of problem solving"*, elaborating further that *What is common to all of these tasks is that they appear to employ the same general kinds of problem-solving processes as chess-players use in choosing their moves*(Simon 1989). Referring to their paper on simulating the discovery process (Kulkarni & Simon 1988): *"... the computer programs contained a set of processes that were sufficient for making discoveries, and thereby provided a possible explanation for the success of human scientists"*, and affirms that (Simon 1989): *...insight that is supposed to be required for such work as discovery turns out to be synonymous with the familiar process of recognition; and other terms commonly used in creative work - such terms as judgment, creativity, or even genius - appear to be wholly dispensable or to be definable, as insight is, in terms of mundane and well understood concepts.*

New ideas are located at the upstream end of the innovation process, or in other words lie at the micro level of analysis. Several questions arise from this fundamental factor: Is there underlying mechanisms that can be associated with discovery? How do we contextualize discovery and its mechanisms within the burgeoning literature on cognition. Is this process amenable to modeling? Can we adapt the influential landscape to describe discovery, if so can we adapt the intuitive NK model in consort? How does attributes of the individual influence ideation? Can we study the dynamics of recombination of ideas, and how does that compare with analogy, which has received attention in management? Under what conditions are these mechanisms favourable. Does discovery mechanisms have implications for nature of collaboration, joint ventures and mergers?

1.2.2 People

Individuals are the originators of new ideas, as well as its carriers, implementors, influencers and users. Purely from a ideation point of view, we previously enquired the implication of the mechanisms of discovery on collaboration among individuals. The 'people' factor relates to one level higher that the micro-level, where decision making behaviour of individuals may be a function of their iden-

tity, training, capabilities and context. Notably, inventions and commercialization belongs to two different broad domains, that of science and business. Inventors whether scientists or not seek solutions to technical problems, hence are trained, socialize in an environment suited to this vocation. On the other hand individuals in the business domain deal with individual, organizational, market and institutional demands.

The differences between the science and business enterprise is well articulated in the following: *"Conflicts between science and business - some obvious, some subtle - are apparent at many levels, beginning with their different cultural norms, values and practices. For example, science holds methodology sacred; businesses focus on results. Science values openness and sharing (with attribution); business generally demands secrecy and propriety. Science demands validity (Is this idea/finding valid? Does it stand up to scrutiny?); business demands utility (Is it useful?). Both areas can be fiercely competitive, but they compete for different currency. Science "keeps score"by intellectual impact and contribution to a body of knowledge, as measured by prestige, academic standing, peer evaluation, and published articles; business does so by financial performance."* (Pisano, 2006)

It is thus expected that their perspectives would differ and their interactions may not be smooth. Innovation entails a dynamic science-business interface that can translate upstream novelty into downstream rents. The people factor is at a level of low or no aggregation of individuals, but at a level above ideation (people are the hosts of ideation). Further it lies more towards the upstream side of the innovation value chain. A larger aggregation of people along with common goals, structure and incentives form organizations and a collection of such people and organizations for the market. Since it is a convention to refer organizational and market related phenomena as macro, the people factor can appropriately placed in the meso level between ideation (micro) and organization/market (macro) levels.

Outstanding research questions in this space include: Do science and business domain individuals differ in opportunity recognition? If so what factors significantly influence opportunity evaluation? Is it merely differences in domain knowledge or fundamental problem solving approaches they differ in? How do science and business domain individuals treat new information, i.e. how do they learn or update prior beliefs? How can they form compatible interfaces? What is the best approach to upskill science and business domain individuals to enable synergetic innovation?

1.2.3 Transactions

The invention that is implemented need to be transacted over the market for commercial gains. In this context the most prominent discussion relates to the theory of the firm. The theory of the firm attempts to address questions of existence, boundaries and internal organization(Coase 1937). The most influential and amongst the earliest is the Transaction Costs Economics perspective (Williamson 1975), which studies the firm in the context of its interaction with the market. On the other hand a bottom up approach evolved more recently from the management perspective focusing on the strategic capabilities of firm (Peteraf 1993, Teece et al. 1997). The most exciting discussions in this space pertains to boundaries of the firm, where every organization is said to use its 'boundary' to distinguish and define itself with respect to its environment(Scott, 2003).

In the context of innovation which spans spectrum from capabilities to transactional efficiencies, either of these theories would be found wanting due to their emphasis on either capabilities or transactions. Hence covering the nature of the firm and its activities in the innovation process, necessitates a more integrated theory. In both the capability and transaction cost perspectives, the boundaries of the firm have also been defined to answer the question of internalization or externalization of firm activities, leading to narrow association of boundaries with ownership and control. This dissatisfaction has been expressed widely in the literature: *"It seems to us that the theory of the firm, and especially work on what determines the boundaries of the firm, has become too narrowly focused on the hold-up problem and the role of asset-specificity..."* (Holmstrm & Roberts 1998). However attempts to address the issue of boundaries (Jacobides & Billinger 2006, Jacobides & Hitt 2005, Santos & Eisenhardt 2005, 2009)have invariably relate boundaries to explicit ownership and control.

Transactions of firms in the market lie at the macro level, representing high aggregation and organization of people at the meso level. Outstanding research questions include: Is the innovation process sufficiently covered by the existing theories of the firm? How could an integrated theory of the firm be formulated to describe the full spectrum process of innovation? Are strict notions of boundaries tenable in the innovation context, if not how else could a firm be identified in the

market milieu? How would an integrated theory of the firm incorporate boundary discussions in the innovation context?

A transactions aspect of the innovation process is not included in this thesis due to length and thematic constraints. A paper on reconceptualizing the innovative firm using two in depth case studies is separately available. The first case study is on the Wisconsin Alumni Research Foundation, for which I was provided access to archival data in addition to interviews and published material on the technology transfer arrangements in the last century. The second case study is on Symbian, for which I assembled data via a full perusal of the Google Timeline for the entire period of its existence (and a little prior to it), published documents and media.

1.2.4 Institutions

Among the barriers to innovation, existing institutional setting, norms and values are the most entrenched. Individuals, organizations and the market exist in the context of multiple institutions exerting a top-down effect on all the levels. The institutional setting can be considered at a level higher than the macro organization/market level, as it represents an over-riding context for all the levels. Institutions have more stable existence and exert pervasive impact compared to other levels. The micro, meso and macro levels were discussed in terms of increasing levels of aggregation. Similarly the institutional context arguably lies at a higher level of aggregation owing to its wide acceptance - even if it not set up by the emergent dynamics of the lower levels. Due to this factor of institutional context lies at the meta level, indicative of transcending the lower levels.

One of the prominent discussions in innovation is the increasing involvement of universities in commercialization and innovation. The changing nature of universities, which primarily has an educational mandate has notably entailed significant institutional challenges. The key questions for this factor include: How did organizations with potential for participating in the innovation process perform in the presence of institutional constraints? How did the universities realize their commercial potential? What are the mechanisms of institutional change? How can people and organizations effect institutional change effectively?

1.3 Methods, Data and Structure

The thesis adopts several methodologies and sources of data in addressing the foundational questions related to four factors of innovation. Each chapter provides a literature review on the respective research questions. Each chapter summarizes its findings within the chapter in the form of a conclusion or discussion. Chapters 2, 3, 4 and 5 are thus written to stand independently addressing research questions not only within the framework of innovation but also research questions of mainstream interest in its own right. The final chapter is a synthesis of the four central factors in the management of innovation, leveraging on the insights of previous chapters and opening the discussion of a coherent multi-level perspective of the innovation process. The latter is a larger undertaking, and this thesis hopes to contribute to this effort.

The second chapter on the model of discovery uses in depth case study of Nobel Prize winning biochemist Thomas R. Cech obtained from published sources, in addition to a large number of less rigorous case studies on discoveries ranging from science to business from secondary sources. These observations are corroborated with semi-structured interviews with leading scientists in the UK. This is followed by formal modeling building on the NK framework, which is then used as a test bed for simulations under strategically chosen conditions. The simulation was coded in Matlab, and benchmarked against the original NK paper in management (Levinthal 1997). The number of iterations for all plots given in the thesis is 10,000 to ensure convergence. The basic NK model upon which the extensions were build is presented by way of a gentle introduction.

The N-K model was introduced by (Kauffman 1993) to analytically model complex biological evolving systems based on mutations on a DNA string and conflicting constraints due to interdependencies among them. Originating in theoretical biology, a stream of literature in management has emerged applying the N-K model including firm strategy (Gavetti & Levinthal 2000, Levinthal 1997, Rivkin 2000), production technology (Auerswald et al. 2000, Kauffman et al. 2000) and innovation (Frenken 2001). Complexity is a reference to inter-relatedness within a particular structure. In biology, dependencies between the genotype and the phenotype give rise to complexity. Genotype is the level at which mutations occurs, leading to new variants in the population, and phenotypes comprise the ensemble of traits that make up an organism's fitness. A mutation in one gene may affect the activity of other genes, and therefore instead of affecting just the

contribution of the mutation of one gene to the phenotypes, it can also affect the functional contribution of the inter-related genes. Thus a set of genes constrain the evolution, whereby a certain trait can only be improved when the improvements to a trait by a mutation outweighs the detrimental effect on other traits. An analogy is made to technological innovation, where systems comprise a number of elements to achieve a number of objectives. Complexity is caused by the interaction effects of these elements, implying that only certain combinations improve the overall fitness of the system as a whole, which are seen as peaks in a fitness landscape represented combinations.

A string C represented the dimensions and is described by alleles chosen from within the dimension, i.e. binary options of 1 or 0 for each dimension. The fitness W of the system is given by

$$W = \frac{1}{N} \sum_{i=1}^{N} w_i \tag{1.1}$$

where N is the number of dimensions and w_i are the contributions of each allele to the overall fitness of the system. A random seed is used to initialize values for various mutations and effects of dependencies. Full descriptions of the model can be gleaned from (Altenberg 1997, Kauffman 1993). While changes in theoretical biological systems change through random mutations, innovation changes via the agency. The simulations assuming direct equivalence between theoretical biological systems and innovation would therefore be unrealistic. Therefore the conventional N-K model requires a well justified modification to make it suitable to model discovery or agent dynamics and innovation. Considering a system with number of dimensions N= 3 and interdependence K=2 (Figure 1.1), the fitness of each point on the landscape can be determined.

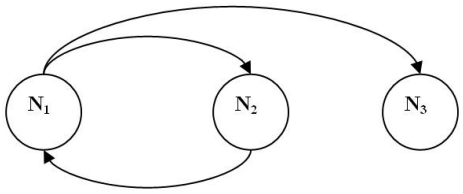


Figure 1.1: An example of N=3, K=2 setting for the Kaufman model.

Based on the interaction shown in the Figure 1.1, an interaction matrix can be formed. The fitness of each combination of the system is shown below in Table 1.1, where the fitness contribution of each dimension constituting a point

C	w_{N_1}	w_{N_2}	w_{N_3}	W
000	0.5590	0.4870	0.3975	0.4812
001	0.5590	0.4870	0.8270	0.6243
010	0.7385	0.9688	0.3975	0.7016
011	0.7385	0.9688	0.8270	0.8448
100	0.4928	0.4870	0.3975	0.4591
101	0.4928	0.4870	0.8270	0.6023
110	0.0595	0.9688	0.3975	0.4753
111	0.0595	0.9688	0.8270	0.6185

Table 1.1: A random sample run of the Kaufman model for N=3 and K=2

in the landscape is averaged. In order to capture the behaviour of an agent in a landscape, a large number of randomized landscapes satisfying N=3 and K=2. In order to do this, the interaction matrix is randomized and agents are launched at random locations in the landscape.

The global peak in the landscape described by Table 1.1 is 0.8448. A basic feature of the NK landscapes is that ruggedness increases with increasing complexity. To confirm this property of NK landscapes, the result is reproduced by averaging over 1000 randomized landscapes, shown in Figure 1.2. By averaging the randomized landscapes, properties such as effect of interdependence on number of peaks, heights of peaks and agent behaviour can be determined.

In order to benchmark movement on the landscape, the result on adaptation on rugged landscapes (Levinthal 1997) was reproduced. Adaptation is systematic search for a local optima. Figure 1.3 close match with simulations given in the literature. Thus the modeling and simulation is verified and can use it as a test bed to apply new extensions to the NK model.

The third chapter on the science-business divide uses quasi-experimental design on a verified sample of science and business domain individuals. The scenarios for the quasi-experiment is taken from 20 selected pitches on the Dragon's Den program, which were edited such that only the pitch remained, devoid of expressions, emotions and judgements of the investors. Three methods were used to obtain data. Firstly verbal protocols were used to record free discussions of teams (of 3) exclusively science and business individuals. Two scenarios were presented

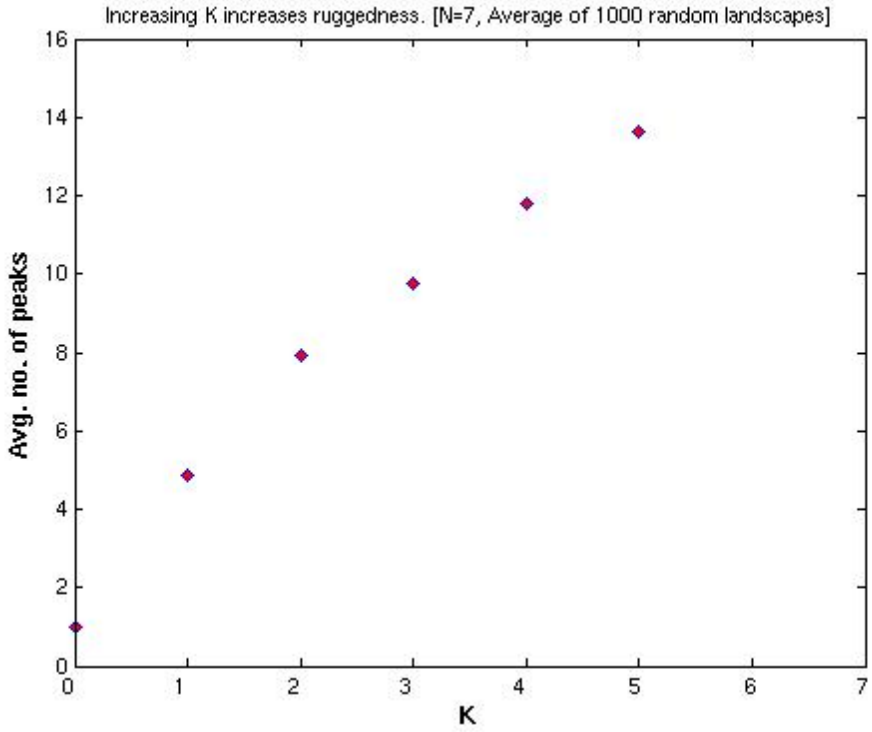


Figure 1.2: Ruggedness increased with complexity

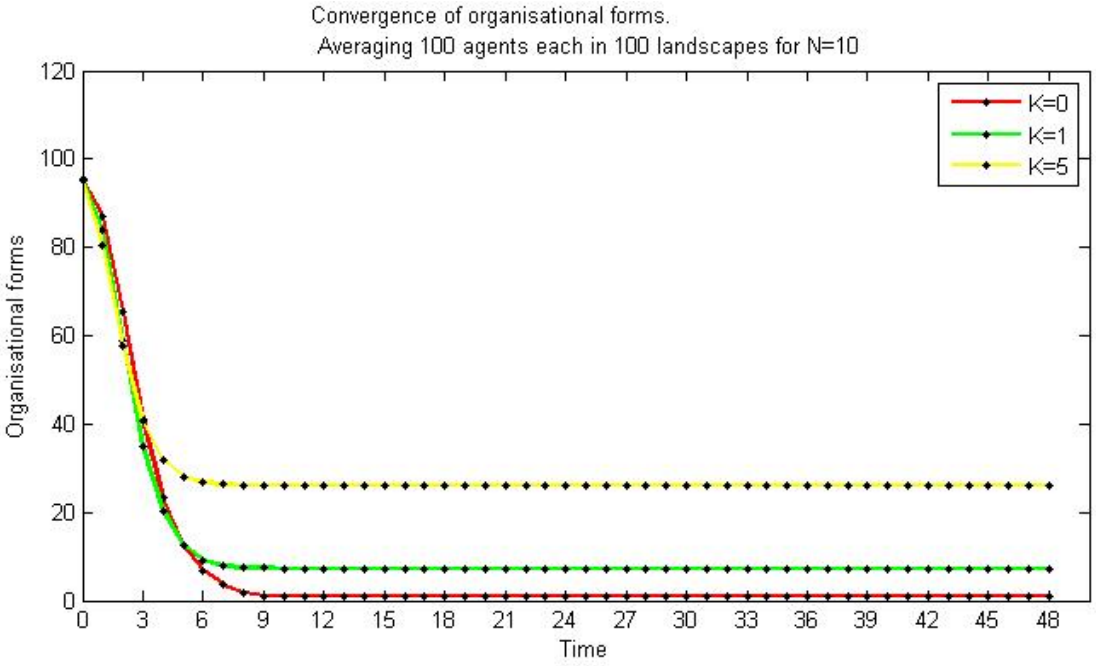


Figure 1.3: Reproduction of plot in (Levinthal 1997).

to each of the 4 team and discussions were recorded for both scenarios separately. The recordings were then transcribed and coded. The second method involved presentation of 15 scenarios to 20 science and business individuals to obtain repeated measures on ten variables for each of the scenarios. This was conducted in a controlled environment in the background presence of the author. The third method involved presentation of 3 scenarios, which were each segmented into 4 parts (representing general overview, technical details on how product/service works, financial information and market information). This was sent as an invitee only online quasi-experimental survey via email to individuals in top tier science and business schools in the UK, from which 120 responses were collected. All the three methods used PhD students in science (without business background) and MBA students (without science background), and were incentivized at the rate of 20 for first method, 15 for the second and 10 for the third. The video editing was performed in Apple's iMovie, and the computer based experimental survey was done in Lime Survey - a freely available open source tool. A predominantly -50 to 50 slider scale with default position at zero (in the middle) was used. The data from the second and third methods were analyzed using STATA.

The fourth chapter on reconceptualizing the innovative firm uses two in depth case studies. The first case study is on the Wisconsin Alumni Research Foundation, for which I was provided access to archival data in addition to interviews and published material on the technology transfer arrangements in the last century. The second case study is on Symbian, for which I assembled data via a full perusal of the Google Timeline for the entire period of its existence (and a small period prior to it), published documents and media.

The fifth chapter on realization of the commercial potential of university research uses archival data and interviews on the Wisconsin Alumni Research Foundation from its inception to 2000, several detailed historical study of the Bayh-Dole Act and its enactment, in particular by (Berman 2008, Mowery & Sampat 2001a,b). An attempt was made to ensure that the information used throughout the historical narrative has not been contested by other source sources.

Part II

IDEATION - *THE MICRO*

Chapter 2

The Problem-Solution Nexus:

Towards a Model of Discovery

Contents

2.1 Introduction 19

2.2 Discovering Opportunities 20

2.3 Approaches To Modeling Discovery 21

2.4 A Discovery Case in Point 25

2.5 Modeling the Characteristics of Discovery 35

2.5.1 Alleviating Limitations of the NK Approach 35

2.5.2 Designing the Universal Landscape 41

2.5.3 Analogy and Recombination 46

2.5.4 Bridging Local and Non-local Information 51

2.6 Concluding Remarks 57

2.1 Introduction

Discovery is the act or process of making an object or concept known or visible for the first time. The philosophy and antecedents of discovery have always been a subject of inquiry, however is far from being fully resolved. Among the philosophers of science, a debate emerged over whether a method or logic of discovery has unique epistemic value; arguing that the so called methods of discovery were concerned with justification of ideas rather than generation of ideas (Nickles 1985). In relation to this, two extreme opinions appear to exist: one that there is no logic to discovery (Bohm 1996, Einstein 1918, Popper 1959), and the other that discovery is very much a process of problem solving (Simon 1989). The problem solving approach, often referred to as the s̈earchp̈aradigm dominates current discussions of the discovery process. Nevertheless, the implausibility of simultaneously knowing and not knowing (akin to the classic Meno's paradox), perhaps led some to claim that discovery does not entail search (Kirzner 1997, Shane 2000). On the other hand discovery as a flash of insight (Root-Bernstein 1989) or genius has eroded with the study of information processing theories of problem solving (Simon 1966), mental processes that underpin scientific achievements (Gorman & Carlson 1990) and psychological analysis of the scientist (Mahoney 1979). The complexities of the discovery process has kept alive an interdisciplinary debate on how the mind works (Fodor 2001, Pinker 2005). Reviewing this interdisciplinary research is beyond the scope of a single study; however it is clear that a model of discovery addressing some pertinent issues would be of much interest and value in understanding human behavior and performance.

This article contributes to further the understanding of discovery by reviewing and extending prevailing notions particularly in the management literature. We first discuss how opportunities can be considered as the target of the discovery process followed by the major approaches to frame and model the discovery process. An in-depth examination of the discovery of the catalytic property of RNA is used as a case in point to elaborate the modes of thinking involved in the discovery process. This is used as a basis to reformulate one of the existing simulation models to explore the discovery process by varying agent attributes. Incorporating satisficing behavior within the discovery model is then discussed before concluding with some implications for the theory and practice of discovery.

2.2 Discovering Opportunities

The target of the discovery process is an opportunity, where an opportunity is a favorable combination of circumstances, whether that is a possibility to earn above market rents or to bring insight into a natural phenomenon or to undertake any beneficial course of action. We approach the process of identifying opportunities as primarily entailing the connecting of problems and solutions. Two approaches to describe opportunities have emerged in the entrepreneurship literature, i.e. found/discovery opportunities and made/creation opportunities - an epistemological dichotomy that seemingly defies integration (Alvarez & Barney 2010). This has also been explored in the context of physics and philosophy as strong objectivity (ontological realism - objective without involving the agent) and weak objectivity (objective but fundamentally involves the agent), where developments in quantum mechanics have substantiated weak objectivity over strong objectivity (d'Espagnat 2006).

The discovery/creation discussion detaches the epistemology of opportunity from the detailed process of how the opportunity is found/made. The term d̈iscoveryïn this stream of literature is used for finding opportunities that exist independently, requiring only alertness or predisposition of the agent to exploit it; whereas the term c̈reationïs used for opportunities that are made to exist via the actions of the agents, requiring only subjective interpretation and enactment. In both cases the intentions behind the agent's actions and how unusual alertness (or interpretation) transpires does not receive sufficient scrutiny within the same discussion. And since d̈iscoveryc̈an be discussed in terms of c̈reationänd c̈reationïn terms of d̈iscovery; and the verification of whether it is an opportunity is measured post-hoc, these definition suffer from tautological and ambiguity problems (Alvarez & Barney 2010, Eckhardt & Ciuchta 2008, Luksha 2008, Zahra 2008). Hence such notions may be useful in providing a multi-dimensional perspective in describing and teaching entrepreneurship, but it leaves the inquiry unresolved. Alternatively, rather than focusing on the epistemological and ontological status of opportunities, we prefer to focus on the realization of an opportunity as it appears to and involves the agent. Thereby the concept of discovery could be redefined more broadly from a process of finding objectively existing nuggets to a process of getting to see or know an opportunity.

The problem-solution pairing perspective (Hsieh et al. 2007) can be adopted and extended to view discovery as a confluence of "find" and "make" processes

en route to unraveling an opportunity in the cognitive mindset of the agent. Opportunities can be said to be necessarily and sufficiently recognized by a process of connecting the relevant problems with relevant solutions and vice versa. This perspective goes one step further than defining opportunity recognition as belief formation regarding benefits by making sense of signals of change (Gregoire et al. 2010) by specifying the sense-making process as one of connecting problems with solutions and vice versa. It is noted that agents may neither be fixated to problems for which solutions are sought nor shuffle among various problems without evaluating them. Hence, a realistic view of how agents connect problems with solutions may be a useful way to understand opportunity recognition. Linking back to the discovery/creation debate, amenable identification of a beneficial problem-solution connection can be said to align with "discovery" notion of opportunities, while getting to a beneficial problem-solution connection via change in the consideration of problems and happenstance can be said to align with c̈reationn̈otion of opportunities. Therefore the process and dynamics of connecting problems and solutions has promise to provide an integrated view of opportunity discovery.

2.3 Approaches To Modeling Discovery

A traditional explanation of the discovery process is through four phases: mental preparation, incubation, illumination and verification (Wallace 1926). Mental preparation entails confronting the problem, identifying its core aspects and making an effort to resolve it. In the incubation phase, the problem is left aside while another matter takes priority. While focusing elsewhere, an abrupt illumination ("flash of insight") occurs unexpectedly, providing a resolution of the initial problem. The verification phase finalizes the details of whether it can be successfully defended. These phases are indicative of the individual's discovery journey; however the phases are not sharply defined. Incubation gives the notion that something is being warmed or prepared, which is perhaps consistent with the prepared mind perspective (Seifert et al. 2006), but it does not shed light into the observed phenomenon of finding solutions to an unintended problems. The illumination phase appears to have a Freudian emphasis that subconscious is more effective than the conscious mind, an approach that has come under much criticism (Sternberg 1999).

The search and problem solving approach on the other hand has yielded to

modeling. Initially used in modeling and optimization in the sciences (Brady 1985, Weinberger 1991), evolutionary biology in particular (Kauffman 1993), the notion of fitness landscapes have found application in the social sciences leading to significant work especially in the area of organizations (Levinthal 1997, Rivkin & Siggelkow 2002) and strategy (Gavetti & Levinthal 2000, Gavetti et al. 2005). The NK model provides a simple framework to model interactions of dimensions and develops intuitions about the structure of complex combinations of individual or organizational parameters.

In general, adaptation in the landscape adopts a "strong view" of bounded rationality of agents (constrained optimization), and the key determinants of performance are the starting points in the relevant landscape and interaction between dimensions which form the landscape. Better agents are usually those that are able to start at a better location in the landscape. Broader aspects of bounded rationality have been considered in the analysis of hierarchical organizations (Rivkin & Siggelkow 2002) and imperfect evaluators (Knudsen & Levinthal 2007), which highlighted cases where local peaks are not chosen due to parochial decision making tendencies by parts of organizations or having sensitivity only to large improvements.

The search and problem solving approach is also central to algorithms in the field of artificial intelligence. A limitation of the individual model of pattern recognition is its inevitable convergence, i.e. when a new reality is observed such models converge monotonically to known datasets. Consequently, it is incapable of exploring inconsistencies and pursuing its resolution, which is essential to discovery and developing new heuristics. Although some limitations can be alleviated, there is much to be developed in the understanding of semantics, concepts and thoughts. Given the analysis is at the connectionist level and the aim of such research in replication and bettering human cognition, the natural language processing and modeling of semantics may be essential throw further light into this topic is a work in progress (Gardenfors & Warglien 2006, Roy 2008).

A rigorous effort towards explaining discovery heuristics is the KEKADA system (Kulkarni & Simon 1988), which searches an instance space (possible experiments and experimental outcomes) and a rule space (hypotheses and the confidences assigned to it). It does count as strategies of experimentation, however these heuristics and hypotheses are from a limited set that are available. The universal set of all possible heuristics and hypotheses is unknowable by an agent,

i.e. there exists a "halting" problem, where one cannot say for certain that all possible heuristics have been found or discoveries have been accomplished. The discussion of whether such a universal set is uncountable or finite is irrelevant, and an effective model of discovery should therefore be constructed such that finiteness should neither be an assumption nor an obstacle. What is important is the recognition that the halting problem makes the potential for discovery to perpetually exist a fact confirmed by the historical progress of knowledge. Therefore a KEKADA-like hypothesis generating and testing system may arguably be seen as a necessary but not sufficient discovery model.

Another study of 40,000 patents culminated in the TRIZ heuristic for problem solving (Altshuller 1984). Despite its impressive coverage of concepts, TRIZ has received mixed opinion when it comes to application, owing mostly to difficulty and lack of clarity in applying the heuristics. This shows that heuristics however specific they become, their role in studying discovery is limited in that access to appropriate knowledge corresponding to discovery is neither guaranteed nor is it exclusive to any specific heuristics.

Empirical investigations of science and creativity can be organized into several overlapping categories such as historical or biographical (Wallace & Gruber 1989), sociological (Latour & Woolgar 1979), computational AI models (Darden 1997), computational process models (Kulkarni & Simon 1988), design process models (Hatchuel et al. 2005), on-line studies (Dunbar 2000), psychological (Amabile 1983), simulated lab studies (Penner & Klahr 1996), biological (Martindale 1999) and linguistics (Fauconnier and Turner 2002) - further description is given in Table 2.1. Broadly approaches to modeling cognition can be classified according to their levels of analysis: 1) behaviorism (psychological approach emphasizing effect of environment on individual without focusing on internal representation of mental states), 2) physical symbol systems (thinking as computation via symbol-manipulation according to formal rules), 3) connectionism (operations at the neuronal level). The refinement of the level of analysis has not necessarily improved descriptive or predictive powers regarding discovery.

Our approach is to model cognition as a dynamical system, which allows the choice of level of analysis and variables to be chosen by the modeler consistent with specific goals that needs to be achieved. With suitable supplementation, the NK based modeling technique can belong in this domain. The aim here is to outline a framework in which the inputs, mechanisms and outcomes of the discovery

Methodology	Description	Key literature
Psychological	Correlation and regression studies surveying, identifying, and constructing factors that can influence creativity.	(Amabile 1983, Guilford 1950, Sternberg 1999)
Experimental	Direct comparisons that systematically manipulate independent variables hypothesized to influence creativity.	(Sternberg 1999)
Biographical	Case study analysis of recognized episodes of creativity.	(Wallace & Gruber 1989)
Biological	Measurement of neurological or other physiological activity during creative task performance.	(Martindale 1999)
Computational	Formal models of creativity, typically using artificial intelligence.	(Boden 2003, Simon 1977)
Contextual	Descriptions of creativity as arising from social and cultural contexts.	(Latour & Woolgar 1979)
Model based	Constructing and manipulating various kinds of representations, such as visual.	(Magnani et al. 1999)
Philosophical	Addressing questions of logic and metaphysics	(Frege 1984, Wallace & Gruber 1989)
High level semantics	Theories based on high level observations instead of focussing on the above low level aspects.	(Fauconnier & Turner 2002, Hatchuel & Weil 2003, Nonaka 1994)

Table 2.1: Review of approaches to study creativity and discovery

process can be organized. This treatment focuses on problem solution connections by drawing on factors that facilitate such opportunity discovery. Business examples of opportunity recognition operate may appear less sophisticated but often operate on more complex scenarios and are more difficult to verify compared to scientific examples. This owes to interdependencies, ambiguity and uncertainty regarding objectivity as well as several other factors that influence discovery in a business setting such as incentives, slack resources, entry and adoption barriers, socio-economic risks and the dynamics of other agents. Therefore we consider scientific examples as a first step, which entails study of relatively stable physical phenomena to explore the discovery process.

2.4 A Discovery Case in Point

To understand discovery, we selected a recorded experimental case with no other bias than its accessibility. RNA enzymes have provided a new tool for gene technology and have the potential to provide new therapeutic agents. The Nobel Prize winning biochemist Thomas R. Cech, who was behind the discovery, admits that they *"were looking for something very ordinary, with no hint or expectation that at the end of this trail would be a discovery that others would perceive as being of such special and fundamental importance"* (Cech 2001). He also benefited from being removed from research in other labs and their paradigms. Further he mentions that teamwork played an important part in Cech's achievement, whose strange results were corroborated by researchers in the lab pursuing distinct but parallel pathways, without which he might have suspected his own judgments.

The discovery process was characterized by a number of notable changes in their problem definition. The initial goal was to perform a step in gene expression called transcription. The results they obtained motivated what they considered a diversion - a shift in focus to examining RNA splicing due to two main reasons: an unexpected bi-product called Intron required explanation and to see whether complement Abelson's results (the only scientist to have observed it before in a similar setting). They proceeded to address this problem by identifying the enzyme responsible for the excision of Intron from RNA. Given the long established belief that proteins are responsible for catalysis, they were surprised to find that splicing happened even in the absence of any cell extract. This led to them questioning their assumption of whether the RNA they were producing was pure.

Standard protein destroying procedures were conducted, only to find that splicing still happened unabated. After exploring some option, they decided to examine if RNA was itself responsible for the catalysis, which was eventually verified. This was such a foreign idea at the time that they had difficulty publishing their work.

Unknown to Cech at the time (in 1982) was that a number of laboratories around the world had the appropriate materials to do the same experiments. He notes that a group in France was trying to infer the answer from genetics by looking at the DNA sequence, missing the non-trivial fact that RNA had catalytic activity. Another group in Denmark was on the same path as them, but could not believe their results, deciding to quit working on the problem before the end. However interlinked and seemingly automatic the sequence might appear post-hoc, the researcher began with performing copying of information from DNA to RNA and ended up discovering that RNA is catalytic.

Several other discoveries can be shown to be more dramatic in terms of where the trail started and how it ended. The discovery of buoyancy principle, law of gravity, electro-magnetism, vulcanized rubber, chemical structure of benzene, x-rays, penicillin, cosmic background, pulsars, telephone, rubber, Velcro, post-it, polypropylene, Viagra, Ritalin are a few that stem from accidental discoveries. In fact, in most discoveries the connection between the problem and the solution was not only unintended a priori but also was non-trivial for their peers. It can be noted that the discovery process, when studied in the context of what was being done prior to instance of discovery, can be generalized as comprising three modes: problem solving, problem reshaping and problem shifting. In Figure 2.1, we describe this process in a flowchart characterized the three modes of discovery. The three modes of discovery are defined below including examples of how they can be gleaned from words of discoverer Cech, in his account of the discovery process.

Problem solving is an approach that proceeds from a given state to a desired goal state in pursuit of a solution to a 'given' problem. The initial problem that Cech was solving was, *"What we were trying to study in this organism was one of the steps in the expression of a gene"*. The desired state is achieved when no more movement can improve existing fitness or solution. Solving the problem Cech set out to solve achieved its desired state, when *"We saw that, yes, this reaction was working, but also than intron was excised from the RNA ..."*. Within the parameter space defined by the problem, the problem was solved, however new outcomes

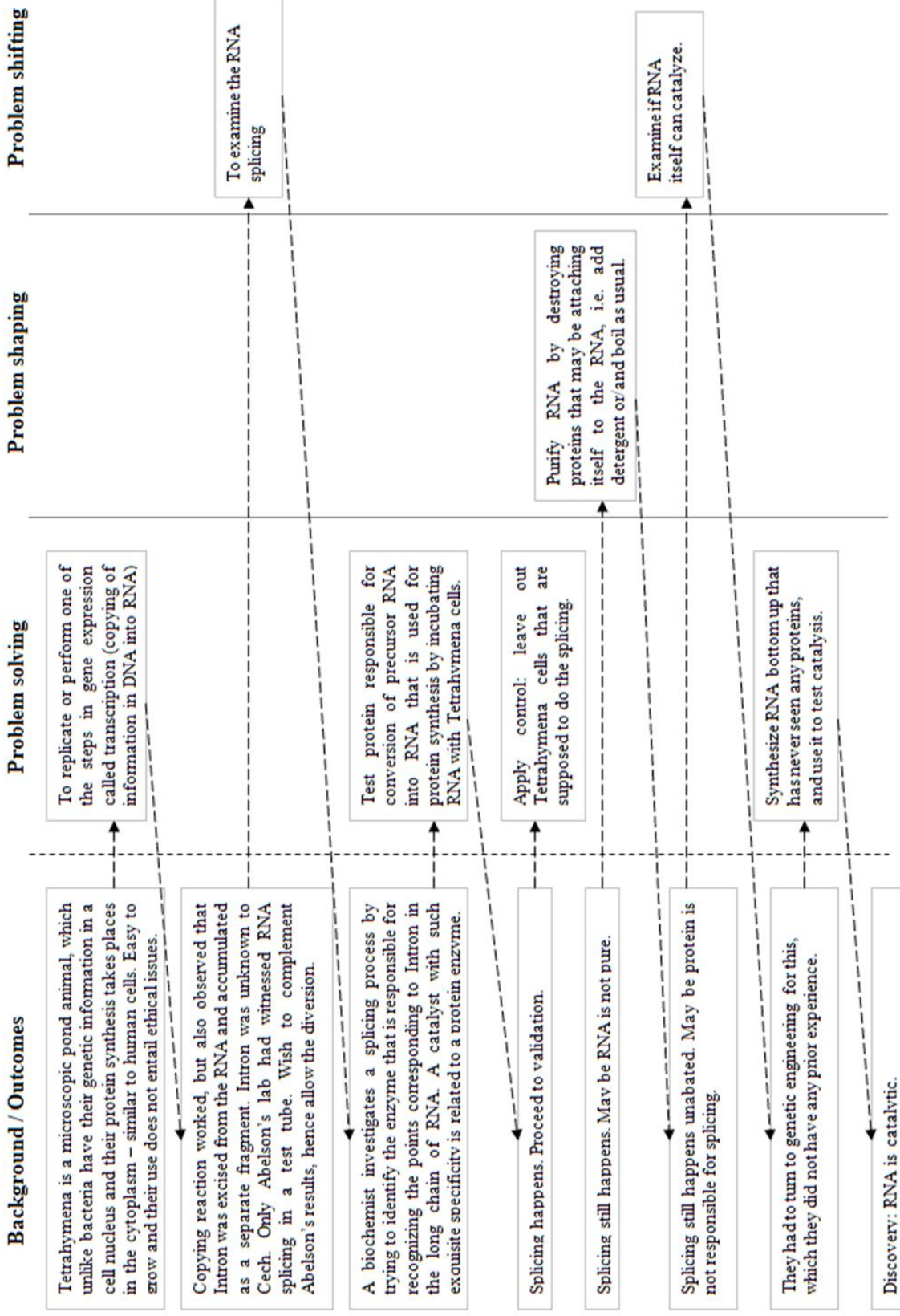


Figure 2.1: Schematic flow chart of the main processes that led to the discovery of the catalytic properties of RNA.

or observations may indicate other problems and parameters which were not incorporated in the previous effort: *"What we did not know when we started these studies was that the coding region of the DNA was interrupted by a stretch of non-coding DNA called an intron"*. Such new information may provoke a re-evaluation of the problem to be solved in the first place, which then determines the scope of the parameter space in which solutions are sought. This transition beyond conventional problem solving to problem-shifting or shaping is often overlooked in the search literature.

Problem shifting is to change the objective in such a way that it is significantly different from the original objective, and may be considered an independent problem in its own right, essentially constituting a 'diversion'. Cech notes, *" At this juncture we became more interested in this downstream step..... we decided to allow ourselves the luxury of a small diversion to examine the RNA splicing step."*. Once such problem redefinition is done, problem solving could proceed as described above, which is exemplified in Cech's approach to this diversion: *" What does a biochemist do to investigate such a process. One goal is to purify the enzyme that is responsible for recognizing two particular points along this long chain of RNA..... After all you could read in any biology or biochemistry textbook that any reaction that took place with such exquisite specificity would have to be catalyzed, and the catalyst, of course would have to be a protein enzyme"*. During such problem solving effort, problem definitions may be changed slightly to broaden the scope of the problem solving approach without diverting to a significantly different problem space.

Problem reshaping is a process of changing the problem definition in a way that it still remains significantly related. Cech's hypothesis that proteins caused the catalysis was proven wrong, as the absence of Tetrahymena cell extract still caused catalysis. The problem of whether or not protein (from Tetrahymena) caused catalysis was solved, but this did not explain the catalysis. *" It turned out that that tube showed as much RNA splicing as the one where we had added the extract! That was not one of the expected results of the experiment. It was incumbent upon me as the director of this young laboratory to come up with some explanations. As you will see they turned out to be wrong. But it does not matter so much whether scientific hypothesis are correct or incorrect - as long as they flow logically from the information you have at the time, and as long as they are testable. They, they either pass or fail the test, and along this type of branched pathway one can make progress in the understanding of a scientific problem."*. A new hypothesis was generated speculating that what they were calling pure RNA may be impure with some type of proteins

strongly attached to it. Although this is related to the previous goal of identifying the protein responsible for catalysis, it required changing an assumption inherent in the previous problem definition, thus redefining the problem necessitating a different course of action.

Following the reshaping of the problem, problem solving ensues: *"How does one test such a hypothesis. Scientists know of many ways to destroy proteins, which, according to the hypothesis, should then block splicing."*. Several solutions in this problem space, such as using detergents and boiling were used, only to find that splicing happened unabated. Instead of resorting to once again reshaping or shifting the problem definition, they proceeded further into problem solving: *"At this point the hypothesis was not looking so good, but we thought may be this was an unusually stable protein enzyme. So we choose harsher treatments, like boiling in the presence of detergent or adding large amounts of non-specific proteases (enzymes that degrade protein) - but nothing seemed to prevent the splicing activity."*.

Left with no other solution within the problem space, they were faced with a dilemma reflected in the following incident: *"... one of my graduate students, Paula Grabowski, gave me a picture of a daisy. Alternate petals were labelled 'it's a protein' and 'it's not'."*. To resolve this dilemma, they decided to see if splicing happened even with pure RNA, in which case their hypothesis would entail a remarkable shift to incorporate the possibility that RNA itself might be the catalyst. In other words they shifted the problem definitions to entertain the null hypothesis that some unknown protein caused the splicing and the alternate hypothesis that RNA was itself catalytic. This surprising and overlooked possibility simply did not exist in the parameter space defined by previous problem definitions. This was followed by a problem solving effort to genetically synthesize pure RNA despite having no experience.

Even in the rather overlapping journey of Cech's discovery, we find that the problem definitions changed substantially from getting transcription to work in a test tube (problem solving) to examining the splicing (problem shifting) and from identifying protein responsible for catalysis (problem reshaping) to finally shifting to analyze whether RNA can self catalyze, which was foreign idea to the entire scientific community combined with their own inexperience in genetic engineering that was required to accomplish it (problem shifting). While problem solving follows every shifting and reshaping of the problem definition, the overall problem solving en route to the instance of discovery is likely to be punctuated

by the other two modes. It is important to note this suggests both deliberate search and non-deliberate processes contribute to discovery. Also important to note is that the logic of transition between three modes suggests an interesting area of research to further deepen our understanding of the discovery process and the factors that influence it.

The dichotomy between "problem reshaping" and "problem shifting", while not a pressing problem for the formulation of the model; the distinction is made to more accurately match the observations of discovery processes. This dichotomy bears similarity to the distinction between "incremental" and "radical" innovations. After the transition to other problem spaces, both problem-reshaping and problem-shifting return to the problem solving mode (the engine of search). While the term "bounded rationality" may be arguably broad enough to describe such processes, given the historical use of the term in modeling, we may use the terms "flexible rationality" and "progressive rationality" to specifically refer problem reshaping and problem shifting respectively.

Cech's case is much simpler (involving relatively shallow theory and testing) than some of the deeper theoretical cases. There are also numerous other examples of remarkable problem identification in the industrial and business arena. To give an tangible example in the context of innovation and entrepreneurship, consider the case of Velcro, which can be described using the three modes of discovery discussed above. Swiss engineer George de Mestrel, led by curiosity, sought to examined Burrs that kept sticking to his clothes after an expedition to the Alps. This arguably problem solving exercise, showed him under the microscope hundreds of hook like structures catching on to anything with a loop structure. In this he was able to see the a more generalized possibility of binding two materials reversibly, shifting this focus and problem definition to fastening two daily use materials together. This discovery then took 10 years of solving various problems to come to commercial fruition, a process which necessitated other discoveries and inventions. We can describe this process as a problem solving effort aimed at lowering the perceived gap of what causes the Burrs to stick followed by problem shifting in seeing a radical use for similar structures to fasten materials, which was then followed by a series of problem solving, reshaping and shifting to yield a feasible commercial product. The discovery of the role of Bacteria in peptic ulcers, unraveling the causes of extinction of Dinosaurs and the technological development of the Java Programming Language have also been shown to have involved a combination of problem solving, reshaping and shifting

(Thagard & Croft 1999).

We also corroborated the above described transitions between problem spaces by conducting semi-structured interviews of scientists (chosen by UK's Engineering and Physical Sciences Research Council as the 10 top achievers during 1995-2005). The interviews of the five scientists who responded are coded in Table 2.2, where initial and final problem spaces are indicated in addition to what trait or technique enabled the transition to the promising problem space. A salient quotation regarding their philosophy of discovery is included. All of the scientists interviewed went through how they traversed different problem spaces in their respective discovery process consistent with the three modes discussed above. Based on the detailed qualitative analysis and the corroboration with interviews on the discovery process, we posit that:

Proposition 1: The discovery process transpires via one or more of problem solving, problem reshaping and problem shifting.

In the study of discovery processes, is important to be specific with problem definitions at every phase, as indifference to the specific problem being solved can easily render a post-hoc reconstruction into a smooth sequence, as if one problem is being solved from the beginning. The transition between problem spaces may be rationalized via the context, micro-mechanisms and repertoire at the disposal of the agent, all of which can be contextualized with the role of problem solving, reshaping and shifting in relation to opportunity discovery (Figure 2.2). These modes of discovery can take into account observations such as adaptation and serendipitous findings. Studying the larger process would suggest an inadvertent or intentional preparation towards the discovery, consistent with prepared mind perspective (Seifert et al. 2006). This movement between problem spaces and connecting with solutions to the respective problems can be described by movement of an agent in a complex knowledge landscape, making this aspect of discovery a researchable phenomenon amenable to modeling.

Agent	Initial problem space	Final problem space	Logic of transition	Discovery philosophy
Pendry	Radio absorbing metamaterials	Perfect lens and negative refraction	Curiosity as analytic continuation, recombination induced by collaboration.	*"there has to be something that you are very familiar, in which you are unusually skilled compared to other people. And there is also got to be something in which you are unfamiliar, and it is collision of these two streams, the technologies and ideas that you know already and the new area in which you find yourself in - that is a very creative environment."*
Friend	Polymer transistors	Polymer Light Emitting Diodes	Curiosity, recombination, surprise	*"a lot of research I would say is known known. But I would say that the sort of discovery space is where . people say nothing interesting would ever happen for all sorts of reasons, and you have to sort of suspend, you have to ignore that. You have to be guided by almost a sort of instinct that actually, we don't really know what's going on here. So, what's the best experiment that we could do to see what we could find out? What would tell us whether it's worth, worth the effort? Now, I don't know how we categorize that, but I would say that is the, the spirit. You can often be very successful."*
Tillmann	K-theory on conformal field theory	Mumford conjecture	Recombination, curiosity, lack of surprise	*"a synthesis of knowing one field and applying the techniques there to something rather different. And though I think there were people who know probably hadn't thought about it mainly because the main questions he probably was trying to answer demanded other techniques set up."*

... contd. in the next page

Agent	Initial problem space	Final problem space	Logic of transition	Discovery philosophy
			... contd. from previous page	
Hinds	Etch spherical mirror on chip	Magneto optical traps	Curiosity as analytic continuation, improvisation	*"not being afraid of imagining something, and just having a go. I think that's probably what the discovery experience is. I do think that being analytical is important. But I also think that there's an element of just having a gut feeling for this in an interesting area. if you knew it was there, somebody would have already done it. So you're on a path that you think is different. You're stuck and all the bits are there , worrying about what's happening So there has been a deductive process and it's left these bits of knowledge in your mind. And then suddenly they plug together and you think, oh blimey, why didn't, of course. That happens a lot. And the really good things that have come out of my lab, that's usually been the way it is."*
Yeatman	Micro-mechanical devices	Miniature power sources	Recombination induced by collaboration	*"...the discovery process has some, if you like, systematic steps and it has some steps that can not be systematised so easily. ...it helps to have a relatively diverse experience ... therefore a wider range of possible solutions are likely to occur to you. ... I think you do need a good well I think of it as a scientific instinct, which is to be able to quickly dispense with ideas that are unlikely to be helpful and to see, without a lot of rigorous analysis, the ones that are really worth pursuing otherwise you waste a lot of time working on things that ultimately are unsuccessful. .... the ability to distil a complex problem into its essence, I think is quite an important one, and I think some people don't do that. They get bogged down by detail."*

Table 2.2: Coding of discovery interviews with scientists and entrepreneurs

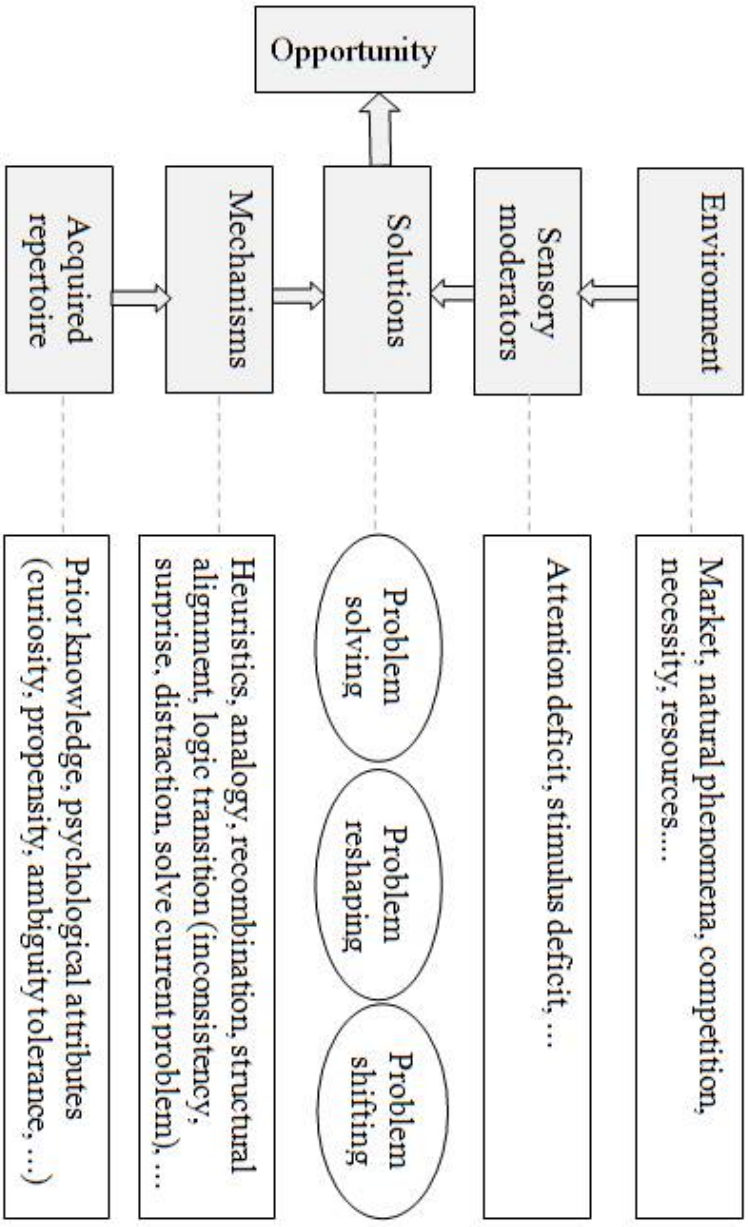


Figure 2.2: A layered framework to contextualize problem solving, reshaping and shifting in relation to other cognitive-psychological constructs

2.5 Modeling the Characteristics of Discovery

Among the modeling tools available, the complexity search techniques are particularly attractive and accessible. The NK complexity approach is well suited to study aggregate population level agent dynamics on a landscape due to its intuitive nature and simplicity. A good review of NK landscape design and properties are available in (Kauffman 1993, Levinthal 1997). However, when seen in light of the discovery process, the currently used NK model and its derivatives have the following limitations: First, the dimensions are accessed in an indiscriminate manner, i.e. all dimensions are accessible; while only constrained by starting locations and landscape ruggedness. This distorts not only the real constraints of the agent but also the notion of bounded rationality. Second, regular movements are constrained to best/better nearest neighbor nodes, which make starting locations have an absolutely defining role in determining outcomes, with no systematic possibility for redefining her position based on other information or new experience. Third, it is only suited to study problem solving dynamics, i.e. the landscape defines fitness of various combinations of dimensions (N) given their interactions (K) for a particular problem. The agent reviews the (locally accessible) combinations to solve only one pre-defined problem. Fourth, in the event of attaining local optima, the agent is confined to it, unable to proceed any further. This over-constrains the agent. Finally, movements in the landscape are not regulated by perception of the environment, but instead forced into monotonic convergence by gradient ascent technique. The agents are perfect local evaluators, i.e. they have perfect perception of the local objective landscape, while they are only myopia to other peaks. This limitation is not removed by NKC models (Kauffman 1993), as it captures co-evolution, which is not comparable to differential perception involved in recognition. Convergence is achieved via Nash equilibrium in the co-evolution and satisficing in discovery decision-making.

2.5.1 Alleviating Limitations of the NK Approach

We attempt to alleviate these limitations by refining this useful modeling technique and enable it explore aspects of discovery that currently are beyond its scope. The first limitation is due to the fact that although three modes can be identified in discovery processes, NK is only suitable to study the problem solving mode. Problem solving is also the domain where the concept of bounded rational-

ity has usually been applied to modeling. The traditional approach incessantly improves the fitness of the agent until encountering a local optimum. To build nuance into the model, we start by describing problem solving as comprising two broad actions: First, perceiving a gap between current knowledge and reality, i.e. inconsistency, and second, taking action to minimize it.

Perceived gap of an agent is the subjectively perceived gap between the mental knowledge representation and what the reality might represent. Commencing on the gap minimization process, in turn may result in awareness of other gaps related the current problem or other problems. The culmination of this gap minimization process can be interpreted as satisficing. We discuss the modeling of the perceived gap and satisficing later in this section, and firstly consider the "actual gap" to discuss the modeling of gap minimization. Actual gap is the objective gap between the current state and the optimum desired state. We discuss minimizing the gap as applied to the actual (objective) gap in order to build on the existing NK model, followed by discussing how a more realistic perceived gap may be incorporated into a model that can study discovery dynamics.

The adaptation of the agent in the NK model is a process of improving fitness or gap minimization, which is the case even though the optimal solution is unknown. This is due to the fact that any landscape is precisely predetermined by the problem definition. For example the illustrative landscape shown in Figure 2.3 (left) is designed by a specific equation or problem, which would be altered if a parameter in the problem is altered or the problem itself is changed. Therefore once the problem has been defined, the agent in the NK model can engage in problem solving by blindly following the gradient ascent technique to minimize his gap until local optima. The fitness of a point in the landscape can be interpreted as an inverse function of the logical distance between that point and the global optima. Let us refer to this logical distance as the actual gap Δ, which can be calculated by determining the Levenshtein distance (generalization of the hamming distance) between the objective representation and the agent's mental representation.

Since the actual gap is unknown, the problem solving agent in the NK model would stop where further improvement is not possible (local optima), which is not necessarily the same as satisficing. A satisficing agent could stop prior to convergence at a local optimum, or on the other hand could still be unsettled after reaching a local or global optimum. In the catalytic RNA discovery the Danish

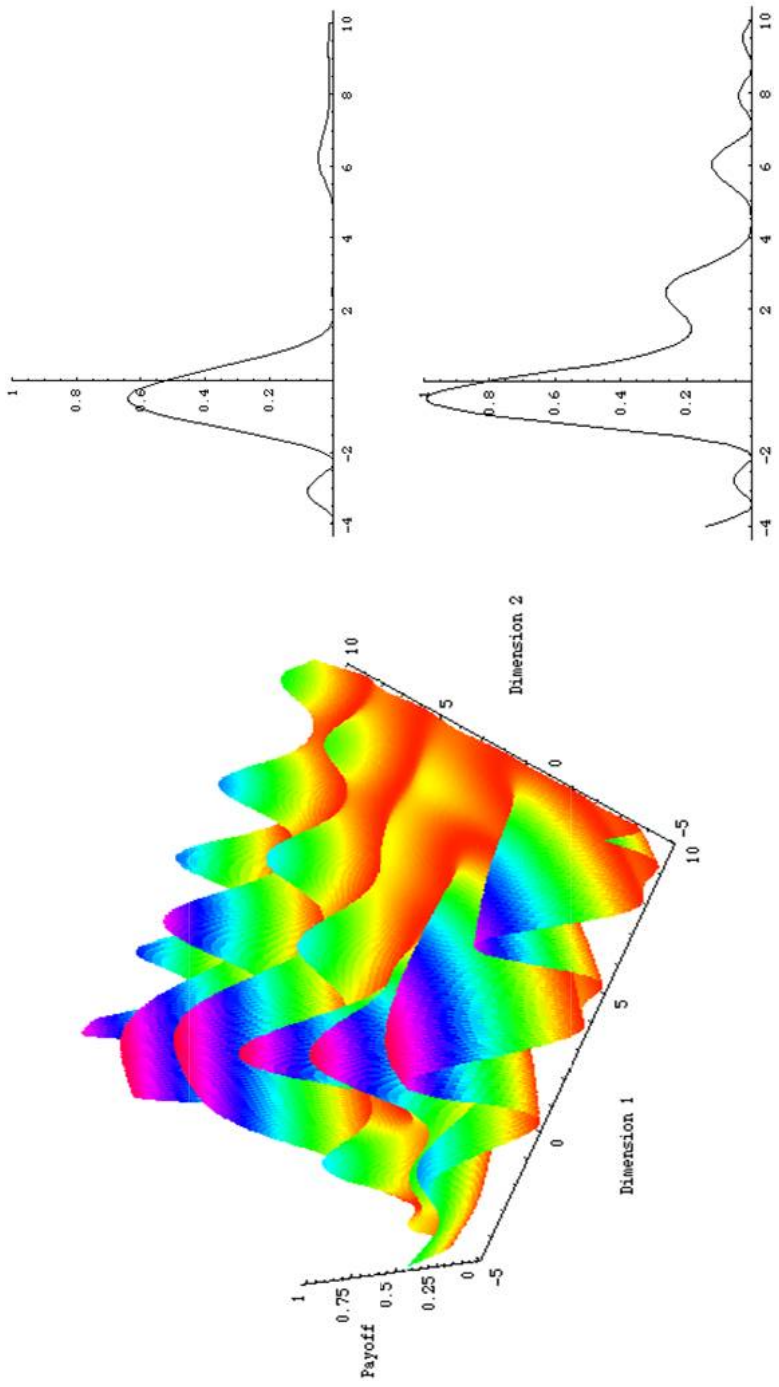


Figure 2.3: (Left) Illustrative landscape for intuition and (Right) Payoffs accessible to 1dimensional agent: treading x while y=5 and y=1

group's abandonment of the pursuit confirms the former and Cech's curiosity to go beyond the existing problem space confirms the latter. This suggests that satisficing may transcend given problem spaces.

Movement beyond local optima can be facilitated by: (1) accessing other combinations of dimensions in existing landscape, or (2) accessing new dimensions that do not exist in the current landscape. The first approach can be achieved in the model via the following methods: (a) Long jumps (shooting in the dark), which is a non-analytical process. Even if the jump size during every time step is varied dynamically, the local optima problem would still persist, with the added disadvantage that the landscape movement picture becomes less intuitive and less systematic. (b) Simulated annealing, which attempts to reduce defects (low lying local optima) in the landscape, which is difficult to establish as an effective metaphor in the discovery context. And (c) increasing risk aversion or reducing sensitivity of the agent, so that choices are based only large improvement, which is equivalent to applying a filter or flattening peaks in the landscape with lower than threshold gradients. While escaping low lying optima to a certain extent, it does not capture dynamic movement beyond local optima that is characteristic in discovery agents. There appears little methodological help available in achieving global optimum in rugged landscapes without unconstrained optimization of all possibilities. As the number of dimensions (N) increases, the possibilities to evaluate rise exponentially (2^N) making it prohibitive for global optimization suffer from the "curse of dimensionality" (Bellman 1957). The first approach therefore does not alleviate the second limitation. However discovery agents do overcome (routinely in many cases) the curse of dimensionality effectively, in contrast to what the traditional model suggest.

We thus suggest the second approach to move beyond local optima by accessing new dimensions from the local optimum (or any other point) in the current landscape, which could unfreeze the agent by leading him to new heights. Figure 2.3 (right) shows how an agent is able access different payoffs from the same points by accessing different dimensions in the illustrative landscape. Note that the landscape in this plot does not use the same binary dimensions that are usually used in the NK model; therefore should only be considered for illustrative purposes.

Here dimensions refer to knowledge elements being considered to address a problem. For example, consider our pursuit i.e. describing the discovery process;

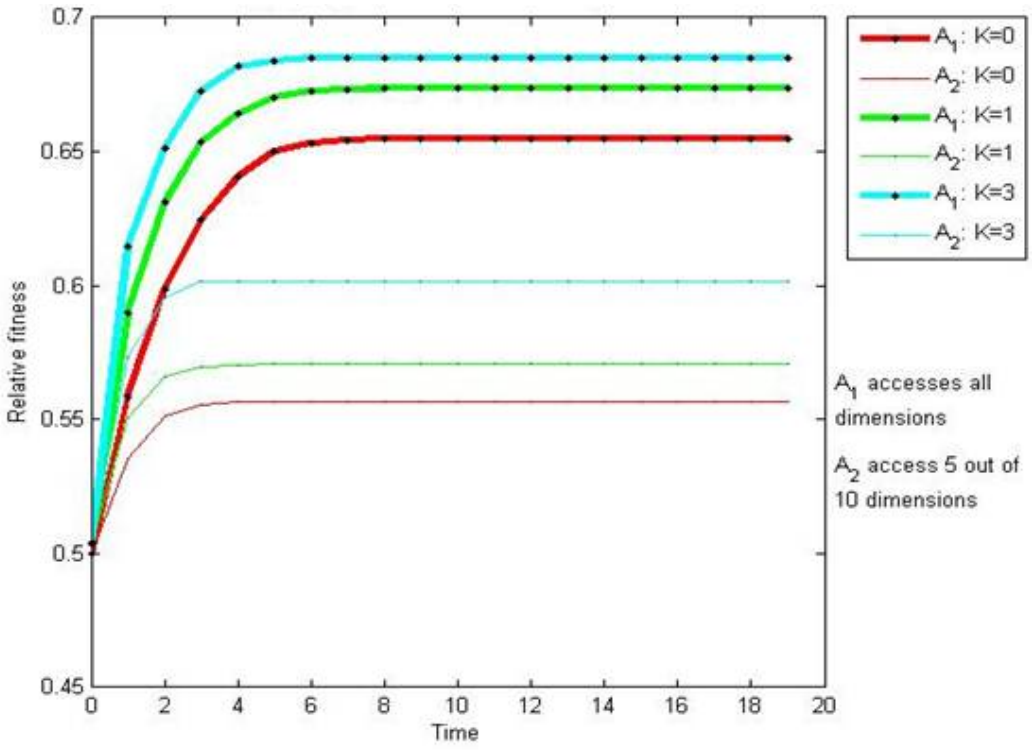


Figure 2.4: Performance of agents with access to different dimensions of the landscape

the knowledge elements that we access to address this research question could be search, analogy, heuristics and the like. The optimality of our solution, would rest on our depth of problem space, and consideration of sufficient knowledge elements that relate to discovery. While idiosyncratic cases of discovery may differ in the correlation of depth and optimality, a randomized average could provide general pattern of the phenomenon, as well provide insight into special cases that depart from the average.

Access to new dimensions can be simulated using the traditional NK model, by allowing two agents with different accessibility properties. We show in Figure 2.4 that agents accessing more dimensions have access to larger payoffs, due to availability larger variety of combinations, despite the same starting location. The simulation is run over 10,000 randomized landscapes, which exceeds the number required for convergence. Henceforth, wherever any non-zero complexity configuration (K) does not change the nature of the plot profile, only the plot for K=2 is given brevity. In the plot agent 1 (A1 thick line) is allowed to access all dimensions, while the agent 2 (A2 thin line) is only allowed to access 5 out the 10 dimensions describing the problem landscape. This improvement in fitness via accessing new dimensions can be understood through the illustration shown in Figure 2.3.

Since the landscape is the solution space of a single problem, and larger coverage relates to the depth of domain knowledge, this result can be interpreted as positive correlation between depth of knowledge and optimality of discovered solutions. Therefore we posit:

Proposition 2: The more knowledge dimensions that are accessed within a given problem space, the higher the optimality of the discovered solution.

This positive correlation between depth of domain knowledge and creativity is supported by the psychology literature (Rietzschel et al. 2007, Weisberg 1999). In practice this implies that given a problem and individuals with varying degrees of knowledge with respect to the problem, the agent who peruses a wider knowledge would produce on average more optimal solutions. This, however comes at the expense of more time (additional 2 units) required for convergence (as shown in Figure 2.3). This simple result is primarily aimed to provide the impetus to help build a more nuanced model of discovery in the next section.

This result has to be differentiated from the case where fresh perspectives can be obtained from novice agents vis-à-vis expert agents. Firstly, expert and novice agents may not necessarily engage in accessing the knowledge that is disposed to them. Secondly, the latter case refers to an inverted U relationship between depth and optimality applies to the case where knowledge spaces of irrelevant problem spaces are accessed to solve an intended problem. We test this scenario in the context curiosity and multiple problem spaces. Analogies and goal consistency requirements could guide the agent to maintain relevance.

2.5.2 Designing the Universal Landscape

To address the third limitation of going beyond problem-solving dynamics, a universal landscape is proposed that depicts semantic knowledge dimensions relating to all problem spaces. We consider operating on semantic space as opposed to information content space, which may complicate the discussion. The universal landscape comprises all problem-solution spaces, where multifaceted bounded rationality limits access to these knowledge dimensions. Current rationality of the agent can by expanded by accessing new dimensions or problem spaces. Poor evaluation is reflective of access to sub-optimal knowledge dimensions.

Access to semantic knowledge K (problem-solution connection corresponding to a discovery) is a necessary and sufficient condition for the respective discovery D. This can be written as a counterfactual tautological proposition:

$$K \Rightarrow D \Leftrightarrow \neg D \Rightarrow \neg K \tag{2.1}$$

In other words, two identical agents would recognize the same opportunity in the environment, given that they access the same dimensions. However, agents merely possessing or being able to access is insufficient for such recognition, rather they should "access" i.e. it should be characterized as their active knowledge at the instance of discovery. Agents merely possessing or having access to same knowledge may not "access" them due to psychological and circumstantial factors. Redundant causation (Lewis 2000) does not apply to this counterfactual, as it does not depict a chain of events such as the pathway to the discovery (where over-determination and pre-emption may apply), rather the above counterfactual relates to the semantic knowledge dimensions that define the discovery tightly and unambiguously. This technical definition is discovery will be adopted for the

model.

Access to a specific combination of semantic knowledge dimensions refers to the particular awareness of what this combination offers. In other words, movement in a semantic landscape produces mental representations of the meaning of events rather than isolated stimuli (which would be the case in information content access). For example, if simultaneous access or active knowledge dimensions related to prime factorization algorithms, its computational complexity, distributed passwords and security, then the agent is aware not only of these dimensions in isolation or merely its information content, but also that it is a certain problem space pertaining to cryptography. The vice versa need not be true. In other words solutions may lead to problems, and problems may lead to solutions.

Let us consider a universal semantic knowledge landscape that comprises solutions to all problems. It has to be noted that the universal landscape is unavailable as a whole to the agent, and access to dimensions and problem spaces is governed by bounded rationality owing from previous experience, contextual and psychological attributes. Problem spaces are defined as a space comprising dimensions that hold optimal and sub-optimal solutions to the problem. The problem spaces may overlap or be distinct and the dimensions that make up the problem spaces may have interaction with dimensions in any other problem space given by the interaction matrix (similar to the NK model). The universal landscape is a set of all problem landscapes, given by

$$U_P = P_1 \cup P_2 \cup P_3 ... P_M \tag{2.2}$$

where $P_1 ....P_M$ are the various problem spaces. The universal landscape is therefore a set of interlinked landscapes, where the fitness of the agent is given by:

$$F_A = \frac{1}{O_{P_j}.N_{P_j}}. \sum_{n=1}^{N_{P_j}} w_n \tag{2.3}$$

where N_{P_j} is the number of dimensions that the problem space P_j comprises, w_n is the fitness contribution of each dimension within the problem landscape and O_{P_j} is the global optima of the problem space P_j . Since different problem spaces have varying height of peaks and the agent may transition from one problem

space to another based on relative attractiveness, P_j can be used to normalize the fitness of each point in the respective problem space so that comparisons of attractiveness can be made. A point in the universal landscape may belong to one or many problem spaces, and its fitness would be defined according which problem space is under consideration by the agent.

Let us allow each dimension to take a value of 0 or 1, which denotes whether the (semantic knowledge) dimension is being accessed or not. Movement is only to one of the nearest neighbor (whose bit string varies by one mutation). Movement of the utility maximizing agents would only transpire if the promise of payoff is higher than current locations. In the problem solving mode this is straightforward, as the agent remains in the same problem space. Movement from one problem space to another can also follows a similar procedure. In case of overlapping problem spaces, a agent at a point belonging to both problem spaces may be said to be in the problem space where normalized fitness is higher. The motivation for entering different problem spaces which is equivalent to problem reshaping or shifting from current problem space occurs due to relatively more promising payoffs. Problem solving would ensue subsequent to problem reshaping or shifting.

We simulate the movement of a knowledge endowed agent on a portion of the universal landscape. In Figure 2.5, agent A_1 is endowed with access to prior knowledge dimensions related to problem space P_1, and is placed randomly in any part of the landscape - either in problem space P_1 or P_2. Problem solving behavior targeting solutions for P_1 at the exclusion of other problem spaces is observed. Figure 2.5 plots the average likelihood of the agents solving either of the problem spaces. At any moment in time, the plot shows average performance of agents in each of the problem spaces. The non-zero steady state existence in problem space P_2 is a result of random initial placements that happen to be a local optimum in P_2, which traps the agent despite possessing prior knowledge only in P_1. This is realistic, as certain situations are not conducive for application of agent's prior knowledge; hence no transition into P1 occurs.

In the conclusion of the last section, we described the limitation of proposition 1 in explaining the case where fresh perspectives may arise from exploring spaces beyond given problem space. The universal landscape provides the test bed to explore this possibility. Particularly, curiosity and serendipity have been strongly associated discovery and creativity. Curiosity is inquisitive behaviour or a drive

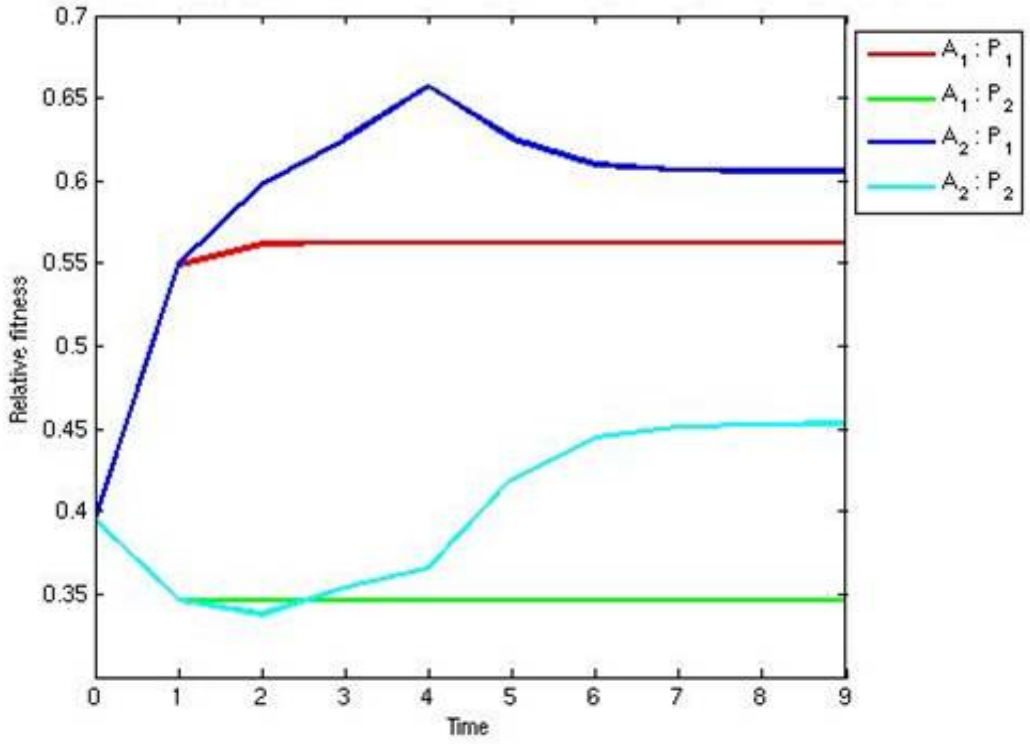


Figure 2.5: Effect of prior knowledge and curiosity (A2 is curious, K=2)

to know new things, and it is often linked to a desire to know things that do not directly concern one or the problem at hand. Serendipity is related to curiosity in the sense that it is propensity to make fortunate discoveries while looking for something unrelated.

To explore the curious and serendipitous behavior, we endow agent A_2 with access to the same prior knowledge dimensions as A_1, but allow A_2 to be curious. Curiosity allows the agents to access knowledge dimensions beyond current problem space resulting in problem reshaping or shifting followed by problem solving in another problem space. The simulation allows initiation of curious behavior once the agent is unable to further improve fitness in the current problem space. New dimensions within P_2 and some equally large irrelevant space are accessed randomly whenever fitness does not improve. As shown by lines $A_2 : P_2$ in Figure 2.5, although A2 begins problem solving in P_1, finds some degree of success in solving an unintended problem. This is despite commencing this process from local optima in the original problem space, which generally makes random transition to another problem space a less attractive proposition. In real scenarios, transition to other dimensions or problem spaces may not be random, suggesting

that the effect of curiosity on solving unintended problems shown in the plot is conservative. Hence, we propose that:

Proposition 3a: The likelihood of discovering a solution to an unintended problem increases with curiosity.

Interestingly the performance of the agent in the original problem space also increases under conditions of moderate curiosity. As shown by line $A_2 : P_1$ in Figure 2.4, the rise of fitness in P1 after 1 unit of time corresponds to a dip in fitness in P_2 (shown by line $A_2 : P_2$). The dip is due to the ability of A2 to find pathways by escaping local traps in P2 to back to better optima in P_1. This was contrary to initial expectation was that average performance improvement in one problem space would correspond to average performance decline in another problem space. In contrast we find that the curiosity sponsored dip after 1 unit of time, kick started problem solving in P_1 and also those among the population that we stuck on low lying traps in P_2. Thus performance in both problem spaces improves (between 2 to 4 time units). As curiosity continues to increase, the likelihood of existence in P_1 begins to decrease corresponding to increase in P_2 (between 4 to 6 time units). Hence, we propose that:

Proposition 3b: The likelihood of discovery of an optimal solution to an intended problem increases with moderate increase in curiosity.

This shows that curiosity has positive effects both in solving unintended as well intended problems. Generation of ideas or solutions to problems other than the one intended is common in the history of discovery in business and science. An attempt to explore this feature was the primary inspiration behind modifying the traditional NK framework. We have shown in Figure 2.4 (line $A_1 : P_1$ and line $A_1 : P_2$) that the dimensions that are accessible to the agent determine the type of problem that is readily solved. Although this is consistent with (Shane 2000), however we would like to add that the agents do engage in processing and that curiosity can alter the criteria of search to solve another related or unrelated problem. By enabling the model to change problem spaces, the rigidity of landscape models is thus alleviated.

In practice, this relates to positive contribution of moderate levels of ex-

ploratory activity, and suggests the detrimental consequences of excessive exploration. In other words, excessive exploration is not merely a matter of wasted time or opportunity costs, in addition the optimality of the eventual solution would also be diminished by unrelated. This touches on the classic dilemma between exploration and exploitation (March 1991), and supports the stream of literature addressing ways to achieve ambidexterity (Andriopoulos & Lewis 2009, He & Wong 2004).

2.5.3 Analogy and Recombination

Analogical reasoning quickly brings an agent to a particular location in the problem landscape. If the agent is aware of the solution to a certain problem, she would immediately converge to the known peak without unnecessary wandering in the landscape. Analogy is basic process (core of cognition) that links prior knowledge to current reality. Such analogies may produce what is termed as intuition. Analogy can also be a higher level process, which allows one to transfer solutions from one problem space to another or from one context to another, by taking advantage of structural similarities. Significant attention has been given to analogical processes in the literature on thinking and decision making (Gavetti et al. 2005, Hofstadter 2001).

A higher level process of recombination is often cited method of innovation (Fleming 2001, Henderson & Clark 1990, Nelson & Winter 1982, Schumpeter 1934). A problem space could be attacked using a combination of other problem spaces. Discovery in one sense, can always be broken down as a recombination of prior art. If known analogies existed in those recombining problem spaces, they can also be leveraged to access solutions in the new combined problem space. In the rare case, optima of the combined problem space may be obtained by the direct combination, but may usually require local search or further blending into the space. The latter is similar to conceptual blending (Fauconnier & Turner 2002), and can be said to represent a solution that is more than the sum of its parts (which is reminiscent of the gestalt effect). The combined solution of sub-problem spaces P_j can be expected to provide a better starting location in the combined problem space P_k . Generation of starting locations via combination can be given by:

$$L_t^{P_k} = D\left(\sum_{j=1}^{l} L_S^{P_j}\right) \tag{2.4}$$

where $L_S^{P_j}$ is the location of the solution in P_j , l is the number of problem spaces being combined and $D(X)$ is a digitizing function given by:

$$D(X) = \begin{cases} 0 & \text{if X} = 0 \\ 1 & \text{if X} \geq 1 \end{cases}$$

The new starting locations thus obtained can be shown to be consistent in the Cartesian coordinate system. The modeling literature has developed mainly to perform the basic routine of local search. Local search implies random starting locations followed by traversing landscape via gradient ascent. Both analogy and recombination hence perform the role of producing sophisticated starting locations for the basic search.

To study the effect of recombination vis-à-vis analogical search and local search or a combination of these mechanisms under different conditions, we simulate agents who are endowed with previous knowledge of multiple problem spaces. The agents are then launched in a larger problem space encompassing the previously known problem spaces. Since analogy of a sub-problem space may not constitute optima, it can be used to provide starting points from where traditional local search commences. Recombination can be done by leveraging analogies available from the sub-problem spaces followed by local search. Recombination can also be exclusive of analogy by simply recombining the problem spaces even if analogy of one problem space may provide closer initial match. Based on this, two cases can be tested, where case 1 is one of inclusive search: Best [Best(recombination, analogy) + local-search], [Best(analogy) + local-search] , [local-search] . Case 2 adopts exclusive search: Best [recombination + local-search] , [analogy + local-search] , [local-search] .

For the two cases, three agents endowed with each of these mechanisms are launched on the landscape. Prior knowledge for the agents comprises two problem spaces, which is a much reduced scenario compared to what actually happens in reality; however the model is scalable given computing resources. The simulation is run under varying conditions of complexity and degree of similarity of sub-

		Complexity of problem space	
		Low	High
Similarity with problem space	Low	∘ Analogy ⋆ Recombination ♢ Local search	∘ Analogy ⋆ Local search ♢ Local search
	High	∘ Recombination ⋆ Recombination ♢ Analogy	∘ Recombination ⋆ Recombination ♢ Analogy

Table 2.3: Comparative study of recombination, analogy and local search. ∘: Inclusive search; ⋆: Exclusive search; ♢: Best { [analogy + local-search] , [local-search]}

problem spaces with target problem space, which is summarized in Table 2.3. Contrary to intuition, it turns out that recombination may not be better than analogy and analogy may not better than local search under some conditions. Recombination is a higher level process than analogy, making it more effective generally. However the simulations shows that under conditions of low similarity, recombination distracts the agent to unfavorable starting locations. Therefore, we posit that:

Proposition 4a: For inclusive search, recombination is the mechanism of choice when similarity is high and analogy is preferable when similarity is low, irrespective of complexity.

This position supports (Gavetti et al. 2005) by confirming that analogy is a preferred mechanism over local search for strategizing in complex worlds. We build on it by showing that when similarity of recombining domains is high, recombination offers better results. This also provides some explanation to findings of (Wuchty et al. 2007) by relating that high similarity available from increasingly fine specialization makes teamwork (entailing recombination) superior to solo efforts of analogy and local search. In practice, this suggests that new or

nascent fields of work would benefit from co-worker contributions, much more than mature fields per se. However mature fields employ large teams, as they often become the subject of big science or exploitation oriented work, aimed as enhancing or accelerating output.

Recombination of solutions (coordinates) to arrive at a new coordinate is a form of sophisticated long jump, which has not been considered using the landscape metaphor so far. New methods of systematic movement in the landscape can help bring more intuition to innovation behavior. Exclusive search is a narrower version of inclusive search, where neither recombination nor analogy takes advantage of optimal starting location choices based on comparisons. In this case, the simulations show (refer Table 2.3) that under high complexity and low similarity, both recombination and analogy distracts the agent into unfavorable starting locations, making local search superior.

Proposition 4b: For exclusive search, recombination is preferred except under conditions of low similarity and high complexity.

Building on (Gavetti et al. 2005), our simulations find that when similarity of prior knowledge with target knowledge is low similarity local-search is preferable even with high complexity, putting a boundary condition on the superiority of analogy vis-à-vis local search.

Proposition 4c: For exclusive search, analogy is powerful when similarity is high, and local search is preferable when similarity is low.

The above comparative study of the three mechanisms suggests that high overlap between problem spaces is likely to enhance efficacy in the transferability of solutions. As a direct extension of the above study, we can simulate likelihood discovery when agents with different nature of knowledge endowments, i.e. if the knowledge they hold is highly integrated or fragmented. Integrated knowledge may be represented as knowledge spaces which have overlaps amongst them. In addition, the same model can be interpreted as representing the commonality of knowledge between different agents. of In these simulations, agents employ inclusive search. Overlap of recombining knowledge domains refer to structural commonalities in knowledge elements between the two domains. The blending

i.e. local search after recombination would be expected to be more effective, when the larger is overlap, as a large portion of the landscape gets optimized in the recombination process. It can be shown from Figure 2.6 that increasing overlap between knowledge domains recombined and the knowledge domain where a solution is sought increases the likelihood of discovery. Therefore, we posit that:

Proposition 5a: Greater the overlap (depth) of recombining knowledge domains with respect to the problem domain, the higher the performance (likelihood of discovering optimal solutions).

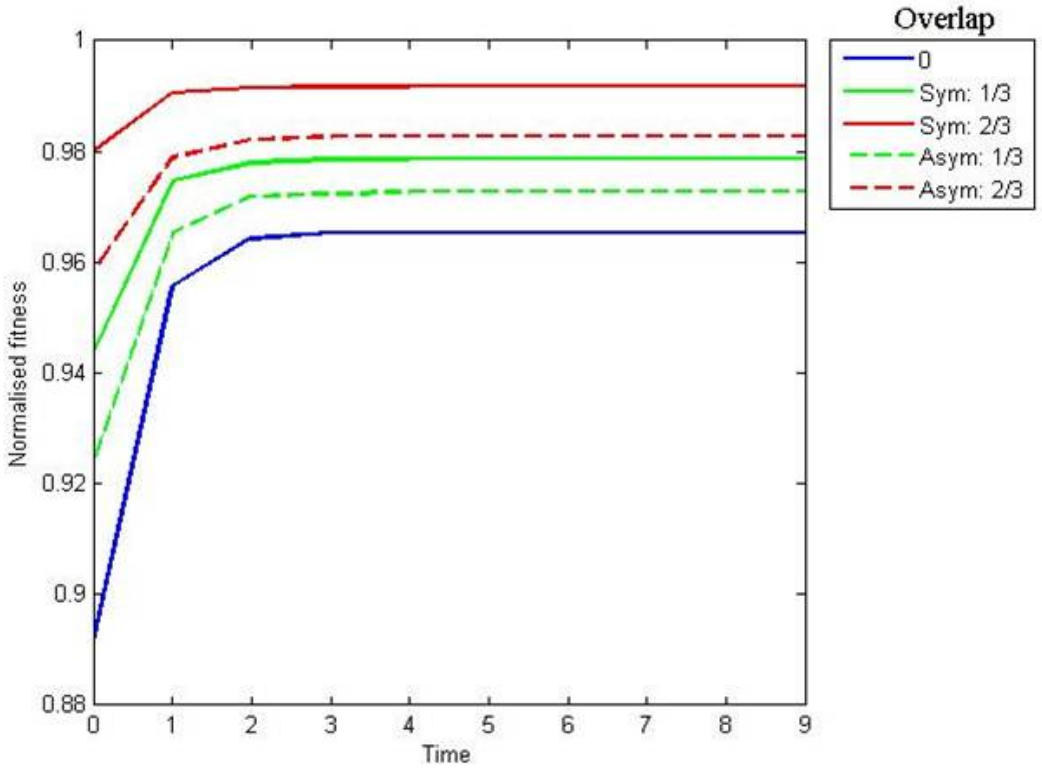


Figure 2.6: Recombining domain commonality and performance (plotted at k=2)

This is an extension of proposition 1 and proposition 4a, and the implication to practice applies equivalently. In addition, overlaps in knowledge spaces also enhance absorptive capacity (Cohen & Levinthal 1990, Zahra & George 2002) - ability to evaluate outside knowledge is largely related to the level of prior related knowledge. The existence of common ground between acquiring parties is also found to reduce coordination and integration costs (Puranam et al. 2009, Sorescu et al. 2007). This is supported by the results of simulations shown in Figure 2.6, where increasing the overlaps improves fitness. Therefore, we propose that:

Proposition 5b: Greater the commonality between recombining knowledge domains, higher the performance (likelihood of discovering optimal solutions).

The nature of the common ground amongst the combining knowledge domains or collaborating parties could also have performance implications. We study the symmetricity of the overlap by combining knowledge domains which have varying degrees of asymmetry in their commonality. Asymmetric overlap is where the common ground is an unequal contribution from the repertoire of each party. The asymmetry biases the determination of the starting location towards the larger domain, from where local is likely to be caught in a local optima prior to sufficiently exploring the other domain. As shown in Figure 2.6, it is found that the more symmetric the common ground between combining parties, the higher the performance. Therefore, we propose that:

Proposition 5c: Symmetric overlaps yield more optimal solutions than asymmetric overlap between knowledge domains that are recombined.

This implies that not only does the degree of commonality matter, but also the degree of non-common aspects of the recombination. This suggests that acquisition of smaller ventures by bigger firms, would need to be managed in such a way that the fruits of the acquisition are not swamped by detrimental asymmetry effects. Flawed integration plans are cited as one of the reasons for failure of acquisitions and mergers (Puranam et al. 2006, Rankine 2001). One way to manage this is to allow a particular division most relevant and symmetric in overlap of knowledge domains to interface with the new venture.

So far we have built upon the NK model by minimizing the actual gap, but such objective comparisons require non-local information. Minimizing the perceived gap depends on the availability of information and the attentiveness of the agent, which realistically utilizes locally accessible information alone. In order to proceed towards a model of discovery, this local and non-local information need to be bridged.

2.5.4 Bridging Local and Non-local Information

The generally accepted notion of how the problem solving mode is halted is when the agent satisfices on a solution or abandons the problem. We focus on satisficing

in particular, which is a decision making strategy that attempts to meet criteria of adequacy, rather than optimality (Simon 1957). Satisficing for a problem under investigation can be said to occur when perceived gap goes below thresholds determined by contextual and cognitive-psychological factors. The landscape may not look like the objective landscape available to the designer, rather the agent moves in a perceived landscape, engaging in minimization of the perceived gap. The question in relation to the aforementioned fifth limitation of the NK model is: How can the actual gap (non-local information) and the agent (local information) connect in a model? The issue lies in the comparison between local (available) and non-local (unavailable) information. Models that do not address this issue limit recognition to a process of programmed pattern matching. Such comparisons is ubiquitous in engineering and artificial intelligence systems such as in back propagation based algorithms; the latter has been criticized as being neurally implausible (Zipser 1986).

Curiosity to pursue a problem is prompted by the perceived gap in our understanding of a reality. "Explicit efforts at sensemaking tend to occur when the current state of the world is perceived to be different from the expected state of the world, or when there is no obvious way to engage with the world" (Weick et al. 2005). However curiosity toward the gap would be the same among individuals, who perceive the same gap. It has been found that. knowledge is positively related to the curiosity (Loewenstein 1994) or pursuit of lowering the gap. Our familiarity of the situation is certainly a factor influencing the perceived gap.

Given the same knowledge endowments, agents may still differentially perceive the environment if incomplete information reached them (stimulus) or they selected incomplete information (attention). Hence the agent could justifiably stop prior to local optima due to the agent perception even through the agent's knowledge warrants otherwise. This also suggests that although perceived gap decreases with increasing match between the agentsẗ mental representation and factual representation, it does not imply that a perfect match necessarily results in a zero perceived gap. Stimulus and attention may be affected by a raft of factors, which is beyond the scope of this paper. However, choosing stimulus and attention together with active knowledge provide the broad ingredients to model perceived gap and thereby discuss satisficing in the context of the model.

We have elaborated on the agent's active knowledge in the discussion on determining the actual gap in the previous section. Here we introduce sensory

aspects of the discovery process to address the fifth limitation of the NK model's suitably to study discovery. Sensation is the first stage in biochemical and neurological events - interaction of a stimulus on the receptor cells of a sensory organ, which precedes perception (which is a result of interpretation). Stimulus is a detectable change in the environment, when applied to a sensory receptor influences decision making or reflexes through a process stimulus transduction (Zigmond et al. 1999). Therefore the function of the sensory system is to provide the central nervous system with an updated representation of the world, which will then be interpreted by the cognitive system. Attention is *"taking possession of the mind, in clear and vivid form ... Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others"* (James 1952). Thus raw representation of the reality is influenced by both voluntary top down goal directed attention processes and reflexive bottom-up stimuli driven mechanisms. Moreover these two processes operate in dynamic competition, for example: goal directed processes might direct immediate attention to particular aspect of the environment, in turn providing stimuli accordingly; and on the other hand arbitrary stimuli can trigger and setup a subsequent goal directed process. These processes are consistent with studies of serendipity in the information seeking context (Foster & Ford 2003).

Attention deficit may arise due to a number of causes including bounded or selective attention, distraction from multiple goals - divided attention or alternating attention (Hirst 1986); and also from lack of time, energy and poor discipline. Stimulus may deficit arises due to a number of reasons including strong objective orientation, escalation of commitment, part of the environment where agent was launched, hidden or implicit nature of the object or phenomenon and insufficient time of exposure. Surprise is an important attention regulator. It brings certain stimuli that were hitherto taken relatively lightly into focused attention. The attention and stimulus deficits may vary in each phase of the process (or iteration in the simulation), depending on contextual and psychological attributes of the agent at the time, which could render discovery as a highly idiosyncratic phenomenon.

We can therefore approach the modeling of perceived gap as a function of the actual gap (related to prior knowledge) moderated by properties of the environment (bottom up stimulus) and the agent (top down attention). In the presence of perfect attention, stimulation and knowledge match, the perceived gap by the agent would be a direct function of the actual gap. On the other hand, attention

and stimulus deficit would mislead the perception of the actual gap, which in turn leads to inappropriate or suboptimal satisficing. Recalling the tautology adopted in the modeling, the above features of sensory system can result in differential access to knowledge and hence discoveries.

The above logic of the perceived gap may be described mathematically by several means. To aid familiarity, here we adapt the widely used formulation of resonance in engineering, which models damping of frequency matching between source and object. In the context of perception, more the resonance less the perceived gap and attention deficit dampens the magnitude of resonance, while stimulus deficit moderates the actual gap. The perceived gap can therefore be modeled as follows:

$$\delta(\Delta, \alpha, \beta) = 1 - \frac{\Gamma(\Delta, \alpha, \beta)}{\lim_{\Delta,\alpha,\beta \to 0} \Gamma(\Delta, \alpha, \beta)} \tag{2.5}$$

where δ is the perceived gap between the agentsẗ mental representation and the focused reality and Γ is the intensity (extent) of resonance or consonance between the agentsẗ mental representation and the focused reality, Δ is the actual gap between the mental representation of the agent and the focused reality, β is the attention deficit of the agent and α is the stimulus deficit of the focused reality. The perceived gap is normalized by dividing the resonance term by its maximum value which occurs when the actual gap, attention deficit and stimulus deficit tends to zero. Adapting the formula for intensity of resonance, the extent of resonance between the agentsẗ mental representation and focused reality can be expressed as:

$$\Gamma(\Delta, \alpha, \beta) = \frac{\beta}{(\Delta(1-\alpha))^2 + \beta^2} \tag{2.6}$$

All the variables α, β, Δ takes a value of between0 and 1. The plot of the perceived gap with respect to knowledge, attention and stimulus is shown in Figure 2.7.

The perceived gap influences judgment, which could be analyzed for errors. Statisticians and psychologists have broadly divided error-in-judgments into two types: type I errors or false positives, which can be viewed as excessive credulity or identifying a reality as something which it is not; and type II errors or false

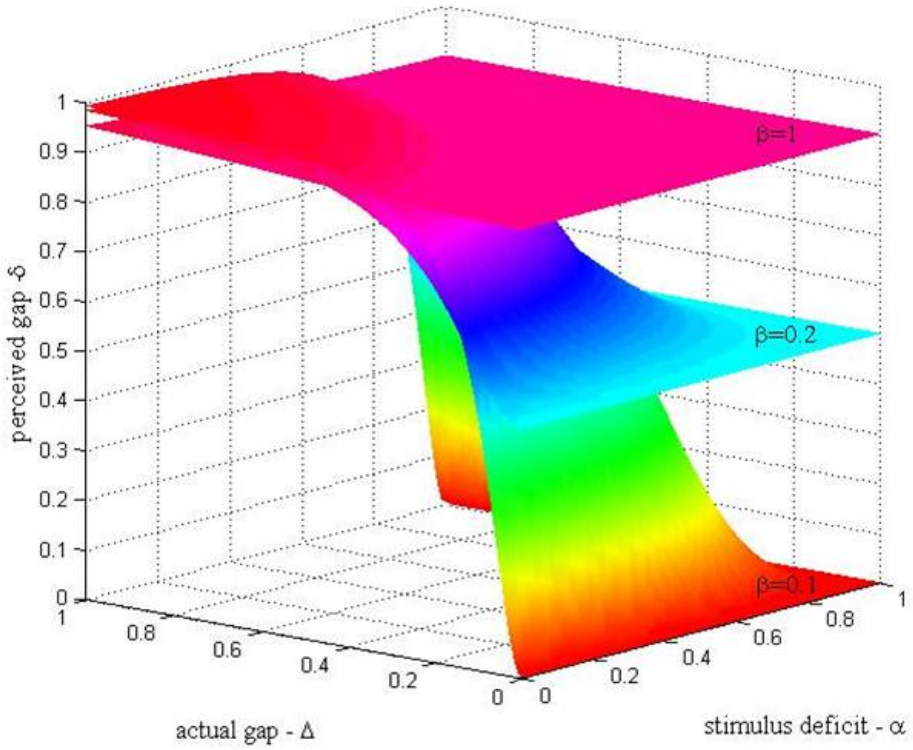


Figure 2.7: Perceived gap as a function of actual gap, stimulus α and attention deficit β

negatives, which can be viewed as excessive skepticism or rejecting something as the reality when it actually is (Green & Swets 1974). In the context of discovery, false positive is ascertained post-hoc when a good solution was rejected and false negative when a poor or non-solution was accepted. This is possible in the model due to information available to the designer which enables the calculation of the actual gap.

According to Equation 6 and 7, perceived gap decreases with decrease in the actual gap, increase in stimulus deficit and decrease attention deficit, which can be observed in Figure 2.7. Since lowering perceived gap results reduces uncertainty thereby increasing propensity to decide, it can be related to false positive; and since increasing perceived gap increases uncertainty reducing propensity to decide, it can be related to false negative. Therefore relationship of attention and stimulus deficit to perceived gap can be related to type I and II errors via the following propositions:

Proposition 6a: Ceteris paribus, satisficing has an increased tendency to result in a false positive with increase in stimulus deficit.

Proposition 6b: Ceteris paribus, satisficing has an increased tendency to result in false negative with increase in attention deficit.

As for satisficing thresholds (how low should the perceived gap be before halting process), they are determined by a number of factors such as curiosity, expectation of the context, preserving reputation, obsession/passion, rivalry, risk aversion and the like. For example, it has been shown that curiosity alleviates regret aversion (van Dijk & Zeelenberg 2007), suggestive of its effect on satisficing/abandoning tendencies. The model could also draw from the stream of literature that explores how context and resources influences the individual attention and risk preferences (March & Shapira 1987, 1992, Miller & Chen 2004). Thresholds have not been specifically explored in this paper, but could be studied within the framework of the model if a specific context and research question is available. However, irrespective of the underlying cognitive psychological setting, the agent's interface with the environment can be represented by attention and stimulus deficits. Therefore the choice of these sensory variables to moderate perception led satisficing can be justified.

2.6 Concluding Remarks

The paper attempts to articulate the discovery process, by focusing on the problem-solution nexus. We explored a number of propositions using the framework and model, starting with the discussion of the three modes of the discovery process viz. problem solving, problem reshaping, and problem shifting. This was followed by providing the necessary reformulation of the NK model to make it amenable to study discovery processes. The model was enabled to allow agents move beyond local optima via problem reshaping. We recognize this as a unique approach, and one that could suggest gaps between current machine computations and human thought processes. Simulations on the model showed that the more knowledge dimensions that are accessed 'within a given problem space', the higher the optimality of the discovered solution. Going beyond problem solving, the model was used to illustrate the effect of curiosity, which showed that the likelihood of discovering a solution to an unintended problem increases with increase in curiosity and enhanced likelihood for intended problem at moderate levels of curiosity.

Three mechanisms for determining launching points in the landscape were studied, including recombination, analogy and local search. Two types of search i.e. inclusive search and exclusive search were studied under varying conditions of complexity and similarity of source and object knowledge domains. A method to study recombination was provided and simulations found it to be the mechanism of choice over analogy in inclusive search when similarity is high. For exclusive search, recombination is preferred except under conditions of low similarity and high complexity, and that analogy is powerful compared to local-search only when similarity is high. The ability to study recombination dynamics allowed us to investigate the relationship of various overlaps of knowledge domains that can be related to cross-domain decision making and collaborations. It was found that greater the overlap of recombining knowledge domains with respect to the target problem domain increased the likelihood of discovering optimal solutions. The extent of commonality and symmetry of the recombining domains were also found to have positive relationship with discovery performance.

We attempted to bridge the local and non-local gap by incorporating perception via the effect of attention and stimulus. The discussion suggested that satisficing has an increased tendency to result in a false positive with increase in stimulus deficit; and an increased tendency to result in false negative with increase in attention deficit. Hence important characteristics of discovery were

identified and a model to study such processes has been provided.

Given the interpretive and contextually constructed characteristics of the discovery process model, it is well suited to provide micro-foundations for what is broadly described as sensemaking (Weick et al. 2005). Notions of entrepreneurial behavior such as causation/effectuation (Sarasvathy 2001) and improvisation or bricolage (Baker et al. 2003) rely on sensemaking foundations, therefore can be considered as concepts that bridge discovery with macro processes. These processes can be discussed from the framework point of view by referring to causation as goal directed and effectuation as stimulus directed processes.

The process of problem reshaping and shifting transitions can accommodate the notion solutions seeking problems of garbage can model (Cohen et al. 1972) or dynamics of push demand. The discomfort of the Austrian school with discovery via 'search' (where this notion of search has overtones of Meno's) could be addressed by redefining search in a way that respects agency, dynamism of the landscape and satisficing via bridging of local and non-local information. The model provides a more realistic setting to revisit innovation literature on exploitation and exploitation (March 1991). The centrality of discovery from this point of view makes the process a relevant micro-foundational area of interest for scholars in many areas of management.

Discovery process play an important role in the competitive market process (Kirzner 1997). Notably, an alternative notion of discovery is adopted to that in the search literature: *"What distinguishes discovery (relevant to hitherto unknown profit opportunities) from successful search (relevant to the deliberate production of information which one knew one had lacked) is that the former (unlike the latter) involves that surprise which accompanies the realization that one had overlooked something in fact readily available, ("It was under my very nose!") This feature of discovery characterizes the entrepreneurial process of the equilibrating market."*. Not to negate search based discoveries, this notion is differentiated *"The earmark of a genuine discovery"*, because it reveals something about which one was utterly ignorant (i.e. not even aware of one's ignorance), rather than merely ignorant. While it appears as a reactionary stance of pitting the deliberate search literature against non-deliberate discovery, a more nuanced - perhaps integrative view is also indicated: *"The notion of discovery, midway between that of the deliberately produced information in standard, search theory, and that of sheer windfall gain generated, by pure chance, is central to the Austrian approach."* (Kirzner 1989). We arguably expand on this

midway approach, where the role of deliberate and non-deliberate processes in discovery is explicated. While problem solving is predominantly a search process, problem reshaping and shifting are results of abductive reasoning and serendipitous encounters. The discovery of the self-catalytic properties of RNA, is a case of how 'what was right under their noses' and utter ignorance was revealed. This being said, the role of search is pre-eminent precursor to such discoveries. Alertness of the entrepreneur is developed and prepared before a chance encounter can be exploited, which is often termed the prepared mind perspective (Seifert et al. 2006). Search is as a fundamental cognitive (and neural process), some of which is automatic in human beings (perception), explicit (remembering and calculating) and implicit (perspective and heuristics) (French & Cleeremans 2002). Therefore, while we acknowledge the existing literature over-emphasises the role of search, it is impossible to discount it in discussions of discovery. One of our salient contribution of the model is enabling the possibility to engage in non-deliberative instances of search (utter ignorance), and move discussions beyond problem solving (mere ignorance).

The description and modeling of the discovery process in this paper is underpinned by same elements of the basic day to day thinking process. Although simple thinking and discovery thinking have not been differentiated as a process, their antecedents are clearly found to contribute to the relative value of the outcomes. The difference is well articulated in the following: "The scientific way of forming concepts differs from that which we use in our daily life, not basically, but merely in the more precise definition of concepts and conclusions; more painstaking and systematic choice of experimental material, and greater logical economy" (Einstein 1950). The emphasis of this paper is to provide a framework, which in part is achieved by alleviating the shortcomings of discussions about the discovery process in the literature.

Overcoming the limitations of the NK model and the attempt to broaden the notion of bounded rationality were part of the objectives of the model. In previous models there was no dynamic build up of mental representation via perceptions and experience, rather a static repertoire of inter-relationships appeared to be evoked. Analogical process and perception were usually separated, which meant that perceptual decisions could not be undone on the basis of observations from analogy mapping process. With the consolidation of psychology, social contexts, knowledge structuration and sensory perceptual aspects, this process feedback model suggests a promising way to think about the discovery process.

While opportunity has been discussed generically above, discovering scientific opportunities may differ from discovering entrepreneurial or business opportunities. There are several sources of differences, which arise from the nature of the opportunity, the arena and speed of decision-making, risk profile of the consequence, proclivity to time variance, constructivist and feedback mechanisms, stakeholder dependency, affective/personal involvement and higher complexity. However discovery of scientific and entrepreneurial opportunities share some foundational similarities, importantly the process connecting problems to solutions, comprising a combination of the three modes of discovery. This is due to the level of analysis, which is connected to the fundamental thinking process, rather than aggregated levels where subject matter attributes become pertinent. Therefore, although the detailed analysis that were presented pertained mainly to scientific examples, the framework focusing on connecting problems with solutions are applicable to discovery in the business domain generally. Further work could address how opportunity discovery is different scenarios such as in business and science, which has been attempted in the next chapter.

Discovery being a central aspect of decision making, this model contributes to a valuable research agenda. This model can be used to revisit the wide ranging previous work in discovery related literature. There are several limitations in this paper including the need for more finely refined mechanisms for prompting problem reshaping and problem shifting; more sophisticated approach to differentiate problem spaces and satisficing. Although an extended NK model was used as a platform for this model, other approaches may be chosen to include the essential characteristics of the discovery process. This paper hopes to contribute to a redirect the management literature to consider realistic discovery processes. The modeling effort and discussions have incorporated a larger than usual number of parameters to study discovery, which should not be considered as an invitation to unbridled holism, but rather is meant to illustrate the insufficiency of using too few invariants to discuss rationality as Simon warned in his Nobel Prize lecture (Simon 1978).

Part III

PEOPLE - *THE MESO*

Chapter 3

Domain Specificity of Opportunity Coherence:

Exploring the Science-Business Divide

Contents

3.1 Introduction 63

3.2 Domain differences 65

3.3 Quasi-experimental design and analysis 72

3.3.1 Discuss aloud verbal protocols 72

3.3.2 Repeated measures experiment 75

3.3.3 Evidence based update experiment 77

3.4 Discussion 92

3.5 Appendices 96

3.5.1 Administering the verbal protocols 96

3.5.2 List of pitches (video clips) shown for experiment 1 . . 97

3.5.3 Scenario related Questions 99

3.5.4 Background Questions 100

3.1 Introduction

Studies show significant challenges faced by scientists who foray into the business world (George & Bock 2008). Recent corporate experience in the pharmaceutical sector saw at least four scientist CEOs replaced by non-scientist candidates leaving only 5 of the 18 leading life science executives as scientists (Mintz 2009). Scientists also often fail to acknowledge or recognize that their motivation and beliefs and goals may be constraints on the growth of their start-up (Kirchhoff 1994). The generally observed differences between science, scientist and the business enterprize have formed the basis for prominent cultural stereotypes (Finson 2002, Tucker 1961). Are these generalizations valid, if so what are foundations on which scientists differ from business domain individuals?

Most high growth technology based start-ups generate greatest rewards for its investors rather than founders. With some notable exceptions, founders other than CEO rarely owned more than 4% of the company at the IPO stage (Nesheim 2000). This is not withstanding the fact that most entrepreneurial ventures fail (Shane 2008); previous studies note that three-quarters of the ventures do not survive beyond seven years (Evans & Leighton 1989). Further *"... results show that intellectual eminence, and the policies of making equity investments in TLO start-ups and maintaining a low inventors share of royalties increase new firm formation"* (Di Gregorio & Shane 2003). The dilemmas facing industrial research has long distinguished the scientific and business domains (Kaplan 1959, Shepard 1956). The ideation process and business acumen of science and business shows telltale signs of differences, which also may also be evidenced by the arduous transition experienced by those who venture across these domains. Different responses between R&D departments and the managers in organizations is also a common occurrence. What are the implications for cross-domain performance, how can the science-business discordance be mitigates and synergies exploited?

Decision making behaviour of individuals may be a function of their identity, training, capabilities and context. Inventions and commercialization belong to two different broad domains, that of science and business. Inventors whether scientists or not primarily seek solutions to technical problems, hence are trained and socialize in an environment suited to this vocation. On the other hand individuals in the business domain seeks financial profits via meeting individual, organizational, market and institutional demands. While hybrid roles are possible, few appear to be well placed in handling both domains successfully. It

is thus expected that their perspectives would differ and their interactions may not be smooth. Innovation entails a dynamic science-business interface that can translate upstream novelty into downstream rents.

The above issues also relate to the tension between exploitation versus exploration, which has been mostly discussed at the level of organizations (Andriopoulos & Lewis 2009, March 1991). The dilemma of exploration or exploitation is endemic and confronted in all domains and time scales. From day to day conundrums of what to do next to choosing long term future, the problem of exploration and exploitation is not unique to a domain. However certain domains have become characterized as explorative and others exploitative, in particular science is consider explorative and business exploitative. Are these categorizations valid, if so at what level are they valid and what are the implications at that level and other levels?

Creativity is at the heart of innovation and can occur in upstream (invention, design, application) and downstream (technology, product planning, marketing) aspects of the opportunity. Scientists may relate to creativity in the upstream arena while non-scientists may have a flair for creativity in the downstream arena. These may not be strictly the case, but their pre-disposition to the ends of the spectrum might make creativity naturally amenable in the respective. Differences are also observed in the mode of manifesting critical information, i.e. the academic orientation towards openness and sharing compared to secrecy and propriety in the business world. Organization work culture in academia has traditionally been more laissez faire compared to more tightly scheduled business demands.

Despite the trend and attention to technology commercialization, scholarly focus on the interaction of scientists with the business domain has been limited. Previous work on the interaction of scientists with commercialization include probing the salience of academic role identity (Jain et al. 2009), mismatch of objectives between academia and business (Pisano 2006), cultural chasm and different frames of reference (Dubinskas 1985, 1988), conflict between science and business values as cause of failure and single minded focus on financial outcomes being correlated with success of ventures by scientists (Gurdon & Samsom 2009), relatively low relationship between reducing uncertainty and willingness to change beliefs or less asymmetry in responsiveness to new information (Jenkins-Smith & Bassett Jr 2006), failure of ventures under stewardship of founding university

scientists due to clash of business and scientific cultures, losses due tensions in the scientist's relationship with the university, and the little or no reconciliation of the new role of the scientists (Samsom & Gurdon 1993), relationship of orientation and values of science and business faculties to entrepreneurial activity (Bird et al. 1993). There is a small stream of literature that explore the differences between entrepreneurs and managers such (Busenitz & Barney 1997, Sarasvathy et al. 1998). General studies comparing science based individuals with the general population has produced ambiguous results (Mahoney 1979). What methods can be used to clearly extract the differences between the science and business domain individuals?

Specialization in education, intense competition and division of labour have further exacerbated the divide. Novelty in ideas as seen in science and business are often influenced by their domain specific perspectives on realizability. Scientists may push for technically sound ideas that may not be easy to sell in the market, while businessmen may push for a sound market idea that may be technically weak or unfeasible. Without appropriate balance scientists embracing the business arena and businessman embracing products/services underpinned by science may face avoidable disappointments. This recognition led a number of institutions to incorporate business studies as a required component in tertiary education. However understanding the nature and role of these complementary exposures in preparing individuals to face real world situations remain hazy. Can the differences between science and business domain individuals be accounted for by domain knowledge or are their more fundamental attributes such as problem solving approach that are influenced by their social and occupational setting?

Given the science and business domains endow agents with different prior knowledge, then different prior knowledge relates to different opportunities (Shane 2000). The relationship between structural features of the reality and prior knowledge (Gregoire et al. 2010) may be moderated by a number of other group characteristics, which is focus of this research.

3.2 Domain differences

This section explores the determinants of decision making that may be different between the groups. Science based individuals do not come in the same flavor, some are more specialized, some have more of a taste for science and some have

particular experiences and others face unique circumstances. These differences impact their interaction with business goals. Higher levels of specialization and education is positively relates to autonomy exercised in organizations (Debackere et al. 1996). Observations of scientists and engineers in large organizations have shown differences in goals (Ritti 1968), where the motivation of scientists and engineers may be a results of a complex set of internal and external forces (French, 1966). There is also heterogeneity in the scientist's taste for science which results in self selection into careers and perspectives (Roach & Sauermann 2010). This surely renders generalization difficult - or perhaps they do not need to be generalized necessarily. The goal here is to tease out such generalities as they may exist, in order to mitigate discordance and exploit the synergies. One of the prominent notions of the two domains in the context of business relate to the tension between exploitation versus exploration, which has been mostly discussed at the level of organizations (Andriopoulos & Lewis 2009, March 1991). The dilemma of exploration or exploitation is endemic and confronted in all domains and time scales. From day to day conundrums of what to do next to choosing long term future, the problem of exploration and exploitation is not unique to a domain. However certain domains have become widely characterized as explorative and others exploitative, in particular science is considered explorative and business exploitative. Scientists are trained in heuristics of exploration, which is the breeding ground for novel insights. On the other hand business objectives emphasize downstream factors related to exploitation. These categorizations could have implications on opportunity recognition at different levels, both in perception and enactment. Science or research domain individuals achieve their goals via exploratory activities and these tendencies might constrain exploitative commitments that business objectives entail.

Hypothesis 1: The intellectual aspirations of scientists constrain their willingness to engage with business opportunities.

Opportunities that align with the goals and strengths of the scientist are expected to be more favored than that which does not add domain value (Dubinskas 1985, Pisano 2006). Hence businesses that facilitate platforms for new ideas positively influence participation of scientists.

Hypothesis 2: Scientists are more excited by business possibilities which serve as a platform for new ideas.

Given that science and business domains endow agents with different prior

knowledge, then different prior knowledge could relate to different opportunities (Shane 2000). Training methods are also significantly different in the two domains. For example, perusing a science or engineering book would show a third to a half of the contents is symbolic or graphical. There are high levels of consensus in science, and building on such consensus repeatedly has resulted in a large body of knowledge that requires significant amounts of training to become proficient. On the other hand, perusing books on business and management or social sciences shows less than a tenth of non-text space. Despite underlying structure, consensus is not high and changing environment and experience allow one to become proficient through means others than long term training. It is common to note individuals with attributes suited to the business environment make the best out of their opportunities. Learning curves and capability development in science and business could hence be different. Therefore while science based individuals may have special skills compared with their peers in understanding symbolic representations of systems, they may not have similar skills in navigating or comprehending complex economic and social relationships. To push the point further, it can be said that an individual's claim to scientific environment or community is largely dependent on his training and proficiency. An individual's claim to the business environment does not necessarily relate to training, rather it would relate to the individual's traits, resources, aptitude and comfort in business management (Baum & Locke 2004, Black & Boal 1994, Cassar 2007). This is not to say that science based individuals would be ill-suited to the business arena. The entrepreneurial agent leverages market disequilibrium via 'alertness' to opportunities (Kirzner 1997). Given the unique knowledge distribution among scientists, they are potentially alert to opportunities, which may be oblivious to non-scientists. Hence these strikingly different groups are bound to differ in their decision making and opportunity recognition process.

Hypothesis 3: Scientists are more likely to evaluate the potential of the venture in terms of its technology compared to business domain individuals.

The relationship between structural features of the opportunity and prior knowledge (Gregoire et al. 2010) may be moderated by a number of other group characteristics. Risk and ambiguity perception may crucially influence decision to commit courses of action towards an opportunity. Risk perception relates to the extent to which the outcome of a venture is unknown or uncertain. Several academics have chosen not to give up their academic position even with ventures commercializing their own inventions (George & Bock 2008). Scientists

have claimed difficulty in accepting the risk orientation and sweeping vision of a commercial opportunity, often an essentiality for a successful venture.

Hypothesis 4: Scientists are more risk averse than business domain individuals.

Only scientists with 'single minded' aspiration to make money were found to display less risk aversion (Gurdon & Samsom 2009). Financial aspiration can replace or alleviate the constraints posed by intellectual aspirations (see Hypothesis 1).

Hypothesis 5: The financial aspirations of scientists enhance their willingness to engage in business opportunities.

One of the factors which may be related to risk perception is ambiguity in the opportunity. Unlike uncertainty in outcomes, ambiguity perception relates to the unclear meaning of the opportunity or multiple meanings suggested by the opportunity. Formal languages such as logic, informatics and mathematics avoid ambiguity, however ambiguity is often the target of resolution in science (Stepansky 1988). Therefore we expect scientists to examine and resolve the ambiguity more than business domain individuals who risk aversion is expected to be relatively lower than scientists in the first place. Beyond ambiguity per se, the resultant attention, challenge and resolution may have a positive effect on engagement with the business opportunity

Hypothesis 6: Scientists tolerate more ambiguity than business domain individuals.

Given familiarity with their respective domain knowledge, science and business domain individuals engage in different kinds of reasoning when presented with a business situation. Instead of adopting the usual distinction of analytic and heuristic or intuitive reasoning (Hammond 1996), a more distinguishable set of definitions need to be used to analyze the groups. This is because training and experience may build analytic processes into intuitive effects. Following discussions in French & Cleeremans (2002), the dynamic graded continuum can be adopted, which distinguishes reasoning into implicit, automatic and explicit. Implicit reasoning involves making a set of abstractions or inferences without concomitant awareness of them. The abstractions or inferences occur unintentionally, are not susceptible to conscious control, and are therefore not directly accessible to manipulation but are still capable of influencing explicit processes.

Explicit reasoning has awareness of the abstractions or inferences that are made, which can be expressed as declarative knowledge. The abstractions or inferences are available to conscious control, and this allows them to be modified directly because they are accessible. There is conscious control of the representations because one has meta-knowledge of them and of their relevance at the time of processing. They have a high rate of activation and can be reliably recalled from memory because they are stable enough to become registered in working memory. Automatic reasoning is skill based and deliberately acquired through frequent and consistent activation of relevant information that becomes highly familiarized. This type of reasoning enables abstractions or inferences to be made without any control because the representations are enduring, well defined, and stable through repeated use. The individuals possess meta-knowledge of these representations' influence and relevance to a task (Anderson 1993), but not the opportunity to control them. For instance, when interpreting the meaning of a sentence, skilled readers process the individual words automatically (Jacoby et al. 1992). The processing is entirely relevant to the task and necessarily entails the recognition of their words and their meaning, but this is not invoked deliberately. When readers' recall and evaluation of the sentences was examined, they expressed accurate meta-knowledge of the words they had processed automatically (Osman 2004).

Hypothesis 7: Scientists engage in more explicit thinking about business opportunities compared to business domain individuals.

Hypothesis 7a: Business domain individuals engage in more automatic thinking about business opportunities compared to scientists.

The differences in reasoning can also be explored via the manner of means-end analysis that is performed by the two groups. Means-end analysis is a "particular heuristic system that finds differences between current and desired situations, finds an operator relevant to each difference, and applies the operator to reduce the difference" (Newell & Simon 1972). The means-end theory is widely used in the marketing literature for understanding goal oriented customer decision making (Gutman 1982, Zeithaml 1988). In the context of marketing, means-end theory distinguishes between three levels of abstraction, namely product attributes, consequences of product consumption and personal values. If connected in the above order represent a means-end chain that is people choose products with attributes that produce desired consequences, and the desirability is determined by

personal values. This can be adapted to the context of entrepreneurship, where personal values relate to traits and background; desired consequences relate to aspirations; and consumption to investment related decisions. The emphasis of the means-end model focuses on why and how product attributes are important, compared to multi-attribute approach which determines if and to what extent they are important (Gutman 1997). Given that scientists are expected to engage in explicit thinking, resolving ambiguity and trained to systematically analyze information, they would engage is more elaborate means-end analysis.

Hypothesis 8: Scientists engage in more elaborate means-end analysis compared to business domain individuals.

Information regarding business opportunities may become available at different times, allowing a re-evaluation of the prospect of the venture. It has been found in the context of nuclear waste and its environmental impact, changes in information uncertainty induced slight change in beliefs amongst scientists compared to business domain individuals. Due to lack of familiarity to the business domain, scientists possess less discriminating cues a priori, necessitating larger investment in information evaluation. Scientists also reconcile extra-domain previous knowledge with the new opportunity, hence performing more complex structuring of available information. Therefore following the discussion on the manner of reasoning and training, it can be said that scientists may exhibit more persistence owing to elaborate and longer effort made en route to prior decision making.

Hypothesis 9: Scientists are more persistent in their views compared business domain individuals.

Decision making research utilizes a number of constructs which can be assembled and tested for the two groups, including ambiguity tolerance: (MacDonald 1970, Norton 1975), planning horizon: (Barringer & Bluedorn 1999, Berry 1998), problem solving approach (Buttner & Gryskiewicz 1993). Due to biases introduced by the scenario from which responses are captured (Aiman-Smith et al. 2002), a quasi-experimental policy capture methodology could be employed where responses are solicited with respect to a number of scenarios. The variables that are of interest from the literature are listed in Table 1. And the following hypotheses are to be tested in relation to these variables:

Construct	code	Description
Investment decision	id	Willingness to invest in the venture.
Planning horizon	ph	The amount of time an individual/organization will look into the future when preparing a strategic plan
Ambiguity perception	at	perceiving ambiguity in information presented
Risk perception	rp	Degree to which risk or loss is perceived
Aspiration (Intellectual)	intl	Desire for achievement relates to intellectual contribution or satisfaction
Aspiration (Financial)	fin	Desire for achievement relates to financial goals
Attention span	att	Amount of time that a person can concentrate on a task without becoming distracted
Exploration (platform for new ideas)	pni	Mode of thinking through new search
Exploitation (end in itself)	eii	Mode of thinking through using what exists
Non-implicit thinking (recall & articulate)	rcl	Necessarily accompanied by awareness - relates to automatic or explicit thinking.
Explicit thinking (explore & analyze)	ea	Understanding a complex situation through slower deliberate and elaborate thinking
Upstream thinking (technology)	tech	Locus of analysis/thinking lies in the technology.
Downstream thinking (returns)	rtns	Locus of analysis/thinking lies in financial gains.
Familiarity	fam	Familiarity with the given information from previous experience or exposure
Confidence level	conf	Degree of confidence behind the respondent's decision to invest

Table 3.1: Independent variables (responses to the pitch) and their description

3.3 Quasi-experimental design and analysis

3.3.1 Discuss aloud verbal protocols

The second approach to explore the determinants of decision making among the two groups is to make careful observations of their discussions regarding business opportunities. In order to do this, real life scenarios are ideally needed - the second best would be a captured scenario where an opportunity is presented and is edited to make it devoid of responses and extrinsic biases. Based on these scenarios verbal protocols are administered to obtain recorded discussions from teams of science and business domain individuals. The teams from top tier UK universities were selected such they belong to the same national demography, age and are not trained in other than there current domain. Two scenarios were presented to a team of science (PhD) and business (MBA) postgraduate students, who are asked to think and discuss aloud amongst themselves until arriving a final decision. The recorded content is then analysed for the manner of information processing by the sample, followed by another set of observations to confirm the findings. This approach is supported by traditional verbal protocol analysis(Ericsson & Simon 1993). The details of the scenarios are discussed below as well as in the appendices at the end of this chapter. Table 3.2 presents findings from recordings of the discussions. Coding was also done for variables in Table 3.1, but did not reveal systematic differences. The noteworthy differences are in the time taken by the two groups in arriving at a decision, and the areas where they focused.

It is clear from the coding in Table 3.1 that the time taken by the business individuals are at least a third less than their science counterparts. Further the science teams attended in a relatively balanced manner to the various aspects of the business. The numbers highlighted in blue occur more times among the science teams, while business teams show high focus on one or two aspects of the business (numbers highlighted in red) while proceeding quickly over the other aspects. This finding is consistent across the two scenarios. This breaking up of discussions into various aspects with different allocation of times reveals couple of potential insights. Firstly they partly explain the consistently longer time to arrive at the decision by the scientists. Secondly, it indicates different approaches to analyzing the opportunity, even though their final decisions are similar.

Given that the situation was broken down into different components and

Parameter	Pitch 1				Pitch 2			
	Science 1	Business 1	Science 2	Business 2	Science 1	Business 1	Science 2	Business 2
Time to finish (minutes)	7:21	5:09	16:16	8.73	5:16	3:47	10:25	6:12
Final Investment decision	0/3	0/3	0/3 (undecided)	0/3 (undecided)	3/3	3/3	3/3	3/3
Initial views	Positive	Negative	Unsure	Not to invest	Yes	Positive	Not declared	Yes
time spent discussing technology	32.76%	12.52%	28.53%	46.15%	13.91%	0%	16.86%	4.83%
time spent discussing market	34.99%	58.21%	21.53%	35.38%	29.40%	6.35%	35.10%	3.38%
time spent discussing finance	20.41%	9.79%	29.99%	17.58%	32.27%	17.85%	21.79%	30.91%
time spent discussing organisation/business model	4.29%	10.10%	12.76%	0%	9.51%	69.74%	15.86%	43.48%
time spent discussing decisions	7.72%	8.63%	9.95%	2.47%	20.23%	11.19%	11.61%	15.46%

Table 3.2: Coding of discussions of four teams (two from each domain), each team comprising 3 each of science and business domain individuals. Other dimensions have not been presented due to lack of systematic variance. Values above 20% (equal weighting) are highlighted in blue and above 40% (double weighting) in red.

evaluated against the decision making goal set up in the verbal protocol, the means-end analysis is very much in application. The times spent on technology, market, finances, business mode and personal interactions shows that scientists are decomposing the potential of the pitch in a more modular fashion giving reasonably balanced inquiry to each. Business domain individuals on the other hand focus on particular areas, appearing to be a cause of concern and seemingly making up their mind before delving into further decomposition.

The means-end analysis can be used to inform the findings of the verbal protocols, where the traits and background play a role in dividing attention to various aspects of the venture. The opportunity is analyzed by the scientists as if they compelled to size up the potential with respect from various angles, in contrast to the business sample, which clearly focused on a few issues en route making the end decision. This indicates that the scientists are trying to reduce more differences between current and desired situations, compared to the business individuals. The benefits of modular thinking are clear for relatively less parameterized systems that common in science and engineering, however high modularity in complex scenarios (as in the business world) can lead to cycling behaviour and lack of performance (Ethiraj & Levinthal 2004). This is indeed observed in the verbal protocols where the science team revisits a point made earlier, and do not differ in their final decision compared to the business team.

Another interpretation to the relatively protracted discussion among the science team related to their manner of updating beliefs during the discussion. If updating of the beliefs require more cues, decisions would exhibit persistence, prolonging the decision time and increasing the aspects of the situation under review. The discuss-aloud setting urges attempts at updating beliefs by hearing points raised by each member of the team before final decision making to transpires. Despite seemingly streamlined thinking by the business team it is unclear whether it relates to lower persistence. This is because all issues may not have been articulated, and some matters could be assumed owing to domain knowledge. Understanding this requires a larger scale of detailed experimental data, firstly address the question - what factors systematically contribute to investment decision making and whether they are the same between the groups. Secondly, how do the groups update their views when given new information.

3.3.2 Repeated measures experiment

To determine what factors contribute systematically to decision making, a repeated measures quasi-experiment is designed. Each individual is presented sequentially with 15 scenarios, each followed by questions related to the determinants of decision making shown in Table 3.1 in addition to questions related to background variables such as age, gender, nationality, education level, discipline, exposure to business, work experience, career preference and job attribute preference (see appendix at the end of this chapter). The larger number would help validate the measures per sample. The information gathered from experiment conducted in a controlled setting is a panel data, with 20 individuals each with 15 data points per variable. The independent variables show low correlations amongst them (see Table 3.5). A panel regression is run on the following model:

$$y_i = \alpha_i + \beta_x.x_i + \nu_j.z_i + u_i \tag{3.1}$$

The terms used in this equations and others in this chapter is explained in Table 3.3. The fixed effects model and the random effects model were used to run a panel regression with the individuals as the panel variable. The Hausman test rejected the null hypothesis that the difference in coefficients are not systematic between the two models at the 5% level, which indicates correlation of the error term with the independent variables. The results of the fixed effects panel regression with only the scenario response variables (x_i). An alternative approach of using error term u_i to predict the scenario relevant error term which is then regressed on individual explanatory variables (z_i), has not been adopted in our case for two reasons. Firstly, the restricted fixed effect model (with only scenario response variables) produces a bias in the coefficients and the error term. Using this error term to perform a biased prediction of an error component will introduce further bias. This predicted error component if regressed on variables which were not included in the previous regression would produce further bias. Secondly, the scenario related variables (x_i) and individual explanatory variables (z_i) would need to be orthogonal to perform this two stage procedure, a difficult assumption in our case.

The results of the analysis is presented in Table 3.4. The combined data with science and business individuals (column 2 and 3) show that investment decision is positive significantly related to familiarity, financial aspiration and financial

Variable	Description
y	Dependent variable
x	Independent variable at individual-pitch level (see Table 3.1 and Section 3.5.3)
z	Independent variables at the individual level see Section 3.5.4
i	Individual (used as subscript)
j	Pitch (used as subscript)
k	Group (used as superscript)
t	Time (used as subscript)
$t-1$	lagged time / at prior time interval (used as subscript)
D	Dummy variable
S	Science domain (used as superscript in place of k)
B	Business domain (used as superscript in place of k)
β	Coefficient for independent variable
ρ	Coefficient for lagged time variable
γ	Coefficient of the unconditional intercept (after removing lagged effect)
λ	Coefficient for latent trajectory variable
α	Intercept
u	Residual error

Table 3.3: Variables in used in statistical model and their description

analysis; and negatively significantly related to ambiguity and risk perception. This is at the level of the entire sample population. The average of the all the responses from the science and business samples is presented in Table 3.9. While it is hard to read into this, it is easy to notice some variables that show an order of magnitude difference. The scientists have scored significantly higher on intellectual aspiration (intl), exploration - platform for new ideas (pni) and analysis of technology (tech).

To obtain the factors that contributed to investment decision making by each group, the science (column 4) and business (column 5) sub samples regressed separately. Familiarity, financial aspiration, exploration-platform for new ideas and financial analysis relate positively significantly and intellectual aspiration, risk perception relate negative significantly to investment decision. On the other hand business group show positive significant relationship of financial goals (stronger effect than science group) and financial analysis; and negative significant relationship of ambiguity perception on investment decision.

This means that scientists decline to invest when they aspire for intellectual goals and see higher risk. While business individuals decline to invest when they perceive ambiguity in the information. In addition when scientists are able to contemplate exploratory new ideas and are familiar with what is presented, they are more inclined to invest. Both science and business groups are more inclined to invest if they have financial aspirations and analyze venture in terms of returns

The constructs used in the study can be analyzed by looking for dependencies of the variables from the responses. The individual is more likely to have intellectual goals if the individual engages in explicit thinking, longer planning horizons, exploration-platform for new ideas, high attention to detail, higher focus on analysis of technology and belonged to a younger age group. The individual is more likely to have financial goals if the individual engages in exploitation-end in itself, perceives high risk, high focus on returns, belong to older age group and has good exposure to business. This is consistent with observations in the literature (first two sections).

3.3.3 Evidence based update experiment

Regarding the updating of beliefs in the presence of new information, there are two questions that need to be addressed: Firstly, how do scientists and business

Parameter	Combined		Science	Business
	Coeff.(P >|t |)	s.e.	Coeff.(P >|t |)	Coeff.(P >|t |)
fam	.1093(⋆⋆)	.0507	0.1859(⋆⋆)	.0812
intl	-.0328	.0600	-.1834(⋆⋆)	.0532
fin	.3735(⋆⋆⋆)	.0668	.1972(⋆⋆)	.5403(⋆⋆⋆)
at	-.1093(⋆⋆)	.0513	-.06670	-.1175(⋆⋆)
rp	-.1165(⋆⋆)	.0504	-.2544(⋆⋆)	-.0171
ph	-.0146	.0491	-.02583	.0140
rcl	.0367	.0600	.0570	.0353
ea	.0131	.0594	.0754	-.0407
pni	.0593	.0539	.1674(⋆)	.0742
eii	-.0387	.0531	.0814	-.0442
ad	.0722	.0471	.0873	.0349
tech	.0807	.0629	.1336	-.0423
rtns	.3354(⋆⋆⋆)	.0701	.3145(⋆⋆⋆)	.2844 (⋆⋆⋆)

Table 3.4: Fixed effects panel estimation for dependent variable - investment decision. Individuals (20) are the panel variable with variance is 0.2060842; when scenarios(15) is used as panel variable variance is .07620888. ⋆ - significant at the p=0.1 level; ⋆⋆ - significant at the p = .05 level; ⋆⋆⋆ - significant at the p = .01 level

	id	fam	intl	fin	at	rp	ph	rcl	ea	pni	eii	ad	tech	rtns
id	1.000													
fam	0.229	1.000												
intl	0.393	0.196	1.000											
fin	0.680	0.223	0.363	1.0000										
at	-0.239	-0.014	-0.144	-0.1540	1.000									
rp	-0.378	0.095	-0.138	-0.3173	0.406	1.000								
ph	-0.006	0.029	0.191	0.0545	-0.024	0.050	1.000							
rcl	0.091	0.379	0.240	0.1459	-0.145	0.031	0.166	1.000						
ea	0.148	0.415	0.335	0.1712	-0.025	0.057	0.172	0.631	1.000					
pni	0.387	0.215	0.494	0.3024	-0.120	-0.104	0.012	-0.028	0.100	1.000				
eii	0.215	0.134	0.100	0.4274	-0.128	-0.107	0.196	0.318	0.280	-0.0292	1.000			
ad	0.350	0.106	0.284	0.273	-0.0355	-0.112	-0.005	-0.062	0.048	0.3409	0.033	1.000		
tech	0.433	0.121	0.661	0.365	-0.1466	-0.111	0.179	0.149	0.250	0.5429	0.110	0.244	1.000	
rtns	0.625	0.122	0.356	0.744	-0.0686	-0.233	0.091	0.098	0.168	0.2584	0.439	0.314	0.406	1.000

Table 3.5: Correlation between variables that scenario responses used in the fixed effects model in Table 3.4.

domain individuals update their beliefs, and secondly, what is the persistence in this updating process. To address this, the number of scenarios are reduced and each scenario is segmented into four parts, and responses are elicited for each scenario and segment. The details of the scenario and segment is shown in Table 3.6. The first two scenarios were used in the verbal protocols, without segmentation. The interpretation from the verbal protocols motivate this experiment.

In order to obtain data from a large sample, this experiment designed to take under 30minutes to respond. A private link was sent to a large number of randomly selected science and business domain individuals. The links were deactivated once the requisite number (60 science and 60 business responses) was obtained.

To answer the first question a latent trajectory model on the segments of the videos, for which the following model is constructed with the restricting assumption that there is no significant variation between videos within individuals:

$$y_i = \lambda_{1_i}.D_{1_i} + \lambda_{2_i}.D_{2_i} + \lambda_{3_i}.D_{3_i} + \lambda_{4_i}.D_{4_i} + \beta_x.x_i + \nu_i.z_i + u_i \tag{3.2}$$

where D_1, D_2, D_3, D_4 are dummy variables relating to segments 2, 3, 4 of the videos. A model taking into account variations among the groups (science and business domain individuals) can be written as

$$\begin{aligned} y_{i,k} = \quad & \lambda^k_{1_i}.D^k_{1_i} + \lambda^k_{2_i}.D^k_{2_i} + \lambda^k_{3_i}.D^k_{3_i} + \lambda^k_{4_i}.D^k_{4_i} \\ & +\beta_x.x_i + \nu_i.z_i + u_i \end{aligned} \tag{3.3}$$

where k can refer to one of the two groups science S or business B. This increases the degrees of freedom by 3 compared to the previous model. A model taking into account variations among the groups (science and business domain individuals) and between 3 scenarios, is given below:

$$\begin{aligned} y_{i,j.k} = \quad & \lambda^k_{1_{i,j}}.D^k_{1_{i,j}} + \lambda^k_{2_{i,j}}.D^k_{2_{i,j}} + \lambda^k_{3_{i,j}}.D^k_{3_{i,j}} + \lambda^k_{4_{i,j}}.D^k_{4_{i,j}} \\ & +\beta_x.x_{i,j} + \nu_i.z_i + u_{i,j} \end{aligned} \tag{3.4}$$

where j can refer to one of three scenarios. This means there are 3(scenarios) $\times$

Stimuli	Description	Orientation
Scenario 1	A floatation device: The entrepreneur demonstrates the device with his keys and with a 1Kg weight in metre high water tank. He explains that the nature of the patent, and other possible uses for the technology. Provides very high forecasts in the order of millions of pounds.	Technology
Scenario 2	A folder for large size papers: Reduces the size of folder without creasing it. The demonstration shows a paper folded without a crease, however a fold is induced in the paper. The under 20 year old young entrepreneur has applied for patents, trademarks and obtained manufacturing quotes from mainland China. The simple product is has a high mark up market price with moderate forecasts in the order of half a million pounds and has received interest from two large retailers.	Business
Scenario 3	A mechanical water flow controller: Prevents overflow of water in bathtubs and other such units. How the device is designed is not presented, but how it fits neatly without need to engage in deep plumbing and that it has no electrical components is presented. The device has a patent pending but co-owned by a university Technology Transfer office with a profit sharing agreement. The market is indicated by amount paid by insurance companies towards the problems and target includes housing associations. The university is prepared to sell the patent for 2m at this stage. High turnover rates are forecasted.	Technology + Business
Segment 1	An introduction to the pitch including a general overview of the proposition	Technology + Finance + Market
Segment 2	How the product/service works including technical details	Technology
Segment 3	Financial forecasts, ownership details	Finance
Segment 4	Potential market, intellectual property rights, competitors	Market

Table 3.6: Description of the sequential stimuli presented for updating the beliefs of the respondent.

4(segments) $\times$ 2(groups) = 24 $D_{i,j}$ dummy variables.

To answer the second question, a time lagged autoregressive model is constructed as given below:

$$\begin{aligned} y_{i,t} = & \quad \gamma_{2t}.D_{2t} + \gamma_{3t}.D_{3t} + \gamma_{4t}.D_{4t} \\ + & \quad \rho_{2t}.y_{i,t-1}.D_{2t} + \rho_{3t}.y_{i,t-1}.D_{3t} + \rho_{4t}.y_{i,t-1}.D_{4t} \\ + & \quad \beta_x.x_i + \nu_i.z_i + u_{i,t} \end{aligned} \tag{3.5}$$

Similar to the latent trajectory three models with varying levels of restrictions can be built in, giving the following model taking into account the two groups:

$$\begin{aligned} y_{i,k,t} = & \quad \gamma^k_{2t}.D^k_{1t} + \gamma^k_{3t}.D^k_{2t} + \gamma^k_{4t}.D^k_{3t} \\ + & \quad \rho_2.y^k_{i,t-1}.D^k_{2t} + \rho_3.y^k_{i,t-1}.D^k_{3t} + \rho_4.y^k_{i,t-1}.D^k_{4t} \\ + & \quad \beta_x.x_i + \nu_i.z_i + u_i \end{aligned} \tag{3.6}$$

and the following model taking into account the three scenarios.

$$\begin{aligned} y_{i,j,k,t} = & \quad \gamma^k_{2t_j}.D^k_{2t} + \gamma^k_{3t_j}.D^k_{3t} + \gamma^k_{4t_j}.D^k_{4t} \\ + & \quad \rho_2.y^k_{i,j,t-1}.D^k_{2t} + \rho_3.y^k_{i,j,t-1}.D^k_{3t} + \rho_4.y^k_{i,j,t-1}.D^k_{4t} \\ + & \quad \beta_x.x_i + \nu_i.z_i + u_{i,j} \end{aligned} \tag{3.7}$$

A good discussion of latent trajectory models and autoregressive models and the combined model is discussed in (Bollen & Curran 2004). The coefficients of the variables from ordinary least squares estimation is presented in Table 3.7, 3.8. It can be observed from Equations 3.6, 3.7, 3.8 that *gamma* is the unconditional effect of each segment, due to extraction of the autocorrelations from the previous segment in ρ. Considering Equations 3.2, 3.4, 3.5 together it can be shown that λ is the conditional effect on each segment, where:

$$\begin{aligned} \mathbb{E}[y_t] &= \frac{\gamma}{1-\rho_i} \\ &= \lambda \end{aligned} \tag{3.8}$$

where $\mathbb{E}$ is the expectation of the dependent variable (ignoring other independent variables, subscripts and superscripts for simplicity). The expectation reduced the dynamic autoregressive model to the static latent trajectory model. Therefore plotting γ would give the pure effect of the current segment removing the carried over effect from the previous segment. This provides further important details to the analysis, as science and business domain individuals may respond uniquely differently to each of the segments.

For the latent trajectory and the autoregressive models, the F test (or the Wald test) could be run to test the significance of the one model over its restricted model. This would inform as to whether the group or the scenarios explain the data any better than if they were pooled together. The F statistic is given as:

$$F = \left(\frac{R_1 - R_2}{p_2 - p_1}\right) / \left(\frac{R_2}{n - p_2}\right) \tag{3.9}$$

where R is the reduced sum of the squares, p_1 and p_2 are the degrees of freedom of the restricted and full models respectively and n is the number of observations. If the F statistic is greater than the critical value (obtained from the F distribution tables), then the models can be said to improve the fit significantly.

The full model in both latent trajectory (Equation 3.5)and autoregressive models (Equation 3.8) are found to support the hypothesis that the additional variables in these models significantly reduce the reduce sum of the squares in the system compared to both the restricted models (given in equations 3.2, 3.4, 3.6, 3.7).

The analysis in Tables 3.7and 3.8 are plotted below accompanied by discussions. In Figure 3.1 the significance of the contribution to dependent variable when each segment is presented is plotted for data across all the scenarios (restricted model). Overall across the scenarios the scientists relate negative significantly to investment during the second segment and positive significantly in the fourth segment. The business group relates positive significantly only during the 4th segment. This confirms the observations from the verbal protocol which indicate scientists paying attention to a more aspects of the opportunity, compared

Parameter	Latent trajectory(λ)			Autoregressive (γ or ρ)		
	Science	Business	Combined	Science	Business	Combined
D_1	-.170 ($\star\star$)	-.070	-.142 ($\star\star$)	-	-	-
D_2	-.141 ($\star\star$)	.084	-.075 ($\star$)	-.116 ($\star$)	-.012	-.086 ($\star\star$)
D_3	-.069	.130	-.010	-.095 ($\star$)	-.037	-.079 ($\star\star$)
D_4	.163 ($\star\star$)	.388 ($\star\star$)	.227 ($\star\star\star$)	.120 ($\star\star$)	.272 ($\star\star$)	.164 ($\star\star\star$)
$y_{i,j,t-1}.D_{2t}$	-	-	-	-.117 ($\star\star$)	-.012	.321 ($\star\star\star$)
$y_{i,j,t-1}.D_{3t}$	-	-	-	-.095 ($\star$)	-.037	.338 ($\star\star\star$)
$y_{i,j,t-1}.D_{4t}$	-	-	-	.121 ($\star\star$)	.272 ($\star\star$)	.311 ($\star\star\star$)

Table 3.7: Autoregressive and latent trajectory estimation for the restricted models. Note that the columns referring to Science and Business do not denote subsamples, rather they refer to dummies D^S and D^B respectively. Only intercepts (amplitudes of updates) and lagged variables (for persistence) are presented in this table (note that independent variables were included in the model according to Equations 3.2, 3.4, 3.6, 3.7). $\star$ - significant at the p=0.1 level; $\star\star$ - significant at the p = .05 level; $\star\star\star$ - significant at the p = .01 level.

Parameter	Latent trajectory(λ)			Autoregressive (γ or ρ)		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
D_1^S	-.175 ($\star$)	-.276 ($\star\star$)	-.082	-	-	-
D_2^S	-.031	-.417 ($\star\star\star$)	.028	.050	-.478 ($\star\star\star$)	-.021
D_3^S	.066	-.198 ($\star\star$)	-.078	-.063	.129	-.273 ($\star\star$)
D_4^S	.231 ($\star\star$)	.169 ($\star$)	.101	.137 ($\star$)	.203 ($\star\star$)	-.016
D_1^B	-.236	-.166	.182	-	-	-
D_2^B	.052	-.186	.388 ($\star\star$)	.004	-.313 ($\star\star$)	.180
D_3^B	.252	-.099	.235	.085	.034	.039
D_4^B	.255	.318 ($\star$)	.617 ($\star\star\star$)	.103	.296 ($\star\star$)	.379 ($\star\star$)
$y_{i,j,t-1}.D_{2t}^S$	-	-	-	.192 ($\star\star\star$)	.141 ($\star\star\star$)	.144 ($\star\star\star$)
$y_{i,j,t-1}.D_{3t}^S$	-	-	-	.193 ($\star\star\star$)	.244 ($\star\star\star$)	.163 ($\star\star\star$)
$y_{i,j,t-1}.D_{4t}^S$	-	-	-	.155 ($\star\star\star$)	.168 ($\star\star\star$)	.160 ($\star\star\star$)
$y_{i,j,t-1}.D_{2t}^B$	-	-	-	.062 ($\star\star$)	.081 ($\star\star$)	.061 ($\star\star$)
$y_{i,j,t-1}.D_{3t}^B$	-	-	-	.100 ($\star\star\star$)	.130 ($\star\star\star$)	.025
$y_{i,j,t-1}.D_{4t}^B$	-	-	-	.122 ($\star\star\star$)	.095 ($\star\star\star$)	.080 ($\star\star\star$)

Table 3.8: Autoregressive and latent trajectory estimation for the fully specified model. $\star$ - significant at the p=0.1 level; $\star\star$ - significant at the p = .05 level; $\star\star\star$ - significant at the p = .01 level.

to focused thinking by the business group.

The plot indicates that although there is systematic changes along the segments among the scientist, the change in business group overall is higher than that of the scientists. Although useful to see the significance in the change of beliefs during the segments, the latent trajectory model shows the static relationship at each segment, which neither takes into account the carried over effect from the previous segment nor sole effect of the current segment.

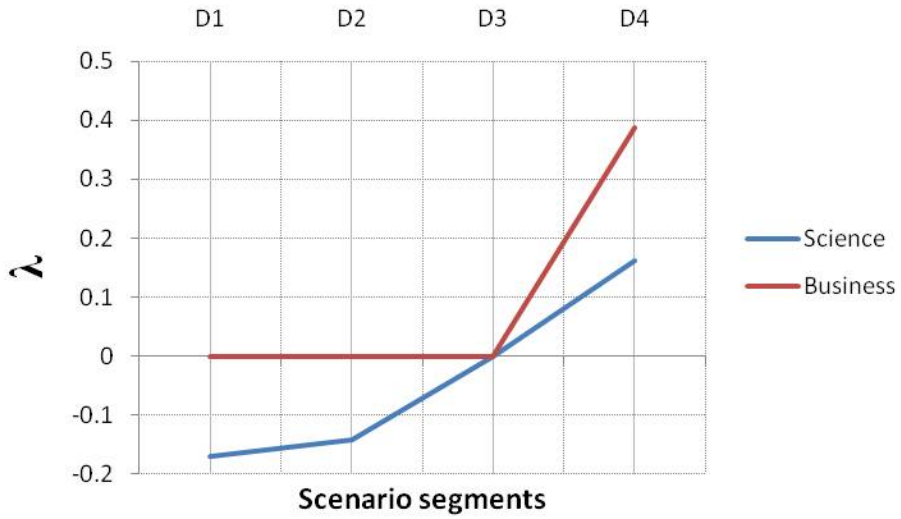


Figure 3.1: Plotting the latent trajectories of the intercepts (λ) for different segments (model not specifying scenarios).

The plot of coefficients for the unconditional intercepts and lagged variables from dynamic autoregressive model is shown in Figure 3.2. Overall across the scenarios, the scientists show higher persistence and lower effect from current information, compared to the business group. This is consistent with observations of (Jenkins-Smith & Bassett Jr 2006), which found that scientists showed comparatively slight relationship between reduced uncertainty and willingness to change beliefs in the case of nuclear waste risk.

The overall results across the scenarios may mask contingent effects based on the peculiarities related to the scenarios.

In the first scenario, which has a primarily technology orientation, the overall results are observed with one exception with regards to the fourth segment (see Figure 3.3). This segment relates to the potential market for the product, and an alternative use for the product is discussed. This was picked up by the scientists

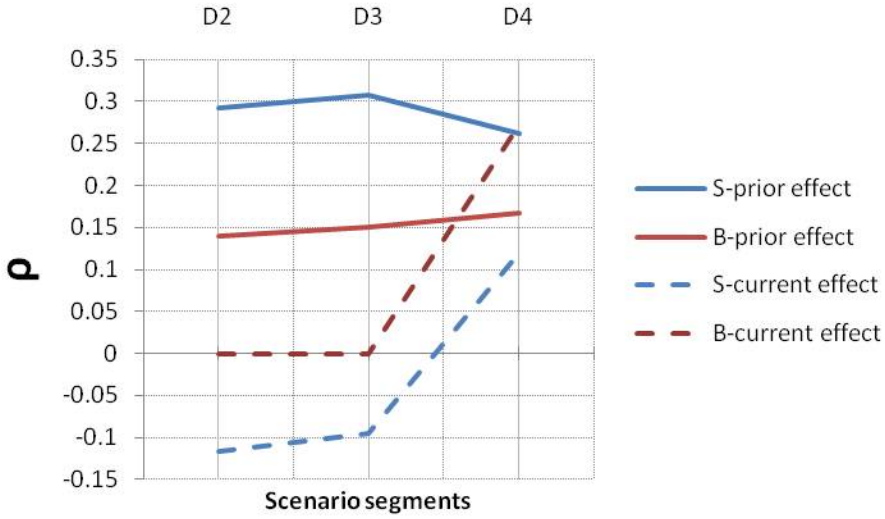


Figure 3.2: Plotting the trajectories of the unconditional intercepts (γ) and coefficient (ρ) of the lagged dependent variable for different segments for the all scenarios considered together.

during the verbal protocols, and has been picked up positive significantly by the scientists. This is a notable exception, as it is the only instance across all scenarios and segments where the current effect exceeds that of the business group.

The persistence of the scientists is consistently high despite positive response to the alternative use of the product during the fourth segment (see Figure 3.4), indicative of a whole new market. The business group shows mixed results, with no segment exciting systematic effect, and persistence levels increase throughout the scenario.

In the second scenario, which has a primarily business orientation, the results from across the segments is followed (see Figure 3.5). The scientists are not impressed with the technicalities of the product results in a dip in likelihood of investing, but picking up later with impressive mark up, manufacturing quotes and interest from retailers. Business group only show systematic interest in the fourth segment where the market potential is discussed. They are unfazed by the fold in the paper, and the markup on the product, which may have been moderated by the low turnover in comparison to the amount requested.

The persistence of the scientists is consistently higher than the business group (see Figure 3.6). The financial forecasts do not seem to have systematically affected both groups, but the market segment had positive effect on both, with

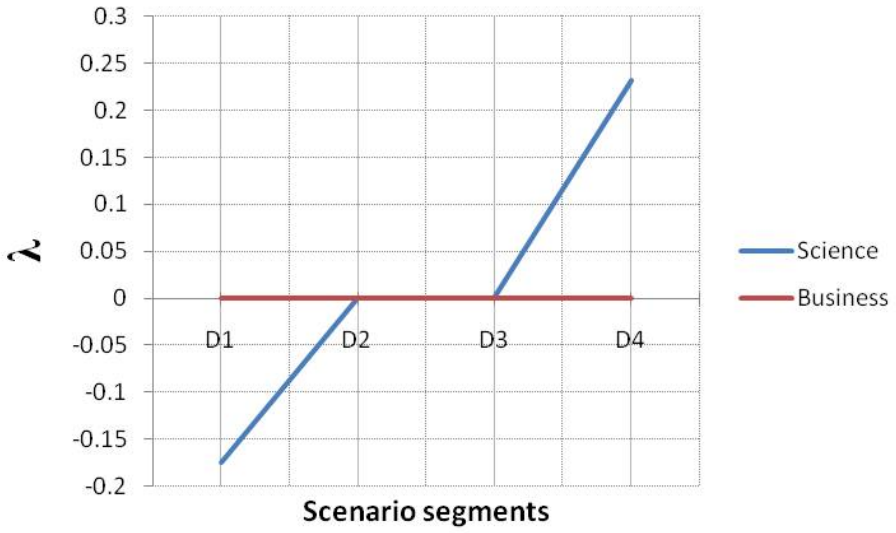


Figure 3.3: Plotting the latent trajectories of the intercepts (λ) for different segments of scenario 1.

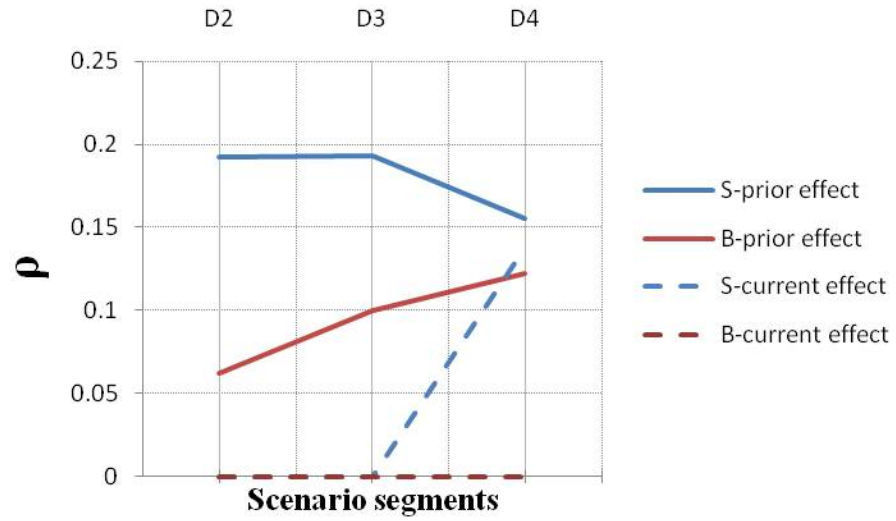


Figure 3.4: Plotting the trajectories of the unconditional intercepts (γ) and coefficient (ρ) of the lagged dependent variable for different segments of scenario 1.

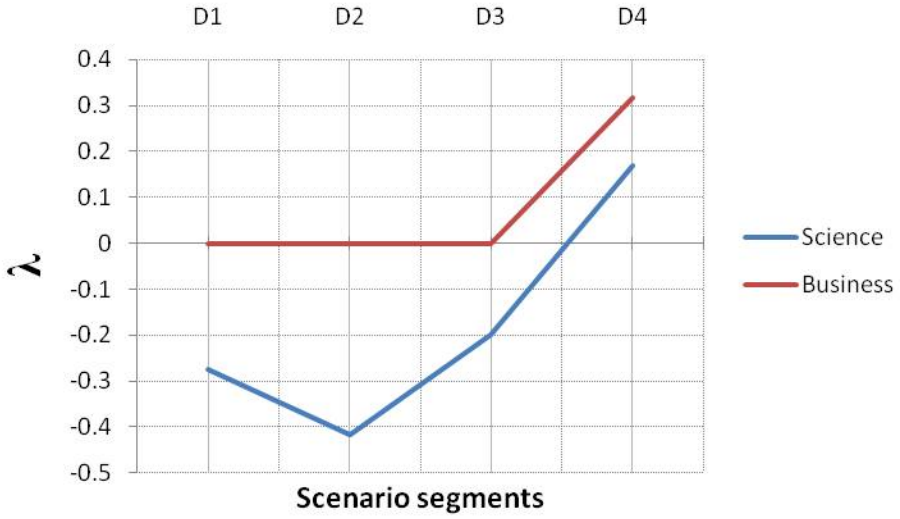


Figure 3.5: Plotting the latent trajectories of the intercepts (λ) for different segments of scenario 2.

business group showing larger response from this information.

In scenario three, which is combines both technology and business orientations, the scientists show no systematic tendencies to invest or not (see Figure 3.7). The business group fluctuates from being mixed about it to turning positive during segment two where the ease of its use and fitting is presented, followed by mixed response due to the revelation of shared ownership and profits, and again turn positive when large potential market is declared.

For the business group, there is no effect of the second segment (technical working details) on the third segment comprising financial details (see Figure 3.8). This is a unique instance across all the scenarios and segments, where lagged effect is non-significant. The pure effect of third segment is also not significant, meaning that it received mixed results. The third segment presented financial forecasts in the form of number of units, and reveals the shared ownership and profit sharing agreement with a university technology transfer office. This revelation could have refreshed the system for the business group, however effect of this information has been mixed, leading to no significant directional effect. Despite market potential information, the effect of the third segment carried into the fourth. The scientist continued to be persistent throughout the scenario, despite responding very negatively to the third segment.

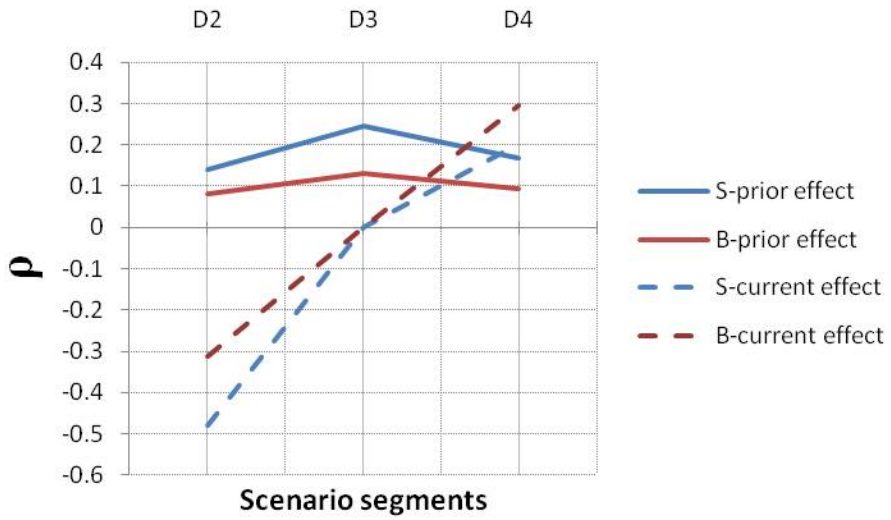


Figure 3.6: Plotting the trajectories of the unconditional intercepts (γ) and coefficient (ρ) of the lagged dependent variable for different segments of scenario 2.

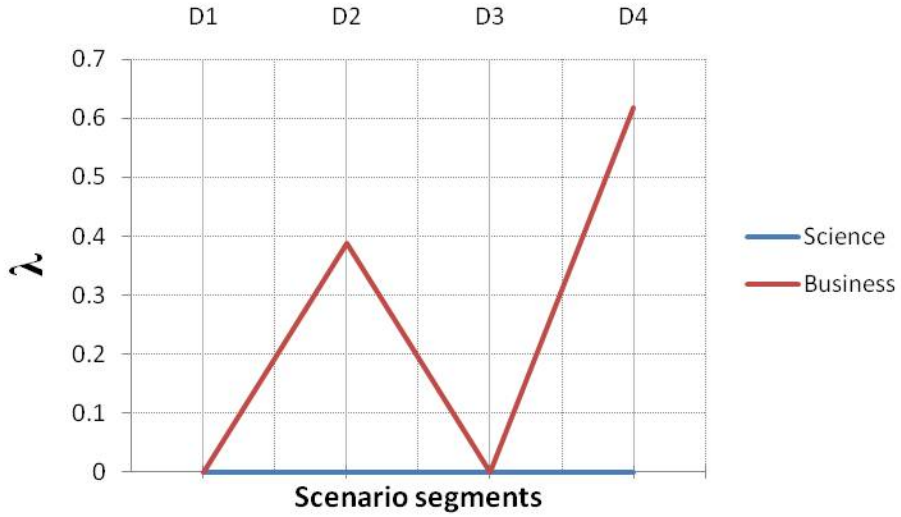


Figure 3.7: Plotting the latent trajectories of the intercepts (λ) for different segments of scenario 3.

	id	conf	fam	intl	fin	at	rp	ph	rcl	ea	pni
Exp. 1: Science	5.1	-	14.025	9.867	18.65	5.2	9.675	3.087	15.558	12.117	12.075
Exp. 1: Business	-2.155	-	12.244	0.363	3.518	5.852	18.074	3.333	21.792	19.340	0.896
Exp. 2: Science	-0.665	14.669	10.280	3.152	17.597	0.620	13.101	2.879	20.842	15.408	0.381
Exp. 2: Business	1.547	13.29	4.957	0.223	14.943	2.043	10.313	2.565	20.92	14.74	7.373

continued below...

	eii	ad	tech	rtns
Exp. 1: Science	13.075	0.675	7.725	21.758
Exp. 1: Business	6.511	0.644	-0.615	6.355
Exp. 2: Science	16.664	0.769	3.852	17.309
Exp. 2: Business	8.2	0.77	8.923	16.36

Table 3.9: Unnormalized averages of the responses by the science and business sub samples for variables in Table 3.4, shown for both the repeated measures and evidence based update experiments.

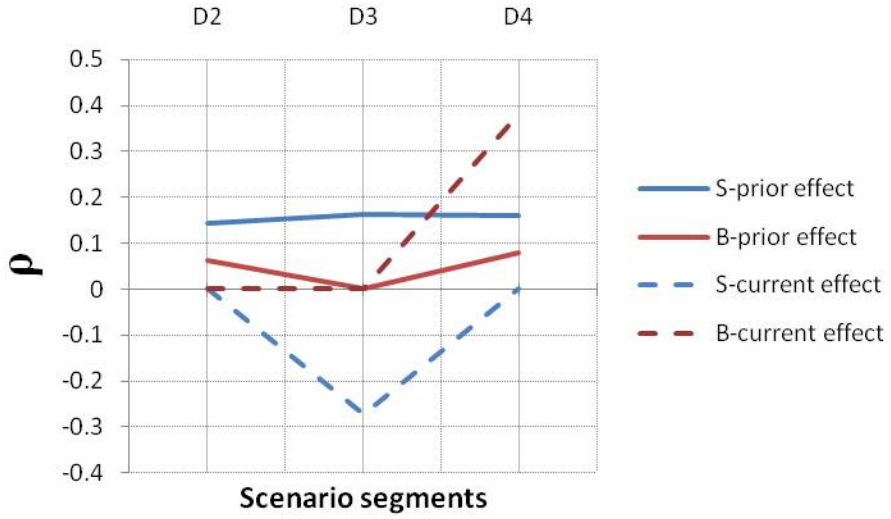


Figure 3.8: Plotting the trajectories of the unconditional intercepts (γ) and coefficient (ρ) of the lagged dependent variable for different segments of scenario 3.

3.4 Discussion

Two approaches were piloted prior to the method presented above. Based on a fictional technology business scenario, a policy capture questionnaire, and measuring responses on deliberative coherence principles (Thagard 2001). Both did not produce systematic variance due the former being too macro and latter being too micro. The experimental scenarios in three settings were used to test a number of hypotheses, which is consolidated below.

Following the analysis in the section above, we note that the intellectual aspiration of scientists constrain their engagement with (hypothesis 1 supported) with significance at the 0.05 level with a constraining effect of about 18%. Scientists are also more excited if business opportunity serves as a platform for new ideas (hypothesis 2 supported) with a low significance at the 0.1 level with an enhancing effect of about 17%. Contrary to popular belief, based on domain knowledge of scientists, they are not systematically given to evaluating business opportunity in terms of technology compared to business domain individuals (hypothesis 3 not supported).

Scientists are clearly more risk averse (hypothesis 4 supported) with significance at the 0.05 level and risk aversion effect of 25%; and also that financial

aspiration (hypothesis 5 supported) alleviates this risk aversion and constraining effect of the intellectual aspiration by about 18% at 0.05 level of significance. In relation to ambiguity perception scientists tolerate more ambiguity than business domain (hypothesis 6 supported), with the additional insight that business domain individuals negatively to it t the 0.05 level significance and negative effect of about 12%.

The thinking mechanisms (hypothesis 7 and 7a not supported) did not show systematic differences, suggesting that domain knowledge is not necessarily a marker of difference between the domains. This is because familiarity did positively influence scientists to engage in the opportunity with (p = 0.05 level) with effect of about 19%.

The verbal protocol team setting shows clearly that scientists take a third longer to evaluation business opportunity information and perform more balanced means-end analysis (Hypothesis 8 supported). It also provides support to theory underlying hypothesis 9 on higher persistence of scientists in the presence of new information. Scientists are consistently more persistent (hypothesis 9 supported) than business domain individuals, which integrates the insight of a number of previous hypothesis. The above results are summarized in Table 3.10.

An interesting observation is the average responses for exploration-platform for new ideas for experiment two (see Table 3.9), which indicates that scientists business domain individuals have been more explorative when new information was presented. This may not just be due to different samples and setting (online in experiment 2) in the two experiments. It has been noted that adaptive agents may choose between exploitation and exploration depending *"on a number of factors, including the familiarity of the environment, how quickly the environment is likely to change and the relative value of exploiting known sources of reward versus the cost of reducing uncertainty through exploration."*(Cohen et al. 2007). This cannot be verified without further analysis of the variation of dependencies of the variables for each scenario and segment. This can be a subject of a future study.

A general methodology for ascertaining the differences between groups of individuals has been explored. We hope this study would encourage more sophisticated analysis to present nuanced findings that validate or bust current stereotypical assumptions. Further analysis can be performed on the variance of the independent variables for the two groups in the evidence based update experiment (for each scenario), testing interaction terms, effect of background variables.

No.	Hypothesis	Argument	Finding
1	The intellectual aspirations of scientists constrain their willingness to engage with business opportunities.	Scientists are trained in heuristics of exploration, which is the breeding ground for novel insights, while business objectives emphasize downstream factors related to exploitation.	Supported
2	Scientists are more excited by business possibilities which serve as a platform for new ideas.	Opportunities that align with the goals and strengths of the scientist are more favored than that which does not add domain value.	Supported
3	Scientists are more likely to evaluate the potential of the venture in terms of its technology compared to business domain individuals.	Science domain agents are endowed with different prior knowledge, which is alert to technology opportunities	Not supported
4	Scientists are more risk averse than business domain individuals.	Scientists have claimed difficulty in accepting the risk orientation and sweeping vision of a commercial opportunity.	Supported
5	The financial aspirations of scientists enhance their willingness to engage in business opportunities.	Scientists with 'single minded' aspiration to make money were found to display less risk aversion.	Supported
6	Scientists tolerate more ambiguity than business domain individuals.	Ambiguity is often the target of resolution in science, hence we expect scientists to examine and resolve the ambiguity more than business domain individuals.	Supported
7	Scientists engage in more explicit thinking about business opportunities compared to business domain individuals.	Given non-familiarity with business domain knowledge science individuals engage in elaborate form of reasoning.	Not supported
7a	Business domain individuals engage in more automatic thinking about business opportunities compared to scientists.	Given familiarity with business domain knowledge, business individuals engage in quicker forms of reasoning.	Not supported
8	Scientists engage in more elaborate means-end analysis compared to business domain individuals.	Scientists are trained to systematically analyze information and resolving ambiguity, hence would engage is more elaborate means-end analysis.	Supported
9	Scientists are more persistent in their views compared business domain individuals.	Due to lack of familiarity, scientists possess less discriminating cues a priori, needing higher effort in the initial reconciliation and structuring of information, leading to stronger initial views.	Supported

Table 3.10: Summary of the results for each of the hypothesis.

The quality of sample can be improved by conducting this in a controlled setting with incentives which are not merely financial.

The scenarios presented to the two groups do not necessarily relate to collaboration between industry and universities - a crucial topic in innovation. The variable 'planning horizon' would be much more accentuated in that context, due to being embedded in strong institutional settings. The institutional setting may not have an active influence on the perception of the pitches owing to their relative independence from existing strengths; the focus rather was on the worth of investing in the venture. Further studies utilize scenarios which includes the elements for addressing other related research questions. The efficacy of means-end analysis in complex scenarios can be studied by comparing various degrees of decomposition. Future work can examine the effect of maturity in a domain (early stage student versus experienced researcher and nascent entrepreneur to experienced businessman) to the decision making process. One study the two groups could analyze their decision making processes to type 1 and type 2 errors. Another interesting study is to identify a case of conflict in assessment of an opportunity by the two groups, and use it as a setting to study the differences, and under what conditions the conflict can be alleviated and at what cost.

The research design suffers from an endogeneity problem, i.e. the sample of postgraduate students may have self-selected into their respective domains. The broad line of inquiry of the research questions is whether the domain differences in opportunity recognition owes to domain knowledge or manner of evaluation, and the answer has been the latter. Given the self-selection problem, it is difficult to ascertain to what extend this comes from domain related training and experience or due to other causes. Considering the current sample to be novice in their respective domains, the endogeneity problem can be alleviated by further work which tests naive and expert practitioners for learning effects. Prior work on between naive, novice and expert cognitive behaviours have found interesting differences (Dew 2009, Snchez-Manzanares 2008). A similar study can be performed to alleviate the endogeneity problem.

One outstanding questions remains: if scientists differ from business domain individuals in a given manner, how can discordance be mitigated and synergies exploited. This would be a research question for a future study. As a start, let us consider that scientists engage in a more balanced means-end analysis, which may lead to lower consistency for highly interdependent complex problems. Scientists

also contend with Multiple goals, which may increase the levels of abstraction in the means-end analysis. A laddering method has been proposed for assessing means-end knowledge structures (Reynolds & Gutman 1988). It involves a series of one-on-one in-depth interviews, where the respondents are given a task designed to elicit basic concepts and distinctions used to differentiate between stimuli of interest. Then the interviewer asks a series of open-ended questions designed to uncover higher level associations/meanings related to the basic distinctions such "why is (this distinction) important to you". This is then taken to the next level by asking "why is that important to you", until the respondent cannot give any more answers. The respondent is thus driven up the ladder of abstraction until he/she cannot go any further. The analysis of the data thus acquired is used to form a Hierarchial Value Map - an aggregate network diagram that characterizes key concepts associated with the particular product domain. A suggestion is to conduct this laddering technique (which can be automated) on all the students to build a customized Hierarchical Value Map (similar to the practice of conducting Myer Briggs Test Indicator). Once this data is obtained, conventional class room activity can be appended with techniques to reduce the level of abstraction to streamline business opportunity evaluation. In addition the factors contributing to willingness to engage in business opportunities would need incorporated in the design of the program. Case studies and analogies with success and failures relating to these factors may help alleviate the effects of detrimental factors. A follow up study can measure the effects of such a program.

Literature on commercialization and innovation are increasingly seeking an understanding of how two salient groups (scientists and business managers) in the innovation process are similar or different. These findings indicate sources of discrepancies in the participation of both domains in the innovation process. This research contributes to understanding the obstacles to the formation of common ground, and differences in enactment of opportunity recognition.

3.5 Appendices

3.5.1 Administering the verbal protocols

Two scenarios were selected from entrepreneurial pitches presented on the BBC's Dragon's den program, which are presented to groups of individuals from the

science and business domains. One of the pitches has a technological orientation (a novel floatation device) and the other has a business orientation (Folio folder for large size papers). Both these proposals were funded by the Dragons and their latest progress can be seen from their respective websites: www.foldio.co.uk, www.water-buoy.com. Two teams of postgraduate students in the science faculty PhD and MBA (with non-science background, British background and same age group) cohorts at Imperial College London were invited (through student lists sorted for required background) and presented with two scenarios (3 minutes each). The following the instructions regarding the conduct of the decision making exercise followed by think aloud discussions (open ended) for each scenario.

- "Thank for your agreeing to participate in this exercise. Two business proposals would be presented to you, and we would like you to discuss aloud among yourself issues that you take into account to decide whether to invest in the venture (this was changed to a role of advisor to an investor, to see if taking out personal financial constraints has an effect on decision making process), and if not whether you would be prepared to engage with them in another way. Please note that we would not interfere between the discussions, there no further information should be expected.".
- Recording starts.
- This is the first pitch. Present clip 1.
- Discuss aloud your thoughts on whether you would invest.
- This is the second pitch. Present clip 2.
- Discuss aloud your thoughts on whether you would invest.
- Recording ends.
- Have you watched or familiar with either of the pitches?
- Thank you for participating"

3.5.2 List of pitches (video clips) shown for experiment 1

Experiment 1 entailed showing a sequence (in the order and description in Table 3.11) of 15 different edited (full) pitches.

Sequence	**Pitch**	**Primary orientation**	**Den success**	**Patent (pending)**
1	Waterbuoy	Scientific	Yes	Yes
2	Foldio	Business	Yes	Yes
3	Magic paper	business	Yes	Yes
4	Slinks	business	Yes	Yes
5	Anyway spray	scientific	Yes	Yes
6	Novaflo	scientific + business	No	Yes
7	Ross	science + social	Yes	Yes
8	Cush-n-Shade	business	Yes	Yes
9	Chocbox	business	Yes	Yes
10	Beeone	Science + Business	No	Yes
11	Wine innovations	business	No	Yes
12	Squeeze with ease	business	No	Yes
13	Mydish	Business	Yes	No
14	Tech21	business	Yes	Yes
15	Prowaste	business	Yes	No

Table 3.11: List of pitches (video clips) shown for Experiment 1

3.5.3 Scenario related Questions

- Have you watched the clip fully? (Yes/No)
- On the scale provided below please indicate your willingness to invest in the venture? (slider)
- What level of confidence do you place on your investment decision? (slider)
- How familiar were you with the scenario? (slider)
- To what extent are you thinking about this venture on the basis of :

  Intellectual contribution (slider)

  Financial gains (slider)
- How ambiguous is the prospect of this venture? (slider)
- How risky do you think this venture is? (slider)
- How far into the future did you plan regarding this venture [please type out below a period of time for example 1.5 years]? (real number)
- To what extent can you recall and articulate the reasoning process behind your investment decision? (slider)
- To what extent did you explore and analyse the particular issues or components in the scenario? (slider)
- To what extent are you thinking about this venture as means for:

  Platform for new ideas (slider)

  An end in itself (slider)
- Would have preferred to attend to more details regarding this sale pitch? (Yes/No)
- To what extent are you currently thinking about the potential of the venture in terms of:

  Technology (slider)

  Returns (slider)

The slider scale is implemented as shown in Figure 3.9 below. No movement would denote unbiased response, while movement to either side intuitively denote positive or negative. This scale can capture both negative and positive inclinations, avoid scaling bias that may arise form a positive 1-100 scale, and increase resolution in comparison to the discrete Lickert scale.



Figure 3.9: Sample implementation of the slider scale.

3.5.4 Background Questions

- What is your gender? (Male/Female)
- What is your nationality? (list of countries)
- What age group do you belong to? (list with 5 year resolution)
- What is your field of study? (list of 42 disciplines)
- Your work experience? (multiple choice)

  Full time work in a corporate setting

  Full time work in a start up

  Founded and worked full time in that business

  Part time work in a corporate setting

  Part time work in a start up

  Founded and worked part time in that business

  No work experience

- What is your exposure to business? (multiple choice)

  Immediate family owns a business

  Relatives or friends own a business

  Keen follower of business affairs

  None

- What is your highest level of formal education or current study program?? (list of qualifications)
- If you are a student, indicate which year in the program you are currently in. (5 point choice)
- Which career option will you prefer and to what extent?

  Academic faculty (slider)

  Established firm/industry (slider)

Startup (slider)

Other (slider)

- Indicate your preference for job attributes.

  Intellectual challenge (slider)

  Job security (slider)

  Salary and financial benefits (slider)

  Responsibility (slider)

  Freedom (slider)

  Peer recognition (slider)

Part IV

TRANSACTIONS - *THE MACRO*

Chapter 4

Reconceptualizing the (Innovative) Firm:

Actions, Assets & Quasi-boundaries

Contents

4.1 Introduction 104

4.2 Real Integration: Beyond TC And Capabilities . . . 106

4.3 Towards an Integrated Theory 110

4.3.1 Existence of the firm 113

4.3.2 Boundary decisions 115

4.3.3 Internal organization 119

4.4 Quasi-Boundaries 121

4.5 Shaping The Ecosystem 124

4.5.1 Shaping the Institutions: WARF 1924-2000 124

4.5.2 Shaped by the Market to Shape The Market: Symbian 1998-2009 130

4.6 Conclusion 133

4.1 Introduction

The theory of the firm helps to explain and predict the decisions and behavior of firms. Studies on the theories of the firm are usually traced back to optimal risk allocation (Knight, 1921), followed by transaction cost economics focusing on the efficiency of markets vs. hierarchies (Alchian & Demsetz 1972, Coase 1937, Grossman & Hart 1986, Klein et al. 1978, Williamson 1975). Several other influential approaches have been explored such as behavioral theory: focusing on cooperation (Barnard 1938), bounded rationality (Simon 1945, 1982), search process (March & Simon 1958), coalitions (Cyert & March 1992); agency theory: focusing on separation of ownership and control (Berle & Means 1932), information asymmetry and incentives (Pratt & Zeckhauser 1985), reasons for divergence between theory and practice (Arrow 1985), heuristics : repetition and relative judgment , (Levinthal 1988), agency costs and contract design (Jensen & Meckling 1976); resource based theory: focusing on services of productive resources, subjective opportunity and limits of growth (Penrose 1959), economies of scale (Chandler 1990), strategic resource options (Peteraf 1993, Wernerfelt 1984); and capabilities theory: focusing on routines (Nelson & Winter 1982), knowledge (Conner & Prahalad 1996, Kogut & Zander 1992), capabilities (Argyres 1996, Langlois 1992), dynamic capabilities (Teece 2007, Teece et al. 1997).

Appreciating the significant contributions of these literatures in their own right and to each other's development, these efforts may be summarized under two broad theories, where the efficiencies and behavior of a firm are reasoned via: organizational and technological capabilities and productive resources which are valuable, rare, imitable and organized (capabilities); and governance structures, property rights and economic incentives (transaction costs). These two broad perspectives originate from different approaches to the firm; and as such have emphasized some aspects of the firm at the expense of some others. Internalization of activities within the firm occurs due to lower cost of governance according to the transaction cost and superior capability according to the capability perspective. Notwithstanding the fact that determination of transaction cost often depends on value of capabilities involved in the production and exchange, and development of capabilities depends on assessments of transaction costs that may be incurred, the dichotomy has generally prevailed over integration.

The researchers of the theory of the firm have long recognized this lopsidedness. Coase remarks on the complex interdependent structure of capabilities

and the institutional context of economics as thwarting a big picture view of the firm: *"The costs of coordination within a firm and the level of transaction costs that it faces are affected by its ability to purchase inputs from other firms, and their ability to supply these inputs depends in part on their costs of coordination and the level of transaction costs that they face which are similarly affected by what these are in still other firms. What we are dealing with is a complex interrelated structure."* Add to this the influence of the laws, of the social system, and of the culture, as well as the effects of technological changes such as the digital revolution with its dramatic fall in information costs (a major component of transaction costs), and you have a complicated set of interrelationships" (Coase 1998)

Commenting on the dichotomous treatment of organizational economics and capabilities in the literature, Foss remarks that *"existing theory does not allow us to understand the modern corporation in its complex entirety..."* (Foss 1996a). Despite the incompleteness of both the perspectives, transaction cost economics in particular has been subject to passionate critiques suggesting that it promotes negative assumptions of human nature (Ghoshal & Moran 1996, Moran & Ghoshal 1996) and for ignoring capabilities (Madhok 1996). The capability perspective has also been critiqued as not being integrated with incentives, moral hazard and governance structures (Foss 1996b). Minimizing transaction costs and market failures cannot be considered in isolation with the development and evolution of the organizational capability, and similarly development or acquisition of capabilities cannot be considered in isolation of the transaction costs involved. Empirical tests have found that decision on vertical boundaries of the firm are strongly influenced by both transaction cost and firm level capabilities (Leiblein & Miller 2003). The combined consideration of firm capabilities and organization design has previously been suggested as a promising program for research (Jacobides 2006). Integration hitherto has mainly proposed co-evolution of capabilities and transaction costs (Jacobides & Hitt 2005, Jacobides & Winter 2005, Madhok 2002).

Interestingly no other perspective or framework has achieved prominence. There may be other ways of formulating a theory of the firm, rather than the entrenched notions of transaction costs and capabilities. We approach the firm from a fresh angle, considering its basic ingredients, and attempt to address the theory of the firm with an aim to be parsimoniously exhaustive. In other words the choice of elements that constitute the firm should not been too reductionist to become useless, at the same time, ample coverage should be given to provide

scope for further development towards an integrated theory of the firm. We identify that the working firm is a bundle of assets and actions, where actions may be coordination, development or appropriation; and assets may be resources, capabilities and value. Firm exist in an ecosystem which includes different levels of analysis such as the market-firm-individual and their institutions. We also recognize that the boundaries of a firm may not absolute as conventionally defined, hence explore a less strict version of boundary of the firm. We wish to employ these basic ingredients to address the questions of the theory of the firm i.e. its existence, boundaries and internal organization.

This paper is organized as follows: we first differentiate mere integration with real integration in the sense of unification, as it not only influences our theoretical approach in this paper but also points to pitfalls of mere integration. Secondly, we elaborate on variables used to build an integrated theory of the firm. This is followed by questioning the strictness of boundaries in the real world, thereby proposing the concept of quasi-boundaries. We illustrate the theory and concepts further by two unique and contrasting cases studies - of a technology transfer office and a company providing a mobile software platform. Finally we discuss the implications of working towards a consolidating theory and future directions.

4.2 Real Integration: Beyond TC And Capabilities

Attempts at integration or synthesis are usually called for between concepts that together would provide a sufficient description of the phenomena. These concepts often occupy different sections of the same spectrum, such as in the planning and emergent schools of strategy or the small scale quantum mechanics and the large scale relativistic physics. In this sense, the integration of the two perspectives of the theory of the firm may be assessed: the transaction cost and capability approaches historically arise from different sub-fields, which is natural as the firm can be approached in many ways owing to its complexity - sociological, organizational, economic, technological and behavioural. However these approaches can be seen as dimensions, which cannot necessarily be placed on different sections on a spectrum, perhaps suggesting that mere juxtaposing or linking insufficient to achieve real integration. On the other hand, transaction cost theory is primarily concerned with exchange, while capabilities theory is concerned with production,

therefore they relate to the firm-market and individual-firm levels of analysis respectively. Here integration could mean that contribution of both theories would enable the new theory to operate on the combined levels of analysis.

A conceptual framework addressing multiple levels requires relevant variables that carry some common aspect across the levels, at the same time be distinct enough to be associated with different levels. This is so that the variables could be distinctly labelled at the same time their relationships with each other could be established. For example, interactions of nano-scale devices with macro fields can be seamlessly modelled due to presence of common units among the differently originating/labelled variables that are interacting. Coming back to the variables of the transaction cost and capability theories, they indeed influence each other; however they come in different units. While transaction costs are more quantitative, capabilities are qualitative in general. Taking pride in its operationalization, transaction cost is seen as the economic counterpart of friction in mechanical systems:

"Transaction cost analysis entails an examination of the comparative costs of planning, adapting, and monitoring task completion under alternative governance structures". (Williamson 1996)

Capabilities perspective on the other hand compares capability based on achievement of certain objectives ex post, with only qualitative measures for latent capability. One way to solve this is to further breakdown transaction costs and capabilities into its constituents, where reductionism proceeds until a common aspect/unit is found across the levels of analysis. We ambitiously call this as an integrated approach, for not only do the variables of our theory aim to cover capabilities and transaction costs, but also other aspects of a firm (at a certain level of reductionism). Therefore this way of approaching at theory has striking resemblance with the following view:

"In its classical form, economic theory is simply a language designed to provide a systematic framework within which to analyze economic problems. On the one hand, it is an exhaustive set of general concepts. Any variable observed in the system can be assigned to an appropriate niche. The theory is a set of filing cabinets with each drawer bearing the title of an economic concept. Within each filing drawer there is a set of folders for each economic variable relevant to the concept. Within each folder there is a breakdown in terms of the factors affecting the variable. At the same time, theory is a statement of critical relations among system variables. These relations may

be assumptions about interdependence among variables, about the functional form of the interdependencies, or about broad structural attributes of the system. One of the most important requirements for usefulness of theory conceived in this general way is the requirement that all important variables in the system be conveniently represented within the concepts of theory." (Cyert & March 1992)

To this end, we reduce the firm to its constituent actions and assets in a general manner, such that action variables and asset variables with respect to the relevant to each level of analysis (market-firm-individual) can be used to achieve real integration. In other words, a theory aims to identify a set of distinct observations as a class of phenomena and make assertions about the underlying reality that affects this class. A comparison of the emphasized levels in transaction cost, capability and the integrated approaches is given in Figure 4.1. We thus settle for reduction above the level of cognition and motivation, as the latter is too fundamental, such that it has to be studied in its own right contingent to stimulus and responses at the different levels of analysis. Delving into cognition and motivation would be necessitated if a theory is meant to explain success and failure, which is beyond the scope of the theory of the firm:

"That there are firms who consistently maker mistakes, over-estimate what they can do, guess wrongly the future course of events, no one can doubt, but they do no interest us here; no theory of growth will explain their actions - only a theory designed to explain 'mistakes' or failure". (Penrose 1959)

Adopting the existing premises set up the two prominent theories of the firm, may have stifled efforts towards real integration. A back to basics approach would help rearrange the premises, so that theoretical analysis can made without inheriting the failings of either approach. A detailed critique of the transaction cost and capability theories are not included in this paper, for which we suggest recent literature on these perspectives (Arend & Bromiley 2009, Foss & Klein 2008) in addition to the reviews cited above.

Our approach parallels the ongoing effort to integrate the two prominent theories of the firm (Langlois & Foss 1999), including the work on co-evolution of transaction costs and capabilities. The latter explained their intertwined character with respect to the determination of vertical scope (Jacobides & Winter 2005). This approach integrates the two approaches within an evolutionary framework and goes full circle touching upon the firm's internal development processes influencing the market development process and vice versa. Accordingly capability

Figure 4.1: The emphasized level of analysis in the three approaches, and the correspondence between the levels and integrated framework

differences are necessary for vertical specialization; transaction cost reductions are pursued but leads to specialization only if capabilities are heterogeneous; vertical scope in turn influences capability development process; and capability development process changes the roster of qualified participants in the market. The contribution of our paper is in the unification approach through reductionism, and the explication of a different set of micro-foundations, which is hoped to effectively bridge the competing aspects of coverage and operationalization in the theory of the firm.

4.3 Towards an Integrated Theory

The theory of the firm is meant to addresses three broad questions, namely: why do firms exist, i.e. why are they better means of organizing for commercial purpose; how are boundaries of the firm determined and how do they differ; and how are they organized (Coase 1937). Given that the firm performs several activities with several objectives, it is only fair to see if there is more than one reason why firms are better than simple market relations. The same logic applies to boundaries of the firm and their internal organization. Consolidating these reasons within a consistent theoretical framework would be the aim for the integrated theory of the firm.

Unification requires some binding ingredients that can sufficiently glue the seemingly disparate branches of the phenomenon. We consider actions and assets of the firm, which naturally occur as explanans and explananda in the existing theories of the firm. Actions can be interpreted as operators and assets as operands and outcomes, thus making it sufficient to explain all aspects of the firm, where boundaries are outcomes of operations, which in turn influence future operations. Actions and assets are present at all the levels of individual-firm-market, where these levels are influenced and influence the institutions. Therefore institutions are considered in parallel and implicitly to the three levels of analysis, but the special role of institutions would be revisited in later part of this section. Categories of actions and assets that are chosen also need to interact sufficiently with levels of analysis, to obtain sufficient coverage. The strength of association of the variable with the level of analysis would be based on the purpose and arena of application. The specific interactions also ensure that all the levels of analysis are appropriately addressed, avoiding the need to unnecessarily stretch

interpretations of the ensuing theoretical framework.

All actions undertaken by the firm can be classified under three categories, namely: coordination, development and appropriation. Coordination refers to the set of actions that make people or things combine in harmonious relation to achieve a specific goal. Development refers to the action of bringing growth or transformation to existing assets. Appropriation refers to the action of taking possession of the worth of an asset. This categorization is chosen such that there is sufficient overlap with each level of analysis providing coverage for a firm's activities across the levels. We will subsequently argue that these action operations on the assets are accomplished more efficiently via firms than through market relations, thereby addressing the question of firm existence.

Similarly assets of a firm can be classified under three categories, namely: resources, capabilities and value, which can also be interpreted to interact with the different levels. Resources refer to means that are the accessible to the firm. Capability generally refers to the ability to perform a set of tasks, utilizing resources, for the purpose of achieving a particular end result (Peteraf & Helfat 2003). Capability may be expressed in terms of the resources such as human, physical, financial, informational and intellectual. In other words capability may be enabled when the resources come to life. Value is the worth, usefulness or importance of a resource or capability. We will argue that firms pursue the enhancement of one or more of them, either by internalizing or externalizing its production, thus setting up the primary basis for boundary determination.

In addition to interactions of action and asset variables with the levels of analysis, the actions specifically operate on (all) the assets. This interacting set of variables covering the necessary levels both at the action and asset level is well suited to address the third question on internal organization. Table4.1 shows a stylised comparison between the transaction cost, capability and integrated approaches.

Before each of these variables is further clarified with a view to cohere with the levels of analysis, it is helpful to define what these levels of analysis refer to. Unlike the unit of analysis which is to do with what to study, the level of analysis is to do with context of study i.e. which has implications on how to study it. Therefore there could be different units of analysis in the same level of analysis. The constituents at the individual level are independent human and inanimate resources, which may interact between themselves. The constituents

Features	TC	Capabilities	Integrated
Theoretical emphasis	Why do firms exist?	Why do firms differ?	Why do firms exist differently?
Comparison	Markets and Hierarchies	Firm and Competitors	Ecosystem and Firm
Level of analysis	Market-Firm	Firm-Individual	Market-Firm-Individual
Primary driver	Efficient governance structures	Competitive advantage	Advantages of the firm in the ecosystem
Conceptual anchor	Exchange, transaction costs	Production, knowledge/resources -VRIO	Coordination (C)-Development (D)-Appropriation (A)
Raison d'tre of firm	Hierarchies more efficient in governing asset specificity and uncertainty	Indirectly addressed: Coordinate specialization	Achieve efficiencies in C and/or D and/or A
Boundary decision	Minimize transaction cost	Superior capability or knowledge utilization	Priority enhancement of existing resource and/or capability and/or value coupled with attractiveness of market option
Internal organization	Indirectly addressed: incentive alignment improves performance	Routines, tacit knowledge, dynamic capabilities	Operation of (CDA) with respect to resources, capabilities and value

Table 4.1: Stylised comparison between the three approaches

at the firm level are a collection of individuals that act collectively towards firm goals, where interactions particular to this level are between such collectives or between organizational systems. Here a firm or enterprize is a partnership of two or more persons, which is recognized as a legal entity engaged in commercial activity. The constituents at the market level are firms, individuals and institutions, where interactions particular to this level happen across a market interface (arms-length). Every higher level encompasses the lower level, but constituents and interactions are attributed to the lowest level at which they can be justifiably defined. For example, if two individuals were to interact with each other via an arms-length transaction (reflecting a market value for the deal), then it would be at the market level, else if the interaction has a professional basis geared towards achieving firm level goals, then it would be at the firm level, else it would be at the individual level. In the following, the actions and asset variables would be explored in relation to questions of the theory of the firm.

4.3.1 Existence of the firm

The inherent purpose of coordination is to primarily achieve cooperation between individuals thereby achieving certain objectives, hence has a strong association with the individual level of analysis. Coordination at the firm level is done in order to achieve cooperation between collections of individuals, where in order to achieve cooperation for the benefit of the firm, common interests and/or incentives are invoked on the individual level analysis. These provisions achieve beneficial cooperation and are expected to lead to development of assets. Coordination at the market level is done in order to achieve arms-length agreements between individuals and individuals; or firms and individuals; or firms and firms; or firms and institutions. This arms-length agreement leads to the appropriation from the assets. Departure from arms-length relationships would resolve the coordination action down to lower levels as discussed previously.

Coordination and cooperation are considered as the essence of an organization (Barnard 1938). Firms are zones of convergent expectations and therefore achieve coordination more efficiently than markets (Kogut & Zander 1996). Even temporary firms exhibit convergence to common ground via role identities (Bechky 2006). Organizational processes and systems considered in subfields such as operations management (Chase et al. 2006) and human resource management (Bratton & Gold 1999) in general come under this category. Interde-

pendence is a key issue in research on coordination, where efficiencies could be obtained by designing architectures for coordination (Baldwin & Clark 2000). The choice of intra-organizational coordinating mechanisms such as centralisation/decentralisation has an effect on problem solving among interdependent divisions of organizations (Argyres 1995). It is interesting to note that interdependent interactions between the internal divisions of the organization and outsourced firms have shown negative implications on performance (Srikanth & Puranam 2008). The case for efficient achievement of coordination with the firm can be made due to manner in which assets are brought together towards sustainable commercial purpose, i.e. by bringing parties to one side of the exchange, where leadership, residual rights, convergent expectations, recombination of knowledge and common culture, would alleviate the haggling and opportunism prevalent in market relations.

The inherent purpose of development is to achieve a beneficial transformation. Development at the individual and firm levels aims to build resourcefulness and capability to achieve operational and strategic goals. Development at the market level aims to shape the value proposition of products/services of the firm in the market. The efficiency of the firm over market in development of assets lies in its recombination advantages, cross-subsidization and possibility to exploit slack potential (Cheng & Kesner 1997, George 2005b, Sharfman et al. 1988). Broader learning and knowledge accumulation within the firm improves absorptive capacity (Zahra & George 2002) enabling better adaptability to change and possibility for ambidextrous behaviour, which has been found to have positive sales growth (He & Wong 2004). Entrepreneurial ideas often do not start without external partnerships with capital owners, which is particularly the case with risky ventures. The process of getting an idea to product involves uncertainty, which would make lone individuals would be averse to proceed without sufficient backing. Investments via market relations to such projects would provide no incentive for the risk, which is the contrary to those who become partners under a firm governance structure, where equity is shared in exchange for risk. Development is a costly endeavour to either increase quality or value of the assets, and often recouped only relatively longer term returns. In high velocity markets in particular, such long term investments via market relations are unlikely to be obtained without high stakes. Shaping value proposition of assets in the market is better achieved using the resource, capability and value base of a firm, which can sustain and withstand competitive and institutional pressures. The endurance of

lone market entities is more likely to wither and be shaped. The action category of development is strongly associated with building a capability, which from the above examples is more efficiently organized in a firm.

The inherent purpose of appropriation is to obtain worth of an asset. At the individual level this would apply to receiving incentives in exchange for effort. At the level of the firm, appropriation may apply in the form of credit for success, financial and non-financial incentives for teams. The most apt arena for this action category is the market level, where the worth of the assets - resources, capabilities and value can be extracted across the market interface. The market is a place for appropriation. Product leadership can be achieved to gain higher rents (by volume or price) via integrated service provisions and cost-effectiveness. Diversification to maintain a portfolio of products grants legitimacy, in addition to brand management. The worth of products/services of firm can be enhanced through protection - IP, supplementation - value added, integration - more than sum of parts, legitimization - conformance or institutional entrepreneurship (Leca et al. 2008). Hence value appropriation can be seen as a capability (Reitzig & Puranam 2009). This action category therefore interacts with the individuals, firms and institutions in the market level. Thus appropriation is strongly associated with the market level. Efficient appropriation requires bargaining power, which can be enabled through protection; value added services and shaping the market. These activities are best performed via the firm, as market relations would open it up for unwarranted competition, opportunism and haggling.

To summarize, firms exist to achieve sustainable efficiencies in coordination, development and appropriation. Transaction cost and capability perspectives have been used profusely in an integrated fashion using the action-asset categories at all levels in the ecosystem. The existence of the firm is thus addressed via an integrated framework.

4.3.2 Boundary decisions

The boundary of the firm is determined by whether efficiencies that underpins its existence are furthered by internalizing or externalizing some of its operations. The actions of the firm are not performed for the sake of performing them, rather to enhance the assets through such actions within or across boundaries. Firms may engage within or without boundary actions to enhance its resources and/or

capabilities and/or value. Based on this premise, there are two factors that firms consider in arriving at boundary decisions. Firstly, firms have priorities that elevate the worth of certain assets at a certain point in time. Secondly, the attractiveness (in the relevant dimensions) of assets that is available in the market.

Although all actions interact with all assets and all levels of analysis, certain actions are natively associated with certain assets when it comes to boundary decisions. This is based eliminating redundancies among combinations of operations of action variables on asset variables. For example: coordination of two resources is performed to merely bring cooperation among them; coordination of two capabilities is performed to bring beneficial transformation, which is the same as development of capabilities; coordination of two value propositions is performed to bring obtain the worth of their combination. In other words: coordination of resources, coordination of capabilities, and coordination of value are equivalent to coordination of resources, development of capabilities and appropriation of value. The other combinations are treated likewise. Therefore the first factor influencing boundary decisions of whether externalize or not is based on priority or need for enhancing the assets, which could be one or more of coordination of resources, development of capabilities or appropriation of value. (See inner circle in Figure 4.2). This approach is consistent with recent findings that market complementary and resource compatibility are critical matching criteria in alliance formation (Mitsuhashi & Greve 2009).

The potential to introduce formalism could be explored here, as it is often seen as the test of the usefulness of a theory. Let us choose r, c, v to represent resources, capability and value; and pr, pc, pv to represent the priority given to r, c, v; and assets variable with subscripts represent a measurement of the attractiveness of existing assets in the firm and represents a measurement of the attractiveness of asset available in the market. The respective priorities are based on cognitive and motivational issues, where the effective priority for a particular asset i is given by: , where is a asset priority normalization factor. The criterion for internalization or externalization is: given the priority is the chosen asset enhanced within the firm or not, which can be given for resources, capabilities and value as

Where are thresholds for r, c, v that can justify the pitfalls of market relations, which is set by firm based on its strategies, risk aversion, cognition and

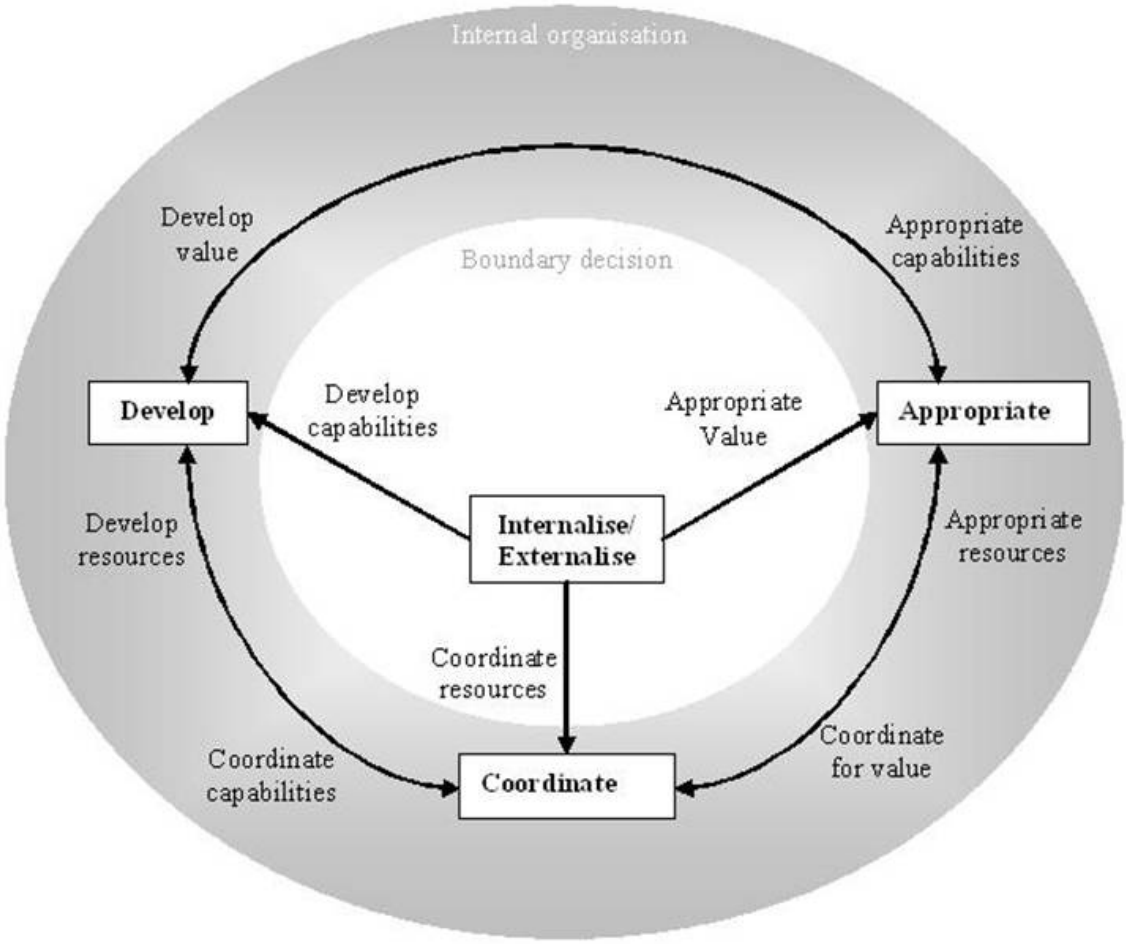


Figure 4.2: Illustrative schema of boundary decision and internal organization in the integrated perspective.

motivational contingencies. Different techniques similar to those currently used in economics and financial mathematics may be adopted to quantify these variables.

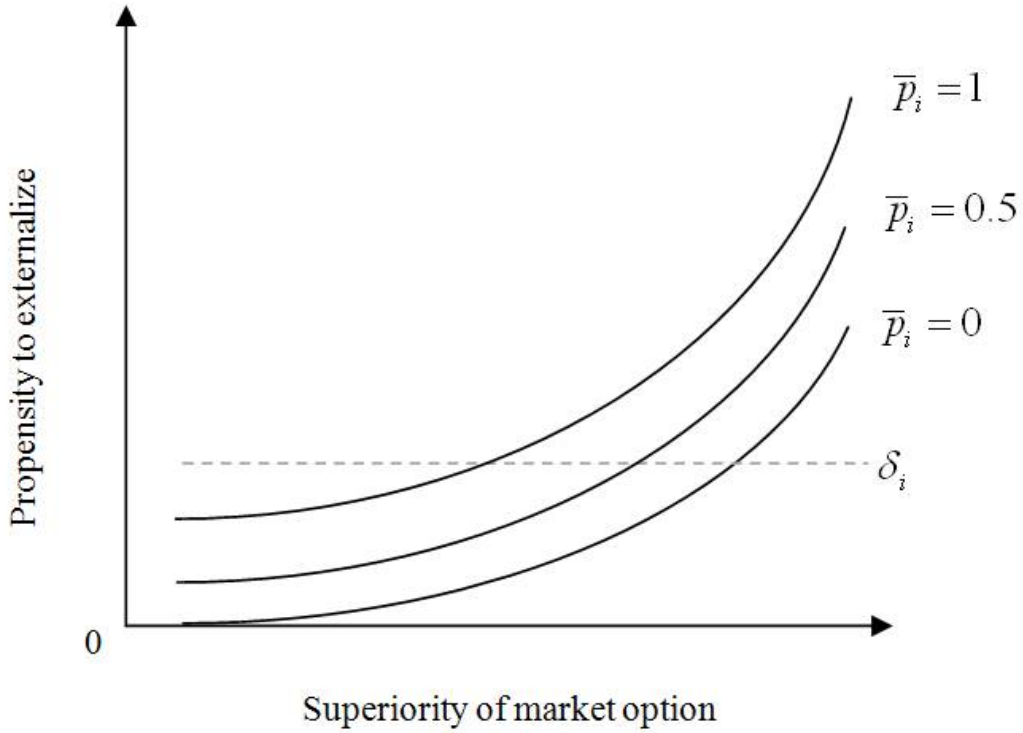


Figure 4.3: Schematic plot to illustrate the relationship between externalisation, priority given to the asset i and the effectiveness of getting it in the market.

Therefore if the effective priority for developing capability is low, then even in the presence of superior/cheaper market capabilities, externalization would not materialize, as the threshold may not be exceeded. Similarly, even if the priority for appropriating value is high, the absence of more attractive value propositions in the market would still not result in externalization, as thresholds may not be exceeded. And finally, if the expectations of the firm, resulting in a high threshold, the presence of priority and attractive market assets would still not lead to externalization, as thresholds may not be exceeded. This is illustrated in the schematic plot shown in Figure 4.3. Therefore in summary boundary decisions are based on the premise of efficiencies underpinning its existence, and are contingent upon the priority for enhancing certain assets and the attractive of the corresponding assets in the market.

4.3.3 Internal organization

The third question of internal organization is more complex than the questions of existence and boundary decisions. This is indicated by the sheer variety of internal organizations, drawing contingencies from every parameter affecting the action and asset categories. Based on the above framework, broad sketches can be made to categorize elements of internal organization, i.e. based on combinations of operations variables on the asset variables. (See inputs to each of the action categories in Figure 4.2). This is beneficial, as it provides a useful and exhaustive criteria for categorizing most (if not all) applied literature in business, management and economics.

The dynamics of internal organization can also be formalized with reference to the measures of strategies/objectives of the firm, based on the effective priorities for respective actions on assets, and appropriate operational measures of actions and assets. The optimal or pareto-optimal set of actions that can then efficiently achieve the objectives of the organization could be an interesting avenue to explore. The solution to such problems can be made easier by incorporating techniques in modular architectures and complex problem solving. In summary, the question of internal organization of the firm has been addressed based on action and asset variables within a consistent framework that was applied to also address questions of existence and boundary decisions of the firm.

We now come back to issue of institutions, which permeate across the individual-firm-market levels of analysis. While firms are shaped by the markets (Porter 2008) and institutions (ang1997), firms also shape the markets (Jaworski et al. 2000) and institutions (Garud et al. 2002, Lawrence 1999). The framework described above is enabled to address both aspects; for example: the actions performed to enhance the asset variable value include the possibility of shaping the market and the institutions. We will review to two case studies which engage in these actions.

We see this consistent framework as a step towards an integrated theory of the firm. It was also shown that this framework is amenable for formalism, modelling and can be easily adapted to currently used operationalizations of actions, assets, priorities and market attractiveness. See Table 4.2 for consolidation of the variables and their interactions with examples. The action and asset variables and their interactions covered all the relevant levels of analysis, thus striking an effective balance between parsimony and comprehensiveness.

Actions	Existence(why firm?)	Assets	Boundary (why externalize?)	Actions on Assets	Internal organization (how are they organized?)
Coordination	Efficient matching of assets towards sustainable commercial purpose, by bringing parties to one side of the exchange, where leadership, residual rights, convergent expectations, recombination of knowledge and common culture, would alleviate the haggling and opportunism prevalent in market relations. Example: mass service/production	Resource	The criterion for internalization or externalization is contingent on whether the respective choice would enhance existing resources. Example: payroll system	Coordinate Resources	Allocating and connecting resources Example: equipment sharing
				Coordinate capabilities	Coordinate existing heterogeneous and/or homogenous capabilities Example: modular project management
				Coordinate for value	Making existing value proposition available. Example: satisfying stakeholder consensus
Development	Efficient platform for learning, trialling, adapting to change and development via combining expertise under uncertainty, cross-subsidization and exploiting slack potential. Example: entrepreneurial venture formed to develop idea into product.	Capability	The criterion for internalization or externalization is contingent on whether the respective choice would enhance existing capabilities. Example: superior technology	Develop resources	Enhance existing resources Example: increase computing power.
				Develop capability	Enhance existing capability Example: training
				Develop value	Enhance existing value proposition Example: Corporate governance, institutional entrepreneurship, platform engineering
Appropriation	Efficient appropriation of value via stronger protection (by sharing assets and risk), platform engineering (value added supplementation), integration (more than sum of parts) and legitimization (institutional alignment). Example: Technology Transfer office.	Value	The criterion for internalisation or externalisation is contingent on whether the respective choice would enhance existing value.Example: investing in platform technologies	Appropriate resources	Utilize resources. Example subsidize infrastructure, obtain a loan.
				Appropriate capabilities	Take advantage of capabilities Example: securing patent.
				Appropriate value	Leverage from value Example hiring inalienable or alienable assets

Table 4.2: A reductionist perspective - actions and assets related to the firm, tabled to address the questions of the theory of the firm

4.4 Quasi-Boundaries

Boundary of an entity may non-controversially be defined by its assets, even in the knowledge economy (foss2002). The debate of boundary versus lack of boundary masks the possibility for smearing of firm boundaries. This smearing can be illustrated by how easily we may define the boundary of a house, but how would one define the boundary of a home? A home is made of more than physical assets. A quick stock take would reveal what may be considered to be assets would include nature of inhabitants in the house and their relationships, the nature of neighbours and their relationship, borrowed and lent items, facilities in the house, surroundings and its relationship. What is outside the boundary of the house is so important to a choosing it as a home that the value of the house depends significantly on its locale. It is often said that one can change their house, but not their neighbours. So where does the boundary of the home lie? And where does the boundary of the firm lie? Are we missing out on important features of firm sustenance by assuming a strict notion of boundary of the firm? - check out Pisano 1990 ASQ R&D boundary paper.

The asset categories of the firm comprise physical (resources) and intangible (capabilities and value) assets, where the intangible assets may derive their worth due to assets and actions that exist beyond the firm. The implications of ignoring these influences could be detrimental to our understanding of potentially key success criteria for the firm. We introduce the concept of quasi-boundary to explore these implications.

Existing theories of the firm assume boundaries that are supposedly absolute. Although permeability (Jacobides & Billinger 2006) and evolution of firm boundaries (jacobides2005) have been discussed, the boundaries however they were defined and modified still followed the strict notion of absolute boundaries. Boundaries may have a less strict version, where a firm could count as its assets that which are beyond what may conventionally be thought of as its boundary. We call this less strict version of the boundary as a quasi-boundary, where there is overlap or have spill-over influence of actions and assets of associated entities. Quasi-boundaries exert positive appeal, enabling the enhancement of its assets within the strict boundary defined by ownership and control.

Does the concept of quasi-boundaries have implications for how the boundary decision question is addressed by the theory of the firm? If the argument is based

on achieving an effect through the cause of externalization without considering alternate modes of achieving the same effect, then argument 'might' fail. The argument may not fail if the alternative modes such are not preferred, due to other disadvantages. The purpose of introducing quasi-boundary is with regard to success factors which can result from it. Quasi-boundaries are inadvertently the arsenal of strategists, for several carefully designed inter-firm relationships exhibit quasi-boundary characteristics. In the context of the discussion on firm boundaries, the main point is that assets can be enhanced without necessarily externalizing i.e. changing the strict version of boundaries, but by leveraging the advantages of quasi-boundaries.

Proposition 1. The effectiveness of exchange between organizations relate positively to extent of quasi-boundary overlaps.

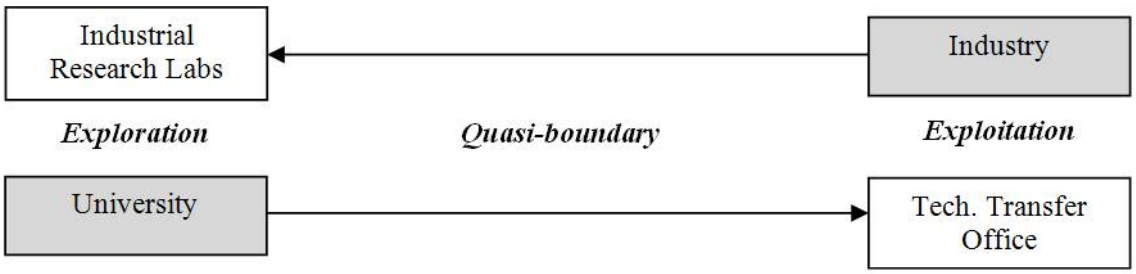


Figure 4.4: Organizations pursuing complementary mode of capabilities: Technology Transfer Offices (eg. WARF, 1924) were formed with an external quasi-boundary, and Industrial Research Labs (eg. Philips Natuurkundig Laboratorium, 1914) via an internal quasi-boundary.

Although less dramatic, the concept of quasi-boundaries also applies internally to the organizational divisions or subsidiaries, with useful implications. The early part of the last century saw the seeking of complementary capabilities among organizations: universities moved to found new organizations that can commercialize their research, and industry players moved to found new autonomous divisions that could conduct path-breaking basic research (See Figure 4.4). The former is an example of an organization having external quasi-boundary, where the successor of that effort continues to exist today in the form of the technology transfer office. The technology transfer offices in many universities are independent organizations having independent ownership and control rights, where

funding by the office and disclosures by academics are both voluntary. Nevertheless they enjoy enormous success in leveraging each other's advantages. The interactions between these organizations may legally satisfy arms-length agreements across the market interface, but relationship between them across other dimensions influence voluntary decisions. On the other hand the industrial research labs were an example of an organization having an internal quasi-boundary, where a non-market facing autonomous division is formed. The difference here is that ownership is still with the firm, but division behaves very differently and seeks very different objectives, arguably is often not necessarily aligned with the transaction cost reduction interests of the parent firm. This independence is evidenced by outcomes: industrial research labs have produced several discoveries that have immense impact in the world (winning several of their researchers the Nobel Prize), but the technology was not commercialized by the parent firm; and technology transfer offices have produced highly commercial entities, several of which are neither attached in anyway nor produced any benefit to the university.

Proposition 2. The strictness of the boundaries would diminish with increasing complexity of the market. (where dimensions of complexity are interdependence, competition and diversity of components in the product/service).

Increasing interdependence, competition and diversity of components comprising a firm's product/service motivated increased interaction with market players to reduce transaction costs, increase value, trump rivals, diversify and collaborate. These interactions are sought to reduce restrictions and rents associated with otherwise arms-length deals in the market.

Organizations that outsource part of their value chain, maintain different relations with those suppliers compared to the general market of traders. Here relational contracting, networks and hybrid forms need to be considered when boundaries are discussed. Apple has vertical integrated its suppliers in the quasi-boundary sense, enabling it innovation in any component or subsystem or at any level in the supply chain. Apple is thus able to take responsibility for every aspect of the product or service. In 2007, iSuppli ranked Apple ranked fourth overall in terms of design influence on semiconductor spending in the United States, trailing Hewlett-Packard, Dell and Motorola.

Even with explicit contracting, arms-length relationships can be transformed

into to collaborative relationship in the supply chain via trust and information sharing (Hoyt & Huq 2000). Strong companies exert significant influence on upstream entities without ownership or control rights, such as the case of Sainsbury's demand to Irish beef makers to upgrade to US standards without incentivising their efforts. Markets conditions can indeed intervene to enforce quasi-boundaries. Other topics of interest which could involve quasi-boundaries include ambidexterity, dynamic capabilities, imprinting effect, trust, loyalty, branding. Quasi-boundaries have implication for discussions on modularity, and analysis on process flows that assume of sequentially interdependent units.

4.5 Shaping The Ecosystem

Two unique organizations WARF-Wisconsin Alumni Research Foundation and Symbian Ltd. are used to illustrate issues related to theory of the firm and the concept of quasi-boundaries. WARF founded in 1924, is the first university technology transfer office in the form it is exists today. Symbian founded in 1998, was founded and owned the top players in the mobile device market with the ultimate goal of establishing the Symbian mobile operation system as a standard, in order to respond to challenging market developments. The content presented on WARF was obtained from published and unpublished historical records, interviews and financial reports sourced directly from the organization. Information on Symbian was obtained from official published information in addition to Google's new Timeline tool, which lists all content on the net about the keyword - Symbian in a chronological format, all of which (up the time of writing) were considered and corroborated wherever necessary with officially released information.

4.5.1 Shaping the Institutions: WARF 1924-2000

In the early part of the 1900's, universities were becoming involved in patenting research, using arrangement that can avoid the sticky problem of patenting of publicly funded research. In 1917 the regents of the University of California accepted an academic's offer of patents and created a patent-management corporation with themselves as trustees. The board of regents at the University of Minnesota decided to process any patents developed on its campus. In 1924 Columbia University established University Patents, Inc., a patent-holding cor-

poration wholly owned by the university, which in turn entered into agreements with the Research Corporation, a non-profit foundation that handled patentable discoveries for institutions and their faculties. Several New York business people had created the Research Corporation at the request of the Smithsonian Institution, as the latter was unwilling to direct a commercial enterprize to manage a donation of the right to an electrical precipitation process (Apple 1989).

University of Wisconsin's Harry Steenbock and company adopted a different solution. Having already lost the opportunity to patent his concentrated Vitamin A discovery due to the dilatory actions of the regents, they were reluctant of to use university funds to patenting his Vitamin D irradiation process, unless Steenbock guaranteed repay. With advice from friends of the University a proposal was made for a corporation similar to that developed in California and Minnesota but keeping the commercial and the academic aspects completely separate. Strongly influenced by the view, that educational institutions would not run an efficient business, the proposal called for an independent organization, directed by friends of the university. With this arrangement, commercial matters would not involve the university and its educational mandate; while at the same time researchers could benefit from a well-managed patent whose royalties would pay for other scientific work. Thus the formation of WARF was based on an deeper understanding that a public funded university lacked efficiencies available to a firm, and what was required to run a successful business, i.e. resources needed, capabilities that need to be developed and value that need to be extracted from it.

The success of WARF is not only in achieving economies of scale in effectively managing patents but also took the responsibility of shaping the institutions of commercializing university research and also bringing to bear the same capabilities to shape the market for acceptance of radical innovations (jain2007). See Table 4.3 new initiatives during different periods. The institutional entrepreneurship of WARF as an organizational form is highlighted by the fact that by 1956 there were more than fifty similar organizations were incorporated (Palmer, 1956). More substantially, the decline of a contemporary organizational form represented by Research Corporation (RC) and explosion in the number of universities entering technology transfer (Mowery & Sampat 2001a), shows the adoption of one form in opposition to another.

As for RC, it began to encounter difficulties in getting its university partners in line with its preferences. Universities cherry picked high-yield patents

Period	Evidence	TC	Capabilities	Integrated
1924	Formation of WARF and patenting Vitamin D.	Avoid shirking at UW, given experience of Vit A. Avoid opportunism of the market given the experience of Babcock tester.	×	Coordination: obtain funds from alumni to setup new organizational form to avoid backlash from public and academia for patenting/licensing publicly funded research. Appropriation: The core product of the organization has demonstrated appeal, which will not realise its true potential from a university base.
1940	Quality assurance, patenting, licensing, receiving disclosures, funding university.	(Partial) incentivise inventors with 15% returns from their patents.	(Partial) capability patenting and licensing, becoming preferred choice for disclosure by UW academics. High involvement in technology development due to in-house capability.	Develop capabilities: of technology along with licensees, generate economies of scale in patenting and licensing capabilities. Develop value: fund university development and research programs to increase value in order to strongly and favourably identify WARF with UW, thus making it natural home for UW discoveries.
1967	Institutional Patent Agreement with National Science Foundation and Department of Health, Education & Welfare	×	×	Appropriate value: UW secures right to patent research funded by DHEW. Less than 5% of university patents held by government agencies were commercialised in any form.
1980	Bayh-Dole Act: lobbying for legislation, testifying before congress, assembling examples of research developments thwarted by gov. policies.	×	×	Appropriate value: Secure right to own federally funded research for all universities and small companies
1990	Legitimising radical inventions such as human embryonic stem cell research	×	×	Appropriation value: Product level institutional entrepreneurship- protection, propagation and influencing - primarily focussed on appropriation, removing obstacles to secure returns from further investment in developing.

Table 4.3: Milestones in the evolution of WARF: comparative logic from transaction cost, capabilities and integrated approaches to the theory of the firm.

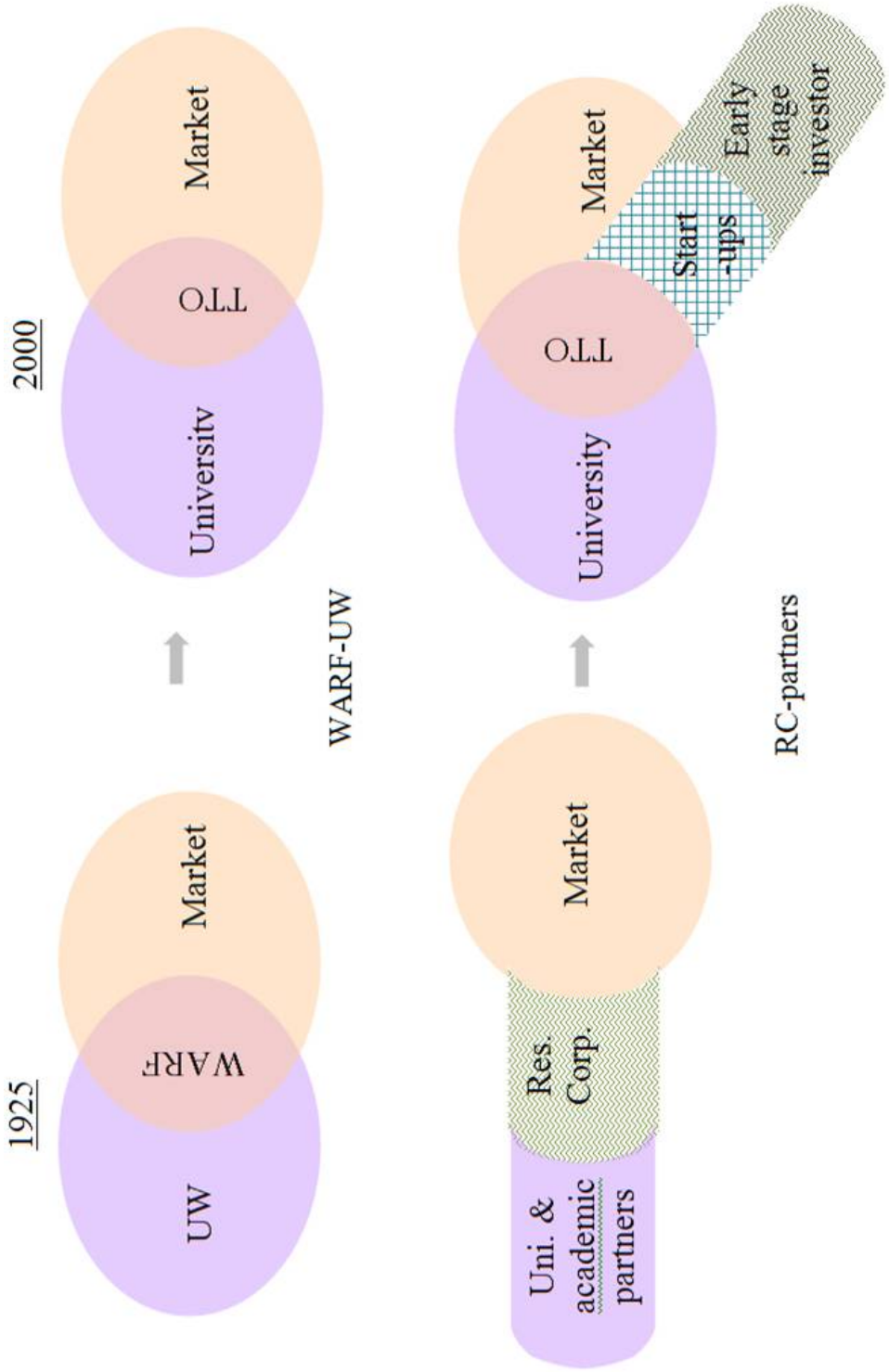


Figure 4.5: Comparison of the persistence of organizational boundaries: snapshots from 1925 and 2000 of Wiscoson Alumni Research Foundation (WARF) - University of Wisconsin (UW); and Research Corporation (RC) - partners.

to achieve significant royalty; excused themselves of patenting non-biopharma research with RC citing its incompetence; conflict of interest arose between the corporation and universities; and the transfer of patenting and licensing capability to university administrators contributed to Research Corporation's decline. The Bayh Dole Act (which was sought by WARF), was the final straw in deciding the fate of the Research Corporation. It replaced the web of agreements for specific individual agencies and other case by case considerations with a uniform policy, which allowed federally, funded research to be patented and licensed (even exclusively). After the Bayh Dole Act, it was further hindered by its charity foundation status, whose activities the US Internal Revenue Service deemed as unrelated trade of business. It took up to 1987 for Research Corporation to transfer its activities to an independent for-profit organization - Research Corporation Technologies. Despite inheriting the patent portfolio, a large endowment as well as the Research Corporation's staff, which has enabled it to continue generating revenues; its activities became focussed on research grants, cooperative administrative and benchmark programs for universities. Recent activities are focussed on early stage funding for research based start-ups from institutions. Figure 4.5 shows a graphical illustration of the persistence of WARF boundary and the evolution and conformance of RC to efficient organizational form.

The success of WARF lies in the careful choice of quasi-boundary, where it drew on the assets of University of Wisconsin. This is opposed to RC, whose boundaries were stricter owing to its lack of shared history and interests with its academic partners. Boundary decisions of WARF was based on several factors including positive perception of its business model; the business relevance of university research; incoherence of commerce and the education mandate; lack of professional support from university; lack of precedent business model that can sustainably leverage university assets for the commercial world and interest of alumni to invest.

It is interesting to note how transaction cost and capability perspective apply with regards to important milestones in WARFs evolution (See Table 4.4). WARF did not have a prior capability of patenting and also had to incur large initial transaction costs for a speculative venture. On the other hand WARF realized that achieving efficiencies in coordination, development and appropriation rests on forming a independent firm structure reducing the institutional and financial barriers, while at the same time choosing a quasi-boundary approach to leverage advantages that exist beyond the boundaries of the firm.

Priority activity	**Size**	**Nature of firms**	**Type of firms**
C	Small	Requires focus on resource and personnel, work with existing or accessible capabilities, taps available opportunities or demand.	Local, rentals, regular services.
D	Small	Works with lesser resources or personnel, requires competitive capabilities, taps available opportunities or demand.	Design, skilled work
A	Small	Works with lesser resources or personnel, work with existing or accessible capabilities, requires access and generation of demand.	Retail, door-to-door sales
CD	Medium	Requires focus on resource and personnel, requires competitive capabilities, taps available opportunities or demand.	Component manufacturers, R&D labs, suppliers and subcontractors
DA	Medium	Works with lesser resources or personnel, requires competitive capabilities, requires access and generation of demand.	Marketing capability, consultancies
AC	Medium	Requires focus on resource and personnel, work with existing or accessible capabilities, requires generation of demand and access.	Recruitment firms, resellers, courier, retail, , multi-level marketing
CDA	Large	Requires focus on resource and personnel, requires competitive capabilities, requires access and generation of demand.	Strong brands, oligopolistic, publicly traded, global enterprises.

Table 4.4: After inception, a firm's priority activities may relate to its size, nature and type.

4.5.2 Shaped by the Market to Shape The Market: Symbian 1998-2009

Facing high stakes competition with Microsoft, several top players in the mobile device market came together to create a globally accepted platform based on Psion's EPOC palmtop operating system (OS). The increasingly popular hand held smart phone devices allowed internet access, messaging, and other information transmission. The Microsoft CE OS was the key rival, which was anticipated to exploit its clout in the computing and software market to trump competitors. Any technology developed would be made available to the venture's owners, as well as licensees. This initiative was also influenced by a philosophy that aimed promoting open standards, to prevent monopolies from crippling its competitors. To keep the scope confined to the theory of firm issues, the evolution of Symbian in an already complex market is discussed by emphasizing the interaction of the firms, leaving out other technical information including product evolution in the market.

Symbian was initially founded in 1998 by Psion, Nokia and Ericsson; the trio were joined by Motorola later that year. In 1999 they were further joined by Matsushita. By this time Philips became a licensee and Symbian signed of a wide-ranging agreement with the Japanese mobile phone giant NTT DoCoMo to develop mobile telecommunication devices and services. Alliances were struck with with Sun Microsystems to include Java within its operating system, with Texas Instruments to work toward an Open Multimedia Application Platform, and other links with Oracle and Sybase were forged. It is interesting to note that Symbian's most influential partner Nokia signed a deal with Symbian rival 3Com's Palm Computing, calling for both to work together.

In 2000 a partnership was signed with IBM, and leading brands such as Sony, Kenwood and Sanyo selected Symbian for its next-generation wireless smart phones. Several other deals were made with software application providers such as Geo and Informix, BrainDock and Metrowerks. In 2001 Motorola and Psion cancelled their Smartphone joint development. Hardly dented, Symbian enjoyed continual success with Siemens and Fujitsu signing licensing agreement and the release of Nokia 9210 Communicator - the first open Symbian OS phone. In 2002, Siemens joined Symbian, and with Samsung licensing the Symbian OS for its smart phones, the world's top five mobile phone manufacturers were now Symbian OS licensees. The growing influence of the Symbian platform drew

Sendo, which ditched Microsoft for refusing access to source code and accusing it of stealing its technology and customers.

In 2003 Samsung joined Symbian, and Sony was also became associated with Symbian at the shareholder level due to the Sony-Ericsson partnership, while Motorola sold its stake and subsequently became a licensee of Microsoft. The Motorola share was picked up by Nokia and Psion. New licensees continue to sign in, including BenQ, Mitsubishi and Fujitsu. In 2004, Nokia attempted to Psion's stake and increase its shares to about 63%, but other shareholders prevented Nokia from exceeding 50%. Legend (Lenovo), LG and Arima also became licensees. Symbian also ran a platinum partnership program during all this time, which was joined by several developers such as NeoMagic, Insignia, Handango, Avaya and Innopath.

In 2006, Motorola and Sony-Ericsson took 50% stake in UI - a Symbian interface developer to face the competition from Apple's iphone, which was now seen as the new key rival. It should also be noted that UI Quartz competes with Nokia's Series 60 software - an interface that also runs on Symbians. In 2008, primary driven by the competition with Apple, Nokia to dramatically bought out all shareholders of Symbian, with a view to make Symbian open source. This was at a time when Google also entered the mobile domain with its Android OS. In mid 2009, the Symbian Foundation was formed, a foundation that is owned by members but not with shares, where foundation membership open to all organizations.

The change in equity holdings in Symbian is depicted graphically in Figure 4.6, which also reflects the change in boundaries of the constituent shareholders. The formation of Symbian was based on the recognition that appropriating value for assets of by the respective companies, would be done more efficiently if they could jointly develop a common platform OS to compete with Microsoft which has demonstrated capability to establish itself as a standard. The commitment of Nokia for Symbian was further enhanced when it realized that appropriating value in a market dominated by platforms, would be benefited by making Symbian open source and set up more effective quasi-boundaries leveraging on its existing influence. Boundary decisions were influenced by value and capability enhancing priorities aided by attractiveness of market shaping options. The response to Microsoft was markedly different from Apple's competition, which is reflected in their appeal and currently potent innovation practices. Nokia's

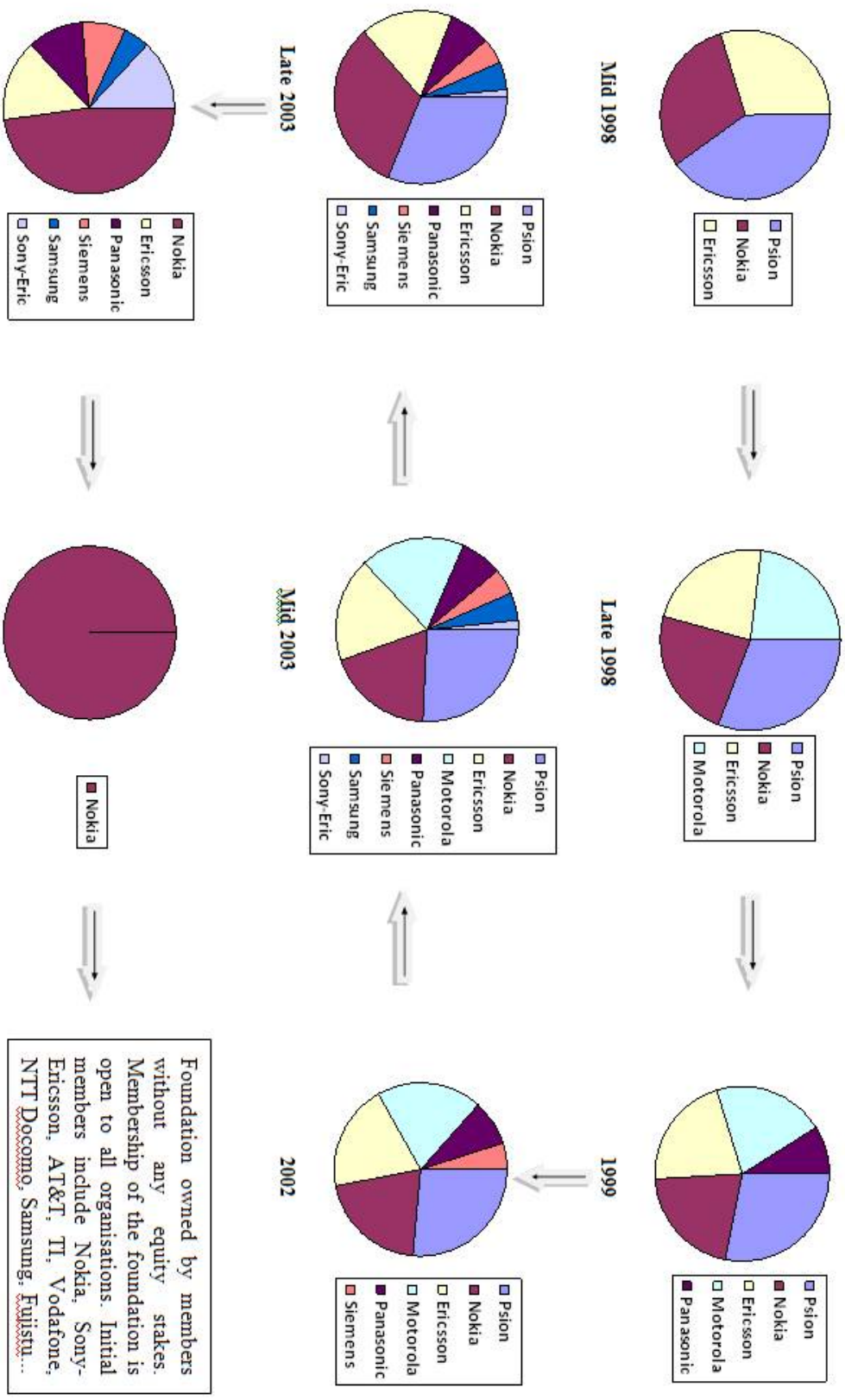


Figure 4.6: Boundary evolution of Symbian Ltd. in a hyper competitive mobile devices market during the last decade.

buying out of Symbian for $410m in order to make it freely available defies transaction cost and capability explanations. In contrast to integrating transaction costs and capabilities directly, the integrated approach is enabled to address it by approaching the firm through a reductionist perspective covering necessary action and asset variables. It would indeed be interesting to observe how Nokia's blend of manufacturing scale, technology influence, rapid innovation cycles and large circle of friends competes with Apple's usability and content partnerships.

4.6 Conclusion

We have presented preliminary efforts towards consolidating the issues related to theory of the firm. Firms exist to achieve efficiencies and sustainability in coordination and/or development and/or appropriation. Boundary decisions are determined by whether efficiencies in coordination and/or development and/or appropriation achieve, contingent upon the priority for enhancing certain assets and the attractive of the corresponding assets in the market. Internal organization of the firm was addressed based on the same consistent framework, by allowing action variables to operate on the asset variables.

In addressing the three questions of the theory of the firm, a select set of variables and their interactions have been introduced, which we believe also helps to categorize the majority of the applied literature (if not all) in the field of business, management and economics. The usefulness of the theoretical framework can be explored via operationalizing and formalism, which would enable modelling and applications to a wide range of scenarios. This suggests that further work could verify if gaps or inconsistencies of previous frameworks are alleviated through the integrated framework. The incorporation of the action and asset variables of the firm treated at the appropriate levels of analysis would add more reality to economic and financial analysis.

We alleviate our treatment of internal organization by exploring via Table4.4, the relationship between the priority actions of the firm and growth potential. Given the coverage of actions a firm needs to be successful in the market, this approach may be useful. Future work can verify and refine them further by establishing unique relationships and relate them to performance and implications for the ecosystem, which would justify why we should really be concerned with the theory of the firm.

Contemporary challenges to the theory of the firm come from several sources mostly spurred by advances in information sharing technologies. Supply chain partners can today work in tight coordination to optimize chain wide performance, sharing the profits suitably. Stakeholders have gained significant importance in the affairs of the firm, due to both expansion of firms into new arenas and increased awareness of stakeholders to negative externalities. Therefore shareholder maximization can be moderated by stakeholder interests. Open innovation (Chesbrough et al. 2006, Von Hippel & Von Krogh 2003) and platform engineering (Gawer & Cusumano 2008) have created new challenges to defining and determining boundaries.

The concept of quasi-boundaries was introduced to address issues which fail to be captured by the strict notion of boundaries. The strictness of the boundary of the firm was questioned, and it was suggested that the effectiveness of exchange between organizations relate positively to extent of quasi-boundary overlaps, and that the strictness of the boundaries diminish with increasing complexity of the market. Although the theory of the firm is not a predictor of success or failure of firm, the case studies on WARF and Symbian reflected sophisticated design of quasi-boundaries taking into account the efficiencies that underpin why a firm exists, is a factor in the success or failure of a venture.

The integrated theory of the firm builds upon the insights provided by the theories of the firm espoused in the last century. While being consistent with the insights of the theories of the firm, we provide a framework in which these insights are contextualized, and in addition provide few of the aspects the firm's behaviour in the ecosystem which has hitherto not been captured.

Part V

INSTITUTIONS - *THE META*

Chapter 5

Realizing the Commercial Potential of University Research: *Multi-institutional Entrepreneurship & Partial Isomorphism*

Contents

5.1 Introduction 137

5.2 A Brief History of University Commercialization . . 138

5.2.1 Connecting the Milestones of University Commercialisation 142

5.3 Multi-institutional Change 145

5.4 Foundations of Isomorphism 149

5.5 Partial Isomorphism 151

5.6 Discussion 153

5.7 Appendix 156

5.1 Introduction

Universities have traditionally held a mandate of education and the open exploration in the sciences and arts. By the early 20th century, the growth of technology based industries and the scale of wealth generation developed a general mindset that was preponderant towards commercialization. Some university scientists and administrators were thus caught between competing logics of universities and the market. Reconciling the two would take almost a century of transformation of multiple institutions rendering universities into entrepreneurial and market facing organizations, while at the same time managing to hold on to their original mandate. Initially seen by the community as being janus faced, the development of market relevant research capabilities and financial health is now seen as indispensable for reputation, growth, ability to attract/retain talent and ensure survival of universities as organizations. This chapter revisits the history of this institutional transformation to study mechanisms and factors of leads to sustainable institutional change.

Institutions exert one of most powerful influences on the ecosystem, owing to its legitimacy drawn either from conceptual justification, past success, adherents, by regulation or by statue. Most forms of human activity can arguably linked to institutional influences. *"Institutions are the humanly devised schemas, norms, and regulations that enable and constrain the behavior of social actors and make social life predictable and meaningful"* (North 1990, Powell 1991). *"Institutionalization refers to the processes by which societal expectations of appropriate organizational action influence the structuring and behavior of organizations in given ways"*(Meyer & Rowan 1977, Scott 1994).

The goal of this chapter is to carefully follow the story of the effort to commercialize university research to draw insight into the mechanisms and factors that leads to sustainable institutional change.. In particular, focus is given to the circumstances of the establishment of the Wisconsin Alumni Research Foundation (WARF), which set up an sustainable organizational form, followed by efforts of other actors such as university patent officers, federal patent attorneys, administrators and political figures.

5.2 A Brief History of University Commercialization

In the early part of the 1900's, universities were becoming involved in patenting research, using arrangement that can avoid the sticky problem of patenting of publicly funded research. In 1917 the regents of the University of California accepted F. G. Cottrells's offer of a patent and created a patent-management corporation with themselves as trustees. The board of regents at the University of Minnesota decided to process any patents developed on its campus. In 1924 Columbia University established University Patents, Inc., a patent-holding corporation wholly owned by the university, which in turn entered into agreements with the Research Corporation, a non-profit foundation that handled patentable discoveries for institutions and their faculties. Several New York business people had created the Research Corporation at the request of the Smithsonian Institution, as the latter was unwilling to direct a commercial enterprise to manage a donation of the right to an electrical precipitation process (Apple 1989).

The reluctance to use university funds to patenting his Vitamin D irradiation process, unless repayment was guaranteed, University of Wisconsin's Harry Steenbock and company adopted a different solution. He had already lost the opportunity to patent his concentrated Vitamin A discovery due to the dilatory actions of the regents, and also witnessed the abuse of the unpatented invention of his predecessor Stephen Babcock. Steenbock argued his rationale for patenting his invention, which he also unusually made evident in a Science article on his discovery: *"to protect the interest of the public in the possible commercial use of these findings, applications for Letters Patent, both as to processes and products, have been filed with the U. S. Patent Office and will be handled through the University of Wisconsin"* (Steenbock 1924).

Twenty years later WARF management would claim that Steenbock's decision was ethical because by giving his patent away, Babcock *"delayed the benefit of his test by 10 years the Babcock test was nearly discredited because of improperly calibrated measuring glasses used by irresponsible persons."* (Ross & Shoenfeld 1948)

In 1921 friends of the university, William Hoskins, a consulting chemist and Russell Wiles, a patent lawyer, proposed a corporation plan similar to that developed in California and Minnesota but keeping the commercial and the academic aspects were completely separate - arguing that no educational institution could

run a successful, efficient business. The adopted minutes of the 1925 Board of Regent's special meeting best describes the formation of WARF and what it stands for:

"The University recognizes that its organization is not well suited to attend to the details of patent procedure; to defend patents in litigation and conduct the necessary business of completing the commercial utilization of patents..

In providing a working plan by which this and similar matters can be handled, it is proposed to create an organization on a broad enough basis so as to embrace any other propositions of a similar nature that may arise in the future.

It is proposed to organize a non-profit-sharing corporation or trust, the necessary capital of which will be contributed by alumni and friends of the University, the management of such corporation to be placed in the hands of Trustees..

. It is understood that members of the University Staff who may assign patents secured in their name to this corporation for the ultimate benefit of the University research to which such funds shall be allotted." (Schneider 1973)

Setting the institutional change process in motion requires strong underlying claims and capable sponsors. The prospects for Vitamin D was not in question - its antirachitic effect was significant and commercial signals were already established from Quaker Oats. The initial trustees were from the legal and banking fraternity. The success of WARF in introducing a new organisational form modifying existing institutional elements in the university context is highlighted by the fact that by 1956 there were more than fifty similar organizations were incorporated (Palmer 1956). More substantially, the decline of a contemporary organisational form represented by Research Corporation (RC) and explosion in the number of universities entering technology transfer (Mowery et al. 2001), shows the adoption of one form in opposition to another. This indicates a favourable structural contingency in effecting sustainable institutional change.

Refinement WARF regulations and procedures continued for over decade. For example, the Grady resolution had restricted university accepted any grants from incorporated endowments or organisations, which was later rescinded by the board of regents due to alumni pressure. WARF funded research projects at the University of Wisconsin (UW), however disclosure of inventions by UW staff were voluntary and non-exclusive to WARF. WARF decided to incentivise inventors with 15% of profits, however limited their influence on the management WARF. There was significant business model uncertainty, which was rigorously

worked out either side of the supply chain. WARF placed very high importance on quality control of products that license WARF technologies, developing testing facilities. There were instances of quasi- vertical integration where licenses were subsidised in exchange for control on product development. Royalties were also adjusted based on competition and loss of infringement cases pursuing dynamic strategies. WARF was also cautious to patenting only those with commercial potential and without prior-art. It actively and extensively pursued infringement of its patents, and alleviated competition by purchasing processes and patents that competed with it. Leveraging on UW, WARF constantly worked independently to improving its reputation via large marketing campaigns, and relations with stakeholders such as the medical community. Sustainable sources of revenues were sought - Steenbock was encouraged to expand his Vitamin D portfolio, and employed a trademark when patent expiry was imminent. Collaboration, providing patenting services, seeking out inventions and patents from other businesses, universities and governments departments, grants funds for research external to UW were some of the other novel business practices of WARF. All these activities contributed to a steady increase in revenues and investments (see Figure 5.1), a step towards realising the commercial potential of university research. This indicates the learning effects, capability development across time- achieving better economies of scale in patenting and licensing (George 2005a).

The drive for institutional entrepreneurship, new opportunity identification, product development, sponsoring freehold research, strong public relations and legal perseverance, adjusting to changing political, economic and market contexts was continuing to be seen in WARF activities. In 1968, Howard Bremer WARF's then patent counsel, together with Department of Health Education and Welfare (DHEW)'s patent counsel Norman Latker and UW-Madison, obtained the first Institutional Patent Agreement (IPA) granted patent rights to recipients of federal grants. IPA's came in different flavours and were selective. Exogenous support for further institutional change was provided by other universities - Society of University Patent Administrators (SUPA) was formed in 1974, which was also presided by Howard Bremer.

Legislation for patenting federally funded research was in need of reform if universities were to realise their full commercial potential, and effective bring ideas to market. Here we encounter an aspiration embedded within interacting institutions, where institutional change had been achieve in one but not the other.

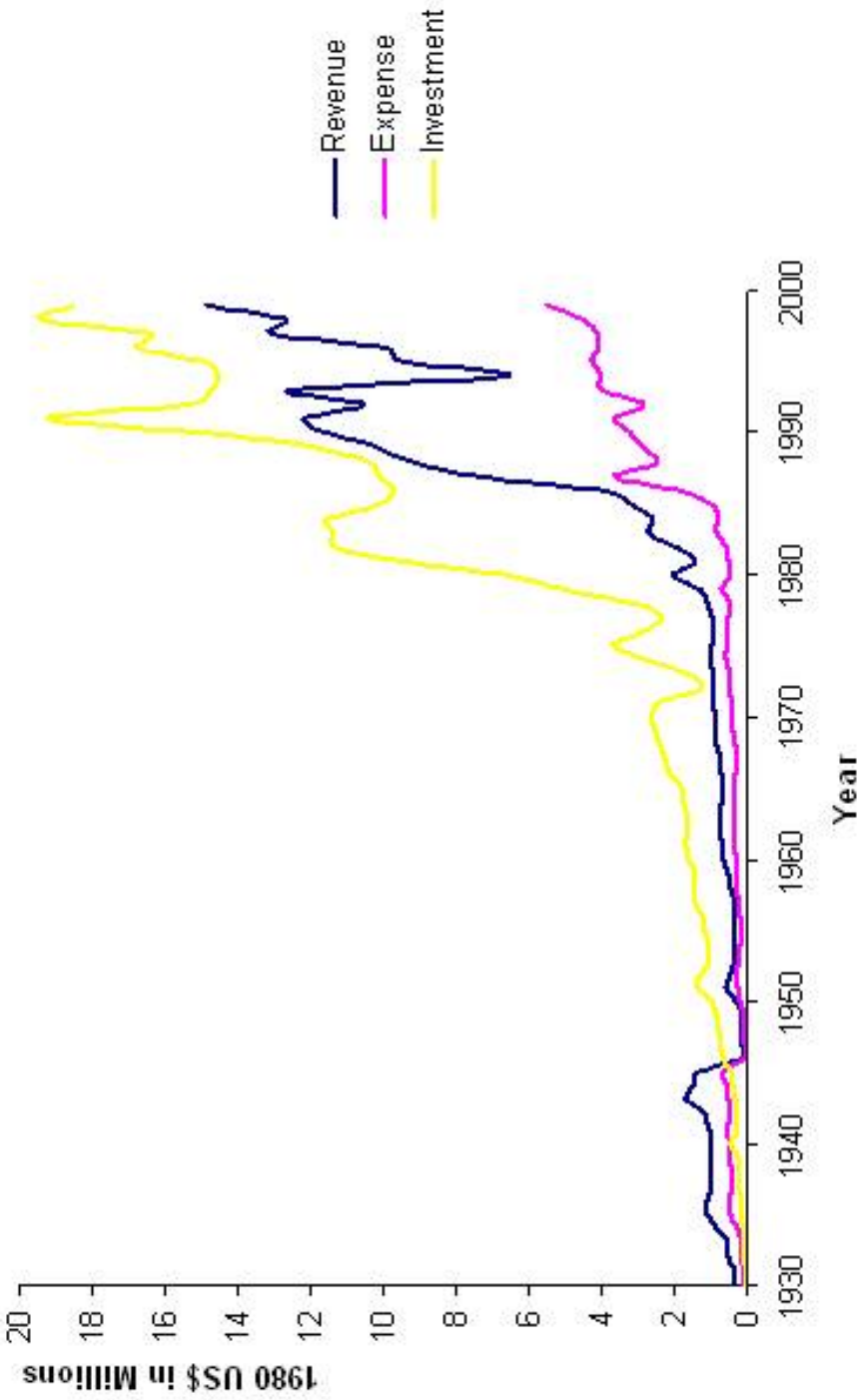


Figure 5.1: Revenue, expenditure and investment of WARF (data courtesy WARF)

The institutional change of the legislation took more than a decade, led by Norman Latker - patent counsel for NIH, a strong proponent of university patenting and small governments. Latker challenged denials of most IPA's requests arguing that public interest was not being served by the department's refusal to neither waive title nor commercialize, which was reinforced by major studies of federal patent policy. This success was later bolstered by the support of Jesse Lasken - patent counsel for the NSF and later Betsy Ancker-Johnson, the assistant secretary for commerce for science & technology and chair of the Committee on Government Patent Policy. For a insightful and informative exposition of efforts leading to the institutional change efforts refer (Berman 2008).

Further discussion on the debates and enactment of Bayh Dole Act is available from many sources including (mowery2001b, stevens2004). Shortly after the Bayh Dole, a Supreme Court ruling allowed patenting of life forms, leading to a surge in patenting dominated by the life sciences in the decades to come. Everything was now in place for the realisation of the full commercial potential of university research. The number of patents grew consistently, and the university-industry interacting flourished both through licensing and collaborations.

The stage was not set for technology Transfer Offices (TTO) based on WARF model perform an emerging role of institutional entrepreneurs involved in building legitimacy for novel technologies by protecting, propagating and influencing of the nascent technologies. A dual mission is thus beginning to be pursued, where the TTO's private and societal interests enable an engagement that can impact the trajectory of the technology (Jain & George 2007).

5.2.1 Connecting the Milestones of University Commercialisation

1900: Early attempts at patenting technology arising from university, but not directly by the university. This included efforts at Colombia, UC, Minnesota.

1925: Formation of Wisconsin Alumni Research Foundation.

1930-1950: Capability development in quality assurance, patenting, licensing, receiving disclosures, funding university activities.

1950: Increasing adoption of WARF organizational model.

1954:Institutional Patents Agreement (IPA) poorly and restrictively adminis-

tered.

1960: Congressional hearing on patent reform fails to bring change.

1963 Norman Latkers effort at HEW(NIH) - uniform IPAs.

1972: Jesse Lasken joins effort at NSF.

1970: Declining role of Research corporation.

1973: Support from Betsy Ancker-Johnson, assistant secretary of commerce for science & technology.

1974: Society of University Patent Administrators formed.

1974: With Latker, Lasken and Ancker-Johnson, support from Environmental Protection Agency, Department of Agriculture was rallied.

Favourable patent policy regulation at newly formed Energy Research & Dev. Agency.

1976: Publication of comprehensive patent reform bill (FCST) giving patent rights to all federal contractors and grantees.

1977: Congressman Ray Thornton (chair of subcommittee on science, research & technology) supports, tried to introduce bill twice into committee.

Lobbying of Senator Birch Bayh, Ted Kennedy, turnaround of Nelsons position.

Howard Bremer (WARF) testifying at congress.

1977: Barry Leshowitz lobbying of Bob Dole.

1977-78: Reframing the bill in economic terms and global competitiveness of the USA and excluding big businesses.

1978 Bayh and Dole along with an array of federal, university and business supported introduced legislation press release with public criticism of HEW failure to waive patent rights (leading to release of waivers the next day).

1979: Bill reintroduced with same overall strategy.

1980: After complicated political machinations Bayh-Dole Act was passed and signed in December.

1990: Boom in biotech basic research commercialisation. University TTO play role in legitimising radical inventions such as human embryonic stem cell research.

1995-2000: University TTO own equity in a large number of companies, hosting incubators, technology management programs for engineers and scientists, acquiring patents. Cutting down departments that do not fit universitys corporate profile.

The overall process of institutional change occurred in a number of phases and more than three institutions during 1925-2000:

1. to justify patenting of publicly funded research,
2. to reward inventors,
3. develop capabilities in licensing and patenting,
4. to play a part in developing the university,
5. associate with other universities to promote patenting rights
6. campaign for regulating patenting rights for the university and the researcher,
7. campaign for statute legislation of patenting rights for the university and researcher,
8. commercialization as an attractive purpose for university research,
9. to influence market for adoption of novel ideas,
10. competitiveness of university rests partly on commercial capabilities.

The experience shows that institutional change may go through various stages with sub-institutional entrepreneurship activities by different actors and even in different institutions, building on the foundations of the previous stage. A program for institutional change could perhaps be charted by deep understanding of the interaction of institutions and other factors promoting change.

This narrative also points out that not all actors are embedded in institutions as neo-institutional theory suggests. People with special needs and aspirations, can mobilise resources to provoke process of change. This may also occur because some are conscious about particular institutions as they are locally influenced by different settings or are agnostic. We find confirmation of the processes behind institutional entrepreneurship suggested by the literature (**?**). However it can also

be observed that the transformation comes to fruition due to some understudied factors such as structural contingencies, strong sponsors and change in one institution promoting change of another institution, which we propose as areas for further exploration in mechanisms for institutional entrepreneurship.

5.3 Multi-institutional Change

Institutional change can be defined as *"... a difference in form, quality, or state over time in an institution. Change in an institutional arrangement can be determined by observing the arrangement at two or more points in time on a set of dimensions (e.g., frames, norms, or rules) and then calculating the differences over time in these dimensions. If there is a noticeable difference, we can say that the institution has changed. If the change is a novel or unprecedented departure from the past, then it represents an institutional innovation."*(Hargrave 2006). Institutional entrepreneurship (Levy & Scully 2007) may be considered a subset of institutional innovation, where the latter may be a result of entrepreneurial activity or may transpires due to events outside such activity. The issue of isomorphism is not prominent in discussions of institutional change.

Institutional change is instigated by goals of individuals, which may comprise ultimate and immediate objectives. While immediate goals may be within the remit of the actors, the ultimate goals may require other actors, organizations and more interestingly multiple institutions. The university is an institution in interaction with several other institutions, and is in relationships with actors within and outside it institutional setup. It is therefore necessary to broaden the scope of the study to include other institutions outside the university and understand how they themselves changed part-taking in the transformation.

Institutions serve as either facilitators or inhibitors of activities. Given activities share a many to many relationships with its context, a multi-institutional context is relevant. Further an institution may overlap and be connected to other institutions. Therefore multiple institutions may need to be changed en route to establishing institutional change in one domain.

Multi-institutional entrepreneurship charactises actors who serve as catalysts for structural change shaping multiple institutions despite pressures towards stasis. This builds on the conventional notion of institutional entrepreneurship cited

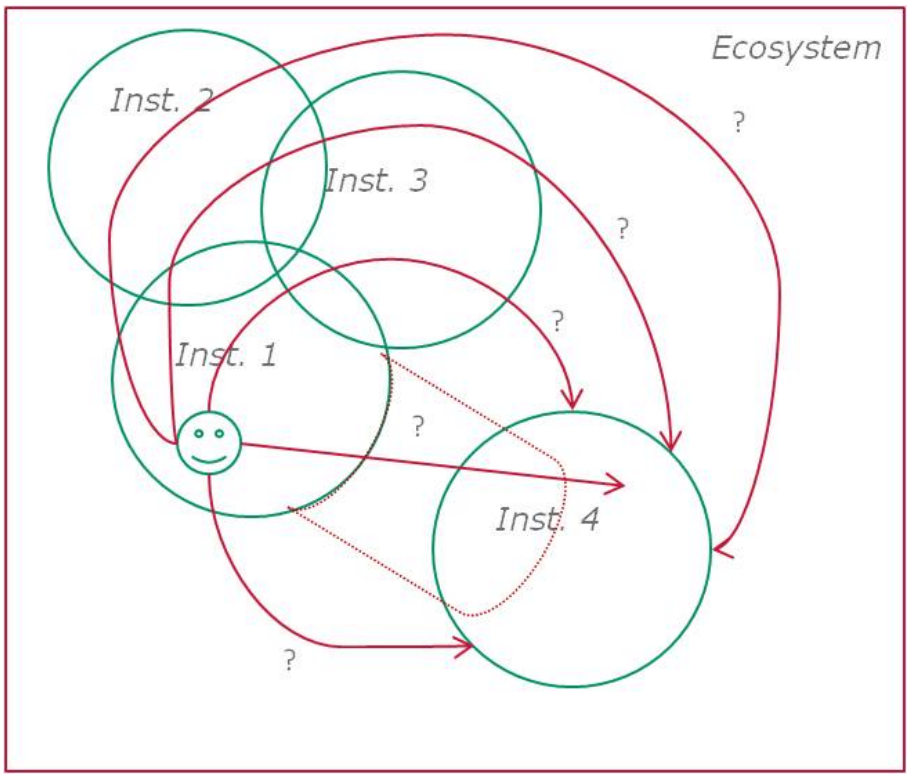


Figure 5.2: Seeking institutional change might entail interacting with multiple institutions

above, where only one change in institution has been investigated hitherto. A tangible example of multi-institutional entrepreneurship is the ongoing case of the development of renewable energy sector. Significant pre-existing institutional barriers are being overcome in the regulation, business, consumer expectation and politics to effect change towards cleaner energy. Several actors, unrelated in most cases, set in several institutions have pan-institutional influence leading to the overall positive consideration of clean energy despite the premium costs both on the supply and the demand side.

The question of institutional change then becomes achieving immediate and ultimate objectives in the milieu of multiple institutions (illustrated in Figure 5.2). Following the historical case study of the transformation of university commercialisation, two options for multi-institutional change can be proposed: First, leveraging current strengths with respect to the institution which is accessible, thereby building the case for change, followed by similar other relevant institutions. Second, simultaneous pursuit of multiple institutions seeking change in them. The first approach is was followed by the actors in the WARF stream of efforts, which represents a sustainable model of institutional change. The second approach dilutes impact of interaction, and becomes unsustainable.

This process was accompanied by designing alternative arrangements in the form of new organizational form (for discussion on the organizational form of WARF, see Chapter 4.) may be necessary to enact institutional change. This approach is not strictly the same as decoupling which limits institutional entrepreneurship in one area while complying with others. The approach here is aim for change in one institution and wait for opportunities, without excluding necessarily.

It is also clear that actors within multiple institutions aided the transformation process. This suggests that rather than one actor or organization spanning multiple institutions, critical actors in multiple institutions may be required for multi-institutional entrepreneurship. This requires complementary projects in multiple institutions (Berman 2008). The process of multi-institutional change is illustrated in Figure 5.3.

In order to understand the foundations of the change in institutions and indeed multiple institutions, the structural aspects of institutions need to be revisited. *"Conformity to institutional norms creates structural similarities, or isomorphism, across organizations"* (Dacin 1997). The concept of isomorphism (Dacin

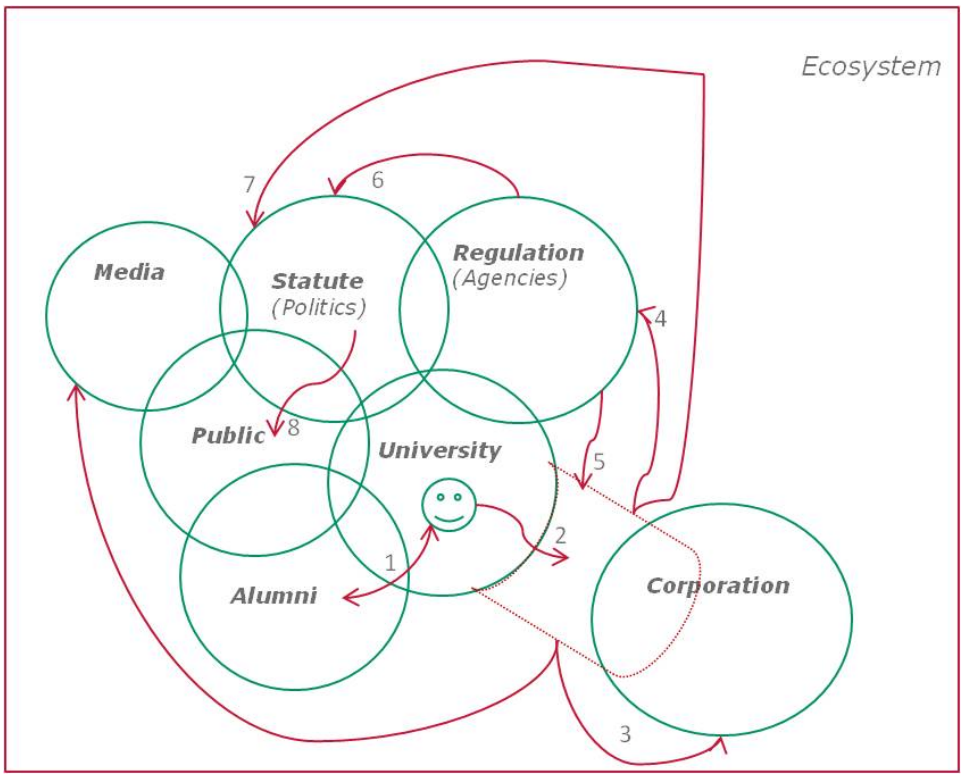


Figure 5.3: Multi-institutional entrepreneurship in action. Objective: Commercialization of university research

1997, DiMaggio & Powell 1983, Glynn & Abzug 2002, Mizruchi & Fein 1999) in its current formulation requires further foundations to study institutional change and the change in isomorphism.

5.4 Foundations of Isomorphism

Isomorphism is homogeneity in structure. Isomorphism is a well selected term to describe compliance with institutional norms. It refers to structural mapping of two forms, where the dominant form among the two is the 'institution'. Such structural mapping (ignoring the local differences) is certainly observed in activities and artifacts in any ecosystem. Isomorphism is a metaphor taken from its origins in the sciences particularly chemistry and mathematics.

In order to derive some foundations for institutional isomorphism, a review of the structure of algebraic groups may be useful, as the concept of isomorphism is well established and formalised. Incidently, the concept of isomorphism in the two fields are isomorphic, which enables us to transfer formalism quite effectively from one to another. The challenge is in the articulation. The following observations can be made from the group named SU(2) (details presented in appendix at the end of this chapter). A group has elements which have a general definition, they are consistent with respect to the definition. The elements of the group describe points on shape (sphere in the case of SU(2) group), which can be accessed or generated using a set of generators on dimensions. Given a set of generators and a set of dimensions, it can be used to describe the group and its shape. The group is usually known by its general definition, which is its identity. Adapting this to the institutional context, the shape, identity (or definition), dimensions and generators can find parallels for the foundations of isomorphism.

The structural similarity between generator in the institutional context would be the rules or logic that defines the institutional. This is analogous to algebraic case, where the rules or logic that define the shape. The dimensions refers to the physical parameters or resources that allow the rules or logic to operate in reality. Similar to the rules of algebra being able to function on the physical dimensions that are available, the institutional rules or logic function on the dimensions or institutional resources that are available. For example, the military as an institution necessarily operates on the physical dimensions of weapons, personnel, rations and the like. It is the operation of the institutional logics of the military

Concept	Description	Institutional example (University)
Shape	Visualisation, impression, notion, connotation	Academia, expertise, learning, freedom of academic exploration, source of knowledge, intellectual objectivity, commercially neutral (+corporation)
Identity	definition, categorization, internal consistency	Educational and research mandate, grant qualifications (+ innovation output)
Dimensions	Objects, anchors used to define the identity	faculty, courses, degree programs, funding, students, research, administration, infrastructure, equipment, literature (+ industry collaboration, commercial technology transfer)
Generators	rules or logic operating on the dimensions to satisfy the shape and identity.	Open advancement and dissemination of knowledge (+ active participant in the economy)

Table 5.1: Foundations of isomorphism, with university as an institutional example.

on the physical dimensions is what gives it the identity, and the physical shape or manifestation. The identity is the definition of the institution, just like it is the definition of the algebraic group, and the shape is the physical manifestation of the institution.

While the institutional literature elaborates sufficiently each of these concepts, the criticism could be, why do we need such a framework with analogy from mathematics to understand this. The benefit of analogies is its ability to transfer insights from one field to another. The existing literature on institutional theory lacks formalism, which is necessary to extend reach as well as well apply the theory effectively. The example of transaction cost economics and the capability view, shows the power of formalism and operationalisation in adoption and application. The current aim to draw principles of institutional change could be aided by crystallising a view of isomorphism that can undergo non-isomorphic change and still be defined.

In Table 5.1 the foundations of isomorphism in the institutional context is presented. The university is taken as an example to relate each of the foundations. They are primarily useful for presenting the make up of an institution (similar to the make up of a mathematical structure or chemical compound) and secondarily to understand how institutions change. As discussed in Table 5.1 the various aspects of an institution such as the university can be represented in terms of its generators, dimensions, identity and shape. The particular choice of terminology aside, the foundations allows microscopic view of what modifications take place in institutions.

5.5 Partial Isomorphism

Drawing from the exposition of isomorphism in the institutional literature and analogous foundations in mathematics in the previous section, departure or deviations from isomorphism can now be explored. Partial isomorphism can be defined as departing partially from established shape and identity or share overlapping foundations with an institution. Partial isomorphism is introduced to describe states of an institution under change. Institutional transience cannot by definition be described by the structural foundations of the old institution. Partial isomorphism also applies to established institutions which share common (not all) foundations. For example, an industrial research lab is partially iso-

morphic to an university research institute. It is isomorphic with the research culture of the individuals involved, however the administrative objectives of the two institutions are not isomorphic. Since, they share aspects of the structural foundations, they can be said to be partially isomorphic. The primary motivation for introducing this concept is to describe change and study what conditions make the change effective or sustainable.

Two approaches to enact partial isomorphism or institutional transience: first, changing its underlying dimensions or generators; second, changing just the shape or identity. Both are unstable due to pressures from established institutional logics or due mimetic, normative and coercive pressures.

Following the historical case, we note both the approaches were pursued by universities. The WARF stream of history adopted the first approach, while some others including the Research Corporation adopted the second approach. Steenbock and company sought to change the generators through discursive strategies, and the dimensions through an alternative organisational arrangements. On the other hand, the effort of the Research Corporation was in comparison, a patch work of incompatible institutional norms, similar to changing the identity while maintaining the shape. The two cases suggest that the generators, dimensions, identity and shape need to consistent with each other for sustainability.

To generalise the conclusion from this observation, we can drawing on the foundations of isomorphism introduced in the previous section. It can be theoretically shown why change in the generators and dimensions are necessary for sustainable institutional change. This discussion assumes a careful appreciation of the analogy between the foundations of institutional isomorphism and the algebraic isomorphism. The generators operators on the dimensions to produce the institutional shape and identity. If the institutional shape and identity are changed without changing the generators and identity, it is susceptible to reforming back as the inconsistency gets resolved. This is because consistency is established via the generators and the dimensions being able to reproduce the shape and identity. Hence we propose that:

Proposition 1: Sustainable institutional change entails changing the generators and dimensions of the institution

The institutional change of university is illustrated in Figure 5.4. The elements that changed are mentioned in braces in Table 5.1. Internal consistency also relates symmetry, which projects a consistent shape for all actors internal

and external. Arriving at internal consistency is an indication that sustainable change has arrived.

Departure from isomorphism can be enabled by introducing new dimensions in addition to existing dimensions inherited from existing institutions. Without explicitly building support for this dimension, and its associated generator, institutional change is likely to be unsustainable. Activities related to introducing new generator is different activities related to introducing new dimensions with respect. Dimensions are tangible ingredients for defining the identity and shape. On the other hand generators are intangible, i.e. rules, thoughts and logics which would bring consistency in the use of the dimensions. For example, the discursive process operates on the generators, while the resource mobilization and alternative arrangements operate on the dimensions. Strategies for institutional change could examine exploiting structural similarity, at the same time avoid constraining overlaps with partial isomorphisms with other institutions.

5.6 Discussion

This paper hopes to contribute to management research in a climate where institutional reforms are found wanting. The boundaries set by existing legislation cannot be relied on for sustainable progress, for loopholes could be exploited, evidenced by recent scandals and crises across the world. Actors within the government and legal bodies may update the law in response to such events, but such top down institutionalism is only a part of the solution. Bottom up institutional entrepreneurial processes could help manage the complexity and pre-empt institutional failures for sustainable progress.

Universities increasingly behaving like corporate entities - patenting in licensable areas have increased concomitant with focus of universities in those areas (Shane 2004). Universities today operate pretty much on a commercial basis, cutting down departments not generating sufficient revenue or burden on university budget, or not contributing to university's corporate profile. This is a clear move towards set up found in the industry rather than what was once considered place of learning and dissemination unlike commercial surroundings. The seepage of popular trends into institutions that originally do not possess such attributes is a corollary of this work.

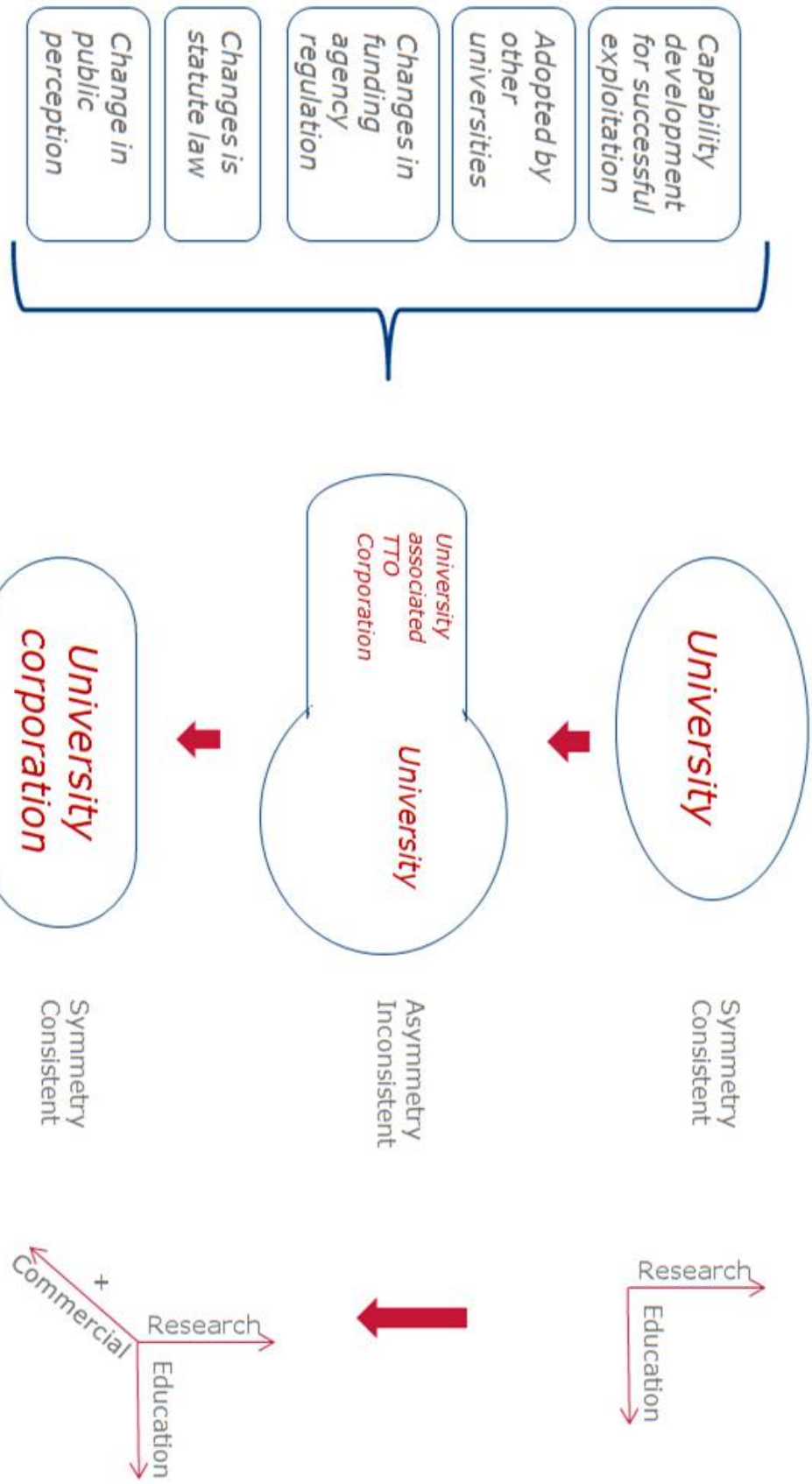


Figure 5.4: Partial isomorphism in action

Role of the concept	Contributors
Enablers	Field level, actor's social position, actor level attributes (leca2008)
Process	Discursive strategies, resource mobilization, designing alternative arrangements (leca2008)
Forces	Mimetic, coercive and normative pressures (DiMaggio1983)
Object of change	Institution(s)
Mechanism of change	partial isomorphism

Table 5.2: Contextualizing the concepts of institutional theory

The revisiting of the foundations of institutions and its mechanisms of change widens the scope of perspective on institutional entrepreneurship. Mechanisms of institutional change can shed light into success and failures of attempts at institutional change. Placing the foundation in the context of concepts in the literature including the processes and motivator of institutional change is shown in Table 5.2. The concept of partial isomorphism helps alleviate the paradox of embeddedness, which is the tension between institutional determinism and agency. Further work can potentially helps devise more predictable strategies for institutional change.

The contribution of this chapter is two fold: firstly, the exploration change in multiple institutions in relation to achieving the objective of commercialisation of university research. Secondly, the exploration of theoretical foundations of institutional isomorphism and change. This contribution attempts to promote formalism within the highly interpretive and textual field of institutional theory.

Current university trends include impact exercise and accounting research audits which have taken place in 1985, 1989, 1992, 1996, 2001, 2008. The university continues to stabilise as a globally competitive educational and research corporation - a far cry from the traditional university.

5.7 Appendix

An algebraic example to appreciate isomorphism:

The special unitary group SU(2) is a unitary 2×2 matrix which has determinant +1. SU(2) is of order 3 and depends on three real continuous parameters (ξ, η, ς), which are called Caley Klein parameters. The general element of the SU(2) is given by

$$U(\xi, \eta, \varsigma) = \begin{pmatrix} e^{i\xi} cos\eta & e^{i\varsigma} sin\eta \\ -e^{i\varsigma} sin\eta & e^{-i\xi} cos\eta \end{pmatrix}. \tag{5.1}$$

It can be observed that det(U)=+1 and $U^{\dagger}U = UU^{\dagger} = 1$. Since the SU(2) algebra spans the surface of a sphere, it can be associated with 3D rotations on the surface.

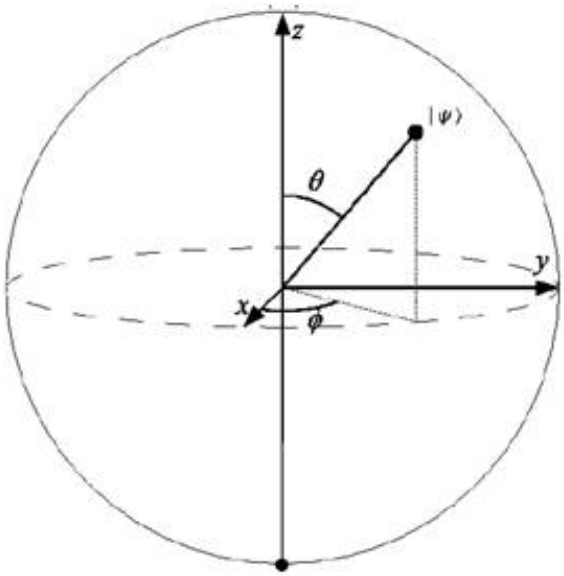


Figure 5.5: Visualization of sphere, which is defined by a generator, dimensions, and a group

The group can be represented through its generators. The elements of the SU(2) may be generated by suitable exponentiation of its generators

$$
\begin{aligned}
U_x &= e^{ia_x\sigma_x/2}, \\
U_y &= e^{ia_x\sigma_y/2}, \\
U_z &= e^{ia_z\sigma_z/2}.
\end{aligned} \tag{5.2}
$$

Part VI

SYNTHESIS - *THE INTERACTIONS*

Chapter 6

The Innovation Ecosystem:

Towards Multi-level Coherence

Contents

6.1 Summary 160

6.2 Multi-level consolidation 162

6.3 Coherence in the Innovation Ecosystem 164

"In theory, there is no difference between theory and practice.
But in practice, there is."- Jan L. A. van de Snepscheut (1953-1994)

6.1 Summary

In the first chapter introduces the central factors innovation process in the form of defining innovation. Several research questions are forwarded for each of the factors, motivating the next four chapters. The methodologies used in the different chapters is briefly discussed including elaboration on the NK model simulation.

In the second chapter a model was developed that focuses on the characteristics of the discovery process by studying opportunity recognition in terms of the modes of connecting problems with solutions. We show that discovering opportunities entail problem reshaping and problem shifting in addition to the widely considered problem solving. We reformulate the conventional NK model to satisfy this reconceptualization of discovery, thereby enabling movement beyond local optima through problem reshaping. We illustrate the application of this model by studying the effect of curiosity on intended and unintended problems; and the various conditions under which analogy, local search and recombination would be beneficial. We finally explore the problem of designer imprint in the form of implicitly connecting the subjective agent with objective information of his environment. We suggest future models to consider incorporation of perception led satisficing, and how this may be achieved by using the agent's sensory attributes such as attention and stimulus deficits.

In the third chapter, the domain differences of the two salient protagonists in the innovation process - scientists and business managers is explored. This is achieved through a quasi-experimental design comprising verbal protocols, computer based repeated measures and sequential update experiments. The findings suggest that scientists are constrained by their intellectual aspirations in contrast to financial aspirations to engage with business opportunities. Scientists also turn out to be more risk averse but more tolerant to ambiguity and more excited by the potential of venture as platform for new ideas than business domain individuals. Evaluating the venture in terms of finance is positively linked to engagement with business opportunities for both domains, and in addition as popular wisdom suggests scientists are not given to evaluating potential of venture in term of technology. Scientists engage in more elaborate means-end analysis and are

more persistent compared to business domain individuals, who are more responsive to new information compared to scientists. These findings indicate sources of discrepancies in the participation of both domains in the innovation process, and suggests insights to alleviate the discordance and exploit synergies.

In the fourth chapter the premises of the theory of the firm was revisited through a reductionist approach, where the firm is considered to be a bundle of actions and assets and quasi-boundaries. Broadly the 'actions' constitute coordination, development and appropriation and the 'assets' constitute resources, capabilities and value. Firms exist to achieve efficiencies and sustainability in coordination and/or development and/or appropriation. Boundary decisions are determined by whether such efficiencies can be achieved internally, contingent upon the priority for enhancing certain assets. Internal organization of the firm can be explained by the operation of the actions on the assets and their interactions. This approach not only accommodates transaction cost and capability perspectives naturally within a framework, but also addresses multiple levels of analysis comparing the advantages of a firm in the ecosystem enabling an integrated perspective. The concept of quasi-boundaries is the introduced to resolve tensions between authority of firms within and beyond its boundary. It is proposed that effectiveness of exchange between organizations relate positively to extent of quasi-boundary overlaps, and that the strictness of the boundaries diminish with increasing complexity of the market. Two unique case studies of an early technology transfer office and Symbian are taken to discuss this approach.

In the fifth chapter the efforts over the last century that went behind enabling university research achieve its commercial potential was discussed. The historical narrative combined the establishment of the Wisconsin Alumni Research Foundation (WARF), federal patent attorneys, administrators and political figures set against its contemporary environment with the eventual passing of the Bayh Dole Act and the nature of universities today. This provides unique insight into the mechanisms and factors that leads to sustainable institutional change. Strategies for multi-institutional entrepreneurship is introduced along the mechanism of partial isomorphism. We find confirmation of processes, forces and enablers of institutionalization suggested in the literature, and in addition contribute to the foundations of institutional change. These are proposed as areas consideration as the foundations for institutional entrepreneurship and contributes to management research in a climate where institutional reforms are found wanting.

6.2 Multi-level consolidation

The factors affecting the innovation process broadly comprises new ideas, people, transactions and institutions. Each of these factors represent different levels of analysis. Perspectives on each of these factors in isolation have flooded the literature, however synthesizing these factors to see the big picture remains a daunting challenge. Incumbent managers or potential entrepreneurs may greatly benefit from appreciating the interplay of the central factors in the management of innovation. This could potentially be achieved by drawing upon detailed studies in the literature on each of these factors and begin a process of multi-level consolidation. Such an framework would inevitable evolve in due course to build consistency and consensus. Isolated treatment of the phenomena at independent levels could potentially breed inconsistency and could slow down the progress of any field. This need not to be confused with the paradigmatic progress of normal science (Kuhn 1970).

Social science theories sometimes come in tides, each time incorporating and reconciling additional concepts. For example old institutionalism was sidelined due to the then emerging work on behavioural aspects and the focus on the individual. Again in the 1980's neo-institutionalism began to use the institutional lens again, where determinism and agency can be studied together rather than separately. These tides indicate the inter-related nature of dynamic processes in the ecosystem. Recognizing this dynamism and their interactions would be an important step in building foundations for consensus. The few parameters within a closed systems that is usually the subject of science has allowed for consensus based progress. Since social systems are neither closed nor based on few parameters, there needs to be a check on imitating methods used in science. Traditional scientific methods make parsimony a necessity. The reality of processes may need more focus before methods are brought in to address a research questions. Bounded research questions are constantly permeated with contextual and cognitive psychological variables, which would also necessitate multi-level studies and reconciliation with the ecosystem.

An attempt at connecting the levels of analysis is stifled by the complexity within and among these factors, blurring the connectivity between them. This problem is common to all the social sciences, however the innovation process touches the full spectrum of these levels and is ideally suited to investigate the connections between them. For example, the strategic-management literature

is primarily concerned with the short run positioning of companies, inquiring about the sources of competitive advantage and the nature of organizational strategic change. In contrast, systemic innovation studies take a longer-term view and inquire about the interrelationship of several dimensions of a socio-economic system whose evolution can be sketched over time to trace the co-evolutionary pathways of technological change.

Among the advantages of understanding the connectivity between the levels is to enable influencing a sub-phenomenon at desired level through sub-phenomena at an accessible level. Among the disadvantages of not appreciating such connectivity between the levels is to provide policy recommendation that could counteract the effects at different levels resulting in failure of what could otherwise been a promising opportunity. Top-down (or taxis or made-order) or bottom-up (or cosmos or emergence or grown-order) process are currently poorly understood. It would be useful to revisit these factors with a view to understand their role in relation to the overall process of innovation.

Topical issues such as sustainable energy problem reveal complex interactions between the levels. [New ideas] Sustainable energy solutions are usually convergent technologies drawing from a variety of disciplines. The dynamics of recombination, explorations and discovery lead to attractive solutions. Given the breadth of supply of ideas and the magnitude of the challenge, small errors can veer the program into escalation of commitments and into unproductive territory. Left alone, this would lead to wastage of resources and opportunities. This level needs to be moderated by other levels, however other levels may not appreciate the dynamics at this level, potentially delaying progress for decades (as is the case with alternative energy technologies). [People] Different technical (scientific) as well as non technical (management and policy) approaches to addressing the needs of the market have been proposed. Suitable initiatives to bridge the gap in order to exploit synergies and mitigate discordance is essential for productive collaborations. [Transactions] Organizational forms and business models need to be conducive for the enhancing the actions and assets of firms providing sustainable, which may not necessarily be the most economically attractive short term solution. This may requires cross-incentivization via quasi-boundary provisions. [Institutions] Achieving the objective of successful development and adoption of sustainable energy solutions may require it to operate in a different institutional environment. The multi-institutional differences need to be carefully navigated to bring the initiatives at the other levels to fruition. Several other contemporary

issues such as poverty alleviation, climate change would greatly benefit from detailed analysis of the interactions between the levels for the policy to have desired effect.

6.3 Coherence in the Innovation Ecosystem

The steady state processes in the ecosystem prefer a low energy state due to stability and sustainability. The steady state processes refer to a settled state with the least contradictions. High energy states relate to unfavourable combinations of parameters. Individuals, organisations, markets and institutions respond to environmental and internal pressures to settle at a low energy state. This metaphor can be usefully applied to the study emergent properties of multi-level systems, as well as the impact of changes in one level has on the other levels. Looking at the energy landscape from different levels of analysis, different attractive energy states may be witnessed. A multi-level illustration of the innovation ecosystem is shown in Figure 6.1.

An individual with high degrees of freedom, would be able to tap into larger set of solutions in the landscape, which higher levels with lesser degrees of freedom would be restricted to access. Hence creativity decreases at higher levels, due to contesting options leading to contradictions. For example, individual ideas may be generated relatively rapidly and some may even be turned into individual technologies, however technology systems changes relatively slowly. By corollary, the impact of the solution adopted at higher levels is high, as they have survived the test of contradictions. Hence such metaphors can lend itself to useful models. In well isolated problems, these landscapes may be considered independently and its dynamics analyzed without taking into account effect of other levels (which is prominent in the strategy literature). Complex problems may have correlated effects of multiple levels complicating conventional approaches to modeling.

A multi-level consideration would be additionally fruitful if the effects of interaction can be studied through a framework. Given the complexity a multi-level system, an over-aching framework to plug-in the variables such that coherence of the system can be studied would be useful. To this end, the connectionist coherence model can be adopted (Thagard 2002, pages 30-33).

This thesis uses more than 30 variables at various levels of the ecosystem.

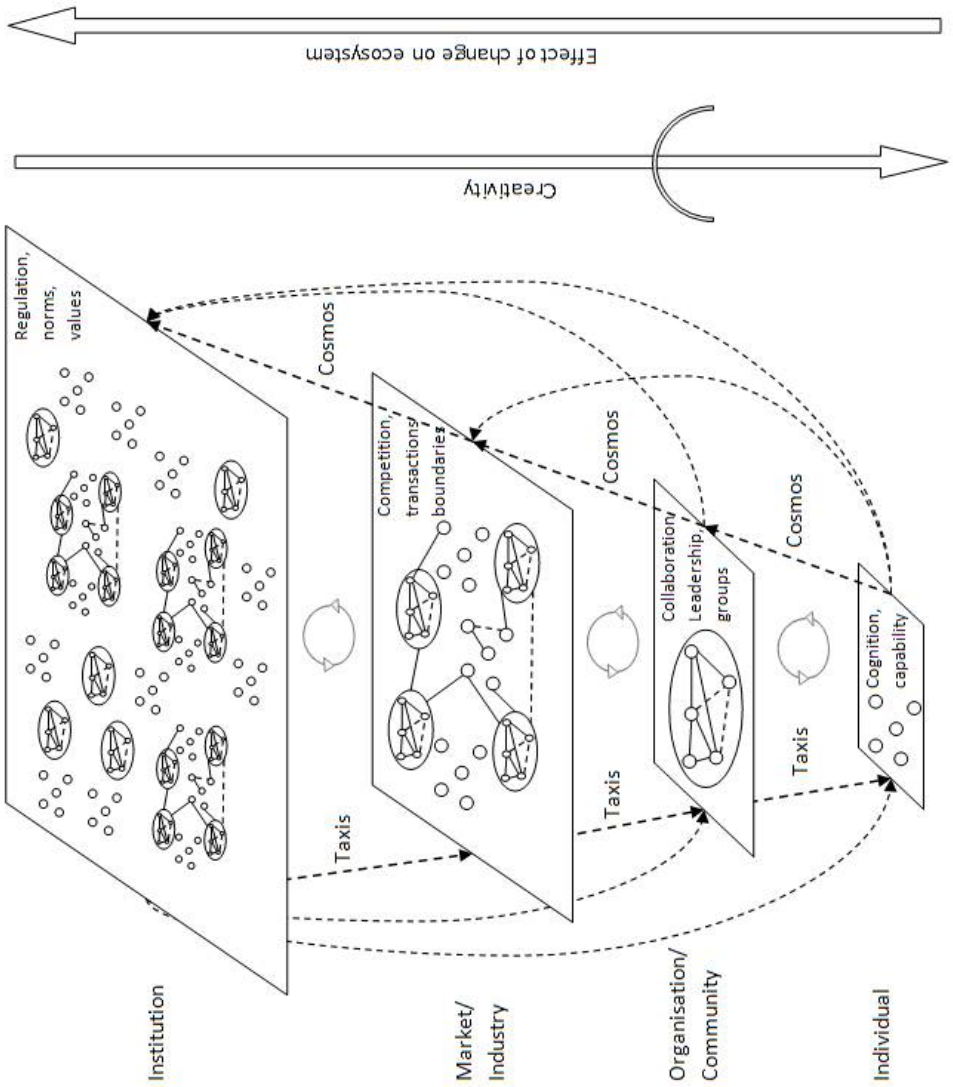


Figure 6.1: A multiple levels in the innovation ecosystem. Creativity decreases at higher levels, and impact decreases at lower levels.

A detailed interaction matrix can be created, considered the nature of effects. Weights can be assigned based on whether the higher level interaction occurs through compilation or composition, directionality, magnitude and polarity of the effect (Kozlowski & Klein 2000). A start can be made with a few variables, and built up into a consistent framework. A set of variables can be reduced to constructs, and a set of constructs can be reduced to effects for a given research question. This would be step towards unraveling the black box of innovation.

References

Abernathy, W. J. & Utterback, J. M. (1978), 'Patterns of industrial innovation', Technology Review **80**(7), 40–47.

Aiman-Smith, L., Scullen, S. & Barr, S. (2002), 'Conducting studies of decision making in organizational contexts: A tutorial for policy-capturing and other regression-based techniques', Organizational Research Methods **5**(4), 388.

Alchian, A. & Demsetz, H. (1972), 'Production, information costs, and economic organization', The American Economic Review **62**(5), 777–795.

Altenberg, L. (1997), NK fitness landscapes, Vol. 2 of Handbook of Evolutionary Computation, B, Oxford University Press.

Altshuller, G. S. (1984), Creativity as an exact science: the theory of the solution of inventive problems, CRC Press.

Alvarez, S. & Barney, J. (2010), 'Entrepreneurship and epistemology: The philosophical underpinnings of the study of entrepreneurial opportunities', The Academy of Management Annals **4**(1), 557–583.

Amabile, T. M. (1983), The Social Psychology of Creativity, Springer-Verlag New York.

Anderson, J. R. (1993), Rules of the mind, Lawrence Erlbaum.

Andriopoulos, C. & Lewis, M. W. (2009), 'Exploitation-exploration tensions and organizational ambidexterity: Managing paradoxes of innovation', Organisation Science **20**(4), 696–717.

Apple, R. D. (1989), 'Patenting university research: Harry steenbock and the wisconsin alumni research foundation', Isis **80**, 375394.

Arend, R. J. & Bromiley, P. (2009), 'Assessing the dynamic capabilities view: spare change, everyone?', Strategic Organization **7**(1), 75–90.

Argyres, N. (1995), 'Technology strategy, governance structure and interdivisional coordination', Journal of Economic Behavior and Organization **28**(3), 337–358.

Argyres, N. (1996), 'Evidence on the role of firm capabilities in vertical integration decisions', Strategic Management Journal pp. 129–150.

Arrow, K. (1985), The economics of agency, in J. Pratt & R. Zeckhauser, eds, 'Principals and agents: the structure of business', Harvard University Press, Boston, pp. 37–51.

Auerswald, P., Kauffman, S., Lobo, J. & Shell, K. (2000), 'The production recipes approach to modeling technological innovation: An application to learning by doing', Journal of Economic Dynamics and Control **24**(3), 389–450.

Baker, T., Miner, A. S. & Eesley, D. T. (2003), 'Improvising firms: bricolage, account giving and improvisational competencies in the founding process', Research Policy **32**(2), 255–276.

Baldwin, C. Y. & Clark, K. B. (2000), Design rules: The power of modularity, The MIT Press.

Barnard, C. I. (1938), The functions of the executive, Harvard University Press, Cambridge, MA.

Barringer, B. & Bluedorn, A. (1999), 'The relationship between corporate entrepreneurship and strategic management', Strategic Management Journal **20**(5), 421–444.

Baum, J. R. & Locke, E. A. (2004), 'The relationship of entrepreneurial traits, skill, and motivation to subsequent venture growth', Journal of Applied Psychology **89**(4), 587–598.

Bechky, B. (2006), 'Gaffers, gofers, and grips: Role-based coordination in temporary organizations', Organisation Science **17**, 3–21.

Berle, A. A. & Means, G. (1932), The modern corporation and private property, Harcourt, New York:.

Berman, P. (2008), 'Why did universities start patenting?: Institution-building and the road to the bayh-dole act', Social Studies of Science **38**(6), 835.

Berry, M. (1998), 'Strategic planning in small high tech companies', Long Range Planning **31**(3), 455–466.

Bird, B., Hayward, D. & Allen, D. (1993), 'Conflicts in the commercialization of knowledge: Perspectives from science and entrepreneurship', Entrepreneurship: theory and practice **17**(4).

Black, J. A. & Boal, K. B. (1994), 'Strategic resources: traits, configurations and paths to sustainable competitive advantage', Strategic Management Journal **15**(S2), 131–148.

Boden, M. A. (2003), The Creative Mind: Myths and Mechanisms, Routledge, London.

Bohm, D. (1996), On Creativity, Routledge, London.

Bollen, K. & Curran, P. (2004), 'Autoregressive latent trajectory (alt) models a synthesis of two traditions', Sociological Methods and Research **32**(3), 336.

Botkin, J., Dimancescu, D. & Stata, R. (1986), The innovators: rediscovering America's creative energy, University of Pennsylvania Press, Philadelphia, PA.

Brady, R. M. (1985), 'Optimization strategies gleaned from biological evolution', Nature **317**(6040), 804–806. 10.1038/317804a0 10.1038/317804a0.

Bratton, J. & Gold, J. (1999), Human resource management: theory and practice, MacMillan Press, London.

Busenitz, L. W. & Barney, J. B. (1997), 'Differences between entrepreneurs and managers in large organizations: Biases and heuristics in strategic decision-making', Journal of Business Venturing **12**(1), 9–30.

Buttner, E. & Gryskiewicz, N. (1993), 'Entrepreneurs' problem-solving styles: An empirical study using the kirton adaption/innovation theory', Journal of Small Business Management **31**(1).

Cabral, R. (1998), 'Refining the cabral-dahab science park management paradigm', International Journal of Technology Management **16**(8), 813–818.

Cassar, G. (2007), 'Money, money, money? a longitudinal investigation of entrepreneur career reasons, growth preferences and achieved growth', Entrepreneurship and Regional Development **19**(1), 89–107.

Cech, T. R. (2001), Overturning the dogma: catalytic rna, in K. H. Pfenninger & V. R. Shubik, eds, 'The Origins of Creativity', Oxford University Press, Oxford.

Chandler, A. D. (1990), Scale and Scope: The Dynamics of Industrial Capitalism, Harvard University Press, Cambridge, MA.

Chase, R. B., Jacobs, F. R. & Acquilano, N. J. (2006), Operations management for competitive advantage, McGraw-Hill, London.

Cheng, J. L. C. & Kesner, I. F. (1997), 'Organizational slack and response to environmental shifts: The impact of resource allocation patterns', Journal of Management **23**(1), 1.

Chesbrough, H., Vanhaverbeke, W. & West, J. (2006), Open innovation: Researching a new paradigm, Oxford University Press, USA.

Coase, R. (1998), 'The new institutional economics', The American Economic Review **88**(2), 72–74.

Coase, R. H. (1937), 'The nature of the firm', Economica **4**(16), 386–405.

Cohen, J. D., McClure, S. M. & Yu, A. J. (2007), 'Should i stay or should i go? how the human brain manages the trade-off between exploitation and exploration', Philosophical Transactions of the Royal Society B: Biological Sciences **362**(1481), 933.

Cohen, M. D., March, J. G. & Olsen, J. P. (1972), 'A garbage can model of organizational choice', Administrative Science Quarterly pp. 1–25.

Cohen, W. M. & Levinthal, D. A. (1990), 'Absorptive capacity: a new perspective on learning and innovation', Administrative Science Quarterly **35**(1).

Conner, K. R. & Prahalad, C. K. (1996), 'A resource-based theory of the firm: Knowledge versus opportunism', Organization Science pp. 477–501.

Cyert, R. M. & March, J. G. (1992), A behavioral theory of the firm, Wiley-Blackwell, Oxford.

Dacin, M. T. (1997), 'Isomorphism in context: The power and prescription of institutional norms', Academy of Management Journal **40**(1), 46–81.

Darden, L. (1997), 'Recent work in computational scientific discovery'. Proceedings of the Nineteenth Annual Conference of the Cognitive Science Society: August 7-10, 1997, Stanford University.

Debackere, K., Clarysse, B. & Rappa, M. A. (1996), 'Autonomy in the industrial laboratory: the dilemma revisited', The Journal of High Technology Management Research **7**(1), 61–78.

d'Espagnat, B. (2006), On Physics and Philosophy, Princeton University Press, New Jersey.

Dew, N., R. S. S. S. D. . W. R. (2009), 'Effectual versus predictive logics in entrepreneurial decision-making: Differences between experts and novices', Journal of Business Venturing pp. 287–309.

Di Gregorio, D. & Shane, S. (2003), 'Why do some universities generate more start-ups than others?* 1', Research Policy **32**(2), 209–227.

DiMaggio, P. J. & Powell, W. W. (1983), 'The iron cage revisited: Institutional isomorphism and collective rationality in organisational fields', American Sociological Review **48**(April), 147–160.

Dodgson, M., Gann, D. & Salter, A. (2008), The management of technological innovation: strategy and practice, Oxford University Press, New York.

Dubinskas, F. A. (1985), 'The culture chasm: Scientists and managers in genetic engineering firms', Technology Review **88**(4), 24–30.

Dubinskas, F. A. (1988), Janus organizations: Scientists and managers in genetic engineering firms, Making time: Ethnographies of high-technology organizations, Temple University Press, Philadelphia.

Dunbar, K. (2000), 'How scientists think in the real world implications for science education', Journal of Applied Developmental Psychology **21**(1), 49–58.

Eckhardt, J. & Ciuchta, M. (2008), 'Selected variation: the population-level implications of multistage selection in entrepreneurship', Strategic Entrepreneurship Journal **2**(3), 209–224.

Einstein, A. (1918), Principles of research, in 'Ideas and Opinions (1954)', Crown, Berlin.

Einstein, A. (1950), Out of My Later Years, Philosophical Library, New York. Pg. 98.

Ericsson, K. A. & Simon, H. A. (1993), Protocol analysis, MIT press, Cambridge, MA.

Ethiraj, S. K. & Levinthal, D. (2004), 'Modularity and innovation in complex systems', Management Science **50**(2), 159–173.

Evans, D. S. & Leighton, L. S. (1989), 'Some empirical aspects of entrepreneurship', The American Economic Review **79**(3), 519–535.

Fauconnier, G. & Turner, M. (2002), The Way We Think: Conceptual Blending and the Mind's Hidden Complexities, Basic Books.

Finson, K. D. (2002), 'Drawing a scientist: What we do and do not know after fifty years of drawings', School Science and Mathematics **102**(7), 335–345.

Fleming, L. (2001), 'Recombinant uncertainty in technological search', Management Science pp. 117–132.

Fodor, J. A. (2001), The mind doesn't work that way, MIT Press, Cambridge, MA.

Foss, N. J. (1996a), 'Capabilities and the theory of the firm', Revue d'conomie industrielle **77**, 7–28.

Foss, N. J. (1996b), 'Knowledge-based approaches to the theory of the firm: Some critical comments', Organisation Science **7**(5), 470–476.

Foss, N. & Klein, P. (2008), The theory of the firm and its critics: a stocktaking and an assessment, in E. Brousseau & J.-M. Glachant, eds, 'Handbook of New Institutional Economics', Cambridge University Press, Cambridge.

Foster, A. & Ford, N. (2003), 'Serendipity and information seeking: an empirical study', Journal of Documentation **59**(3), 321–340.

Freeman, C. (1974), The Economics of Industrial Innovation, The MIT Press, Cambridge, MA.

Freeman, C. & Soete, L. (1997), The economics of industrial innovation, Routledge, Oxon.

Frege, G. (1984), Sense and Reference., Collected papers on mathematics, logic, and philosophy., Blackwell, Oxford.

French, R. M. & Cleeremans, A. (2002), Implicit learning and consciousness: An empirical, philosophical and computational consensus in the making, Psychology Pr.

Frenken, K. (2001), 'Modelling the organisation of innovative activity using the nk-model'. Available online at *www.druid.dk/conferences/nw/paper1/frenken.pdf* as of Apr. 2008.

Gardenfors, P. & Warglien, M. (2006), Cooperation, conceptual spaces and the evolution of semantics, in P. Vogt, Y. Sugita, E. Tuci & C. Nehaniv, eds, 'Symbol Grounding and Beyond', Springer, Berlin, pp. 16–30.

Garud, R., Jain, S. & Kumaraswamy, A. (2002), 'Institutional entrepreneurship in the sponsorship of common technological standards: The case of sun microsystems and java', The Academy of Management Journal **45**(1), 196–214.

Gavetti, G. & Levinthal, D. (2000), 'Looking forward and looking backward: Cognitive and experiential search', Administrative Science Quarterly **45**(1), 113–137.

Gavetti, G., Levinthal, D. & Rivkin, J. W. (2005), 'Strategy-making in novel and complex worlds: The power of analogy', Strategic Management Journal **26**(8), 691–712.

Gawer, A. & Cusumano, M. (2008), 'How companies become platform leaders', MIT Sloan management review **49**(2), 28.

George, G. (2005a), 'Learning to be capable: patenting and licensing at the wisconsin alumni research foundation 1925-2002', Industrial and Corporate Change **14**(1), 119–151.

George, G. (2005b), 'Slack resources and the performance of privately held firms', Academy of Management Journal **48**.

George, G. & Bock, A. (2008), Inventing Entrepreneurs: Technology Innovators and their Entrepreneurial Journey, Prentice Hall, New Jersey.

Ghoshal, S. & Moran, P. (1996), 'Bad for practice: A critique of the transaction cost theory', The Academy of Management Review **21**(1), 13–47.

Glynn, M. A. & Abzug, R. (2002), 'Institutionalizing identity: Symbolic isomorphism and organizational names', Academy of Management Journal **45**(1), 267–280.

Gorman, M. E. & Carlson, W. B. (1990), 'Interpreting invention as a cognitive process: The case of alexander graham bell, thomas edison, and the telephone', Science, Technology and Human Values **15**(2), 131–164.

Grant, R. (1996), 'Toward a knowledge-based theory of the firm', Strategic management journal **17**, 109–122.

Green, D. M. & Swets, J. A. (1974), Signal detection theory and psychophysics, Krieger Publishing Company, Melbourne.

Gregoire, D., Barr, P. & Shepherd, D. (2010), 'Cognitive processes of opportunity recognition: The role of structural alignment', Organisation Science **21**, 413–431.

Grossman, S. & Hart, O. (1986), 'The costs and benefits of ownership: A theory of vertical and lateral integration', The Journal of Political Economy **94**(4), 691.

Guilford, J. P. (1950), 'Creativity', American Psychologist **5**(9), 444–54.

Gurdon, M. & Samsom, K. (2009), 'A longitudinal study of success and failure among scientist-started ventures', Technovation .

Gutman, J. (1982), 'A means-end chain model based on consumer categorization processes', The Journal of Marketing **46**(2), 60–72.

Gutman, J. (1997), 'Means-end chains as goal hierarchies', Psychology and Marketing **14**(6), 545–560.

Hammond, K. R. (1996), Human judgment and social policy: Irreducible uncertainty, inevitable error, unavoidable injustice, Oxford University Press, New York.

Hargrave, T., V. d. V. A. (2006), 'A collective action model of institutional innovation', Academy of Management Journal **31**(4).

Hatchuel, A. & Weil, B. (2003), A new approach of innovative design: an introduction to ck theory, in 'International Conference on Engineering Design', Stockholm.

Hatchuel, A., Weil, B. & Le Masson, P. (2005), Building innovation capabilities. the development of design-oriented organizations, in J.T.Hage, ed., 'Innovation, learning and macro-institutional changes', Oxford University Press, New York.

He, Z. L. & Wong, P. K. (2004), 'Exploration vs. exploitation: An empirical test of the ambidexterity hypothesis', Organization Science pp. 481–494.

Henderson, R. M. & Clark, K. B. (1990), 'Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms', Administrative Science Quarterly **35**(1), 9–30.

Hesselbein, F. (1999), 'The key to cultural transformation', Leader to leader **12**, 67.

Hirst, W. (1986), The psychology of attention, in J. E. LeDoux & W. Hirst, eds, 'Mind and the Brain: Dialogues in cognitive neuroscience', Cambridge University Press, Cambridge.

Hofstadter, D. R. (2001), 'Analogy as the core of cognition', The analogical mind: Perspectives from cognitive science pp. 499–538.

Holmstrm, B. & Roberts, J. (1998), 'The boundaries of the firm revisited', The Journal of Economic Perspectives **12**(4), 73–94.

Hoyt, J. & Huq, F. (2000), 'From arms-length to collaborative relationships in the supply chain: an evolutionary process', International Journal of Physical Distribution and Logistics. **30**(9).

Hsieh, C., Nickerson, J. & Zenger, T. (2007), 'Opportunity discovery, problem solving and a theory of the entrepreneurial firm', Journal of Management Studies **44**(7), 1255–1277.

Jacobides, M. G. (2006), 'The architecture and design of organizational capabilities', Industrial and Corporate Change **15**(1), 151–171.

Jacobides, M. G. & Billinger, S. (2006), 'Designing the boundaries of the firm: From "make, buy, or ally" to the dynamic benefits of vertical architecture', Organisation Science **17**(2), 249–261.

Jacobides, M. G. & Hitt, L. M. (2005), 'Losing sight of the forest for the trees? productive capabilities and gains from trade as drivers of vertical scope', Strategic Management Journal **26**, 1209.

Jacobides, M. G. & Winter, S. G. (2005), 'The co-evolution of capabilities and transaction costs: Explaining the institutional structure of production', Strategic Management Journal **26**(5), 395–413.

Jacoby, L. L., Levy, B. A. & Steinbach, K. (1992), 'Episodic transfer and automaticity: Integration of data-driven and conceptually-driven processing in rereading', Journal of Experimental Psychology: Learning, Memory, and Cognition **18**(1), 15–24.

Jain, S. & George, G. (2007), 'Technology transfer offices as institutional entrepreneurs: the case of wisconsin alumni research foundation and human embryonic stem cells', Industrial and Corporate Change **16**(4), 535.

Jain, S., George, G. & Maltarich, M. (2009), 'Academics or entrepreneurs? investigating role identity modification of university scientists involved in commercialization activity', Research Policy **38**(6), 922–935.

James, W. (1952), The Principles of Psychology, Vol. 1, William Benton, London.

Jaworski, B., Kohli, A. & Sahay, A. (2000), 'Market-driven versus driving markets', Journal of the Academy of Marketing Science **28**(1), 45–54.

Jenkins-Smith, H. & Bassett Jr, G. (2006), 'Perceived risk and uncertainty of nuclear waste: Differences among science, business, and environmental group members1', Risk Analysis **14**(5), 851–856.

Jensen, M. & Meckling, W. (1976), 'Theory of the firm: Managerial behavior, agency costs, and capital structure', Journal of financial economics **3**(4), 305–360.

Kant, I. (1988 edn.), Critique of Pure Reason, (Tr.) Meiklejohn, J. M. D. (First German edition, 1781), J. M. Dent & Sons, London.

Kaplan, N. (1959), 'The role of the research administrator', Administrative Science Quarterly pp. 20–42.

Kauffman, S. A. (1993), The Origins of Order: Self-organization and Selection in Evolution (1993), Oxford University Press, New York.

Kauffman, S., Lobo, J. & Macready, W. G. (2000), 'Optimal search on a technology landscape', Journal of Economic Behavior and Organization **43**(2), 141–166.

Kirchhoff, B. A. (1994), Entrepreneurship and dynamic capitalism: The economics of business firm formation and growth, Praeger, Westport.

Kirzner, I. M. (1989), Discovery, Capitalism and Distributive Justice, Basil Blackwell, Oxford.

Kirzner, I. M. (1997), 'Entrepreneurial discovery and the competitive market process: An austrian approach', Journal of Economic Literature **35**(1), 60–85.

Klein, B., Crawford, R. G. & Alchian, A. A. (1978), 'Vertical integration, appropriable rents, and the competitive contracting process', The Journal of Law and Economics **21**(2), 297.

Knudsen, T. & Levinthal, D. A. (2007), 'Two faces of search: Alternative generation and alternative evaluation', Organisation Science **18**(1), 39.

Kogut, B. & Zander, U. (1992), '"knowledge of the firm, combinative capabilities, and the replication of technology', Organizational Science **4**, 383–397.

Kogut, B. & Zander, U. (1996), 'What firms do? coordination, identity, and learning', Organisation Science **7**(5), 502–518.

Kozlowski, S. W. J. & Klein, K. J. (2000), 'A multilevel approach to theory and research in organizations: Contextual, temporal, and emergent processes', Multilevel theory, research, and methods in organizations: Foundations, extensions, and new directions p. 390.

Kuhn, T. S. (1970), The structure of scientific revolutions, University of Chicago Press, Chicago.

Kulkarni, D. & Simon, H. A. (1988), 'The processes of scientific discovery: The strategy of experimentation', Cognitive Science **12**(2), 139–175.

Langlois, R. (1992), 'Transaction-cost economics in real time', Industrial and Corporate Change **1**(1), 99.

Langlois, R. & Foss, N. (1999), 'Capabilities and governance: the rebirth of production in the theory of economic organization', KYKLOS **52**, 201–218.

Latour, B. & Woolgar, S. (1979), Laboratory Life: The Social Construction of Scientific Facts, Sage Publications.

Lawrence, T. (1999), 'Institutional strategy', Journal of Management **25**(2), 161.

Leca, B., Battilana, J. & Boxenbaum, E. (2008), 'Agency and institutions: A review of institutional entrepreneurship', (08-096).

Leiblein, M. J. & Miller, D. J. (2003), 'An empirical examination of transaction- and firm-level influences on the vertical boundaries of the firm', Strategic Management Journal pp. 839–859.

Levinthal, D. (1988), 'A survey of agency models of organizations', **9**, 153.

Levinthal, D. A. (1997), 'Adaptation on rugged landscapes', Management Science **43**(7), 934–950.

Levy, D. & Scully, M. (2007), 'The institutional entrepreneur as modern prince: The strategic face of power in contested fields', Organization Studies **28**(7), 971.

Loewenstein, G. (1994), 'The psychology of curiosity: a review and reinterpretation', Psychological Bulletin **116**(1), 75–98.

Luksha, P. (2008), 'Niche construction: the process of opportunity creation in the environment', Strategic Entrepreneurship Journal **2**(4), 269–283.

MacDonald, A. (1970), 'Revised scale for ambiguity tolerance: Reliability and validity', Psychological Reports **26**(6), 791798.

Madhok, A. (1996), 'The organization of economic activity: Transaction costs, firm capabilities, and the nature of governance', Organization Science **7**(5), 577–590.

Madhok, A. (2002), 'Reassessing the fundamentals and beyond: Ronald coase, the transaction cost and resource-based theories of the firm and the institutional structure of production', Strategic Management Journal **23**(6), 535–550.

Magnani, L., Nersessian, N. J. & Thagard, P. (1999), Model-Based Reasoning in Scientific Discovery, Springer.

Mahoney, M. J. (1979), 'Psychology of the scientist: An evaluative review', Social Studies of Science **9**(3), 349–375.

Maidique, M. A. (1980), 'Entrepreneurs, champions, and technological innovation', MIT Sloan Management Review **21**(2).

March, J. G. (1991), 'Exploration and exploitation in organizational learning', Organization Science pp. 71–87.

March, J. G. & Simon, H. A. (1958), Organizations, Wiley, New York.

March, J. & Shapira, Z. (1987), 'Managerial perspectives on risk and risk taking', Management Science **33**(11), 1404–1418.

March, J. & Shapira, Z. (1992), 'Variable risk preferences and the focus of attention', Psychological Review **99**(1), 172–183.

Martin, R. (2007), The Opposable Mind: How Successful Leaders Win Through IntegrativeThinking, Boston: HarvardBusinessSchoolPress.

Martindale, C. (1999), Biological bases of creativity, in R. J. Sternberg, ed., 'Handbook of Creativity', Cambridge University Press, Cambridge.

McKinsey (2010), 'Mckinsey global survey results: Innovation and commercialization', McKinsey Quarterly **August**.

Meyer, J. W. & Rowan, B. (1977), 'Institutional organisations: formal structure as myth and ceremony', American Journal of Sociology **83**, 340–363.

Miller, K. & Chen, W. (2004), 'Variable organizational risk preferences: tests of the march-shapira model', The Academy of Management Journal pp. 105–115.

Mintz, C. (2009), 'Science vs. business: Who makes a better ceo?', Life Science Leader .

Mitsuhashi, H. & Greve, H. (2009), 'A matching theory of alliance formation and organizational success: Complementarity and compatibility', Academy of Management Journal **52**, 975–995.

Mizruchi, M. S. & Fein, L. C. (1999), 'The social construction of organizational knowledge: A study of the uses of coercive, mimetic, and normative isomorphism', Administrative Science Quarterly **44**(4).

Moran, P. & Ghoshal, S. (1996), 'Theories of economic organization: The case for realism and balance', The Academy of Management Review **21**(1), 58–72.

Mowery, D. C., Nelson, R. R., Sampat, B. N. & Ziedonis, A. A. (2001), 'The growth of patenting and licensing by us universities: an assessment of the effects of the bayhdole act of 1980', Research Policy **30**(1), 99–119.

Mowery, D. C. & Sampat, B. N. (2001a), 'Patenting and licensing university inventions: lessons from the history of the research corporation', Industrial and Corporate Change **10**(2), 317–355.

Mowery, D. C. & Sampat, B. N. (2001b), 'University patents and patent policy debates in the usa, 1925-1980', Industrial and corporate change **10**(3), 781–814.

Nelson, R. R. (1993), National innovation systems: a comparative analysis, Oxford University Press, New York.

Nelson, R. R. & Winter, S. G. (1977), 'In search of more useful theory of innovation', Research Policy **5**, 36–76.

Nelson, R. R. & Winter, S. G. (1982), An Evolutionary Theory of Economic Change, Harvard University Press, Cambridge, MA.

Nesheim, J. L. (2000), High tech start up: the complete handbook for creating successful new high tech companies, Free Press, New York.

Newell, A. & Simon, H. A. (1972), Human problem solving, Prentice-Hall, Englewood Cliffs, NJ.

Nickles, T. (1985), 'Beyond divorce: Current status of the discovery debate', Philosophy of Science **52**(2), 177–206.

Nonaka, I. (1994), 'A dynamic theory of organizational knowledge creation', Organization Science **5**(1).

North, D. (1990), Institutions, institutional change, and economic performance, Cambridge University Press, Cambridge.

Norton, R. (1975), 'Measurement of ambiguity tolerance', Journal of Personality Assessment **39**(6), 607–619.

Osman, M. (2004), 'An evaluation of dual-process theories of reasoning', Psychonomic Bulletin and Review **11**(6), 988.

Palmer, A. M. (1956), Nonprofit research and patent management in the united states, Technical report, National Research Council, National Academy of Sciences.

Pavitt, K. (1999), Technology, management and systems of innovation, E. Elgar, Northampton, MA, USA.

Penner, D. E. & Klahr, D. (1996), 'When to trust the data: Further investigations of system error in a scientific reasoning task', Memory and cognition **24**(5), 655–668.

Penrose, E. (1959), The theory of the growth of the firm, Oxford University Press, Oxford.

Peteraf, M. A. (1993), 'The cornerstones of competitive advantage: a resource-based view', Strategic Management Journal **14**(3), 179–191.

Peteraf, M. A. & Helfat, C. E. (2003), 'The dynamic resource-based view: capability lifecycles', Strategic management journal **24**(10), 997.

Pinker, S. (2005), 'So how does the mind work?', Mind and Language **20**(1), 1–24.

Pisano, G. P. (2006), Science business: the promise, the reality, and the future of biotech, Harvard Business School Press, Cambridge, MA.

Popper, K. R. (1959), The Logic of Scientific Discovery, Hutchinson and Company, London.

Porter, M. E. (2008), 'How competitive forces shape strategy', Harvard Business Review (January).

Powell, W. W., D. P. J. (1991), The new institutionalism in organizational analysis, Chicago University Press, Chicago.

Pratt, J. W. & Zeckhauser, R. (1985), Principals and agents: The structure of business, Harvard Business School Press.

Prusak, L. (2001), 'Where did knowledge management come from?', IBM Systems Journal **40**(4), 1002–1007.

Puranam, P., Singh, H. & Chaudhuri, S. (2009), 'Integrating acquired capabilities: When structural integration is (un) necessary', Organization Science **20**(2), 313.

Puranam, P., Singh, H. & Zollo, M. (2006), 'Organizing for innovation: managing the coordination-autonomy dilemma in technology acquisitions', Academy of Management Journal **49**(2), 263.

Rankine, D. (2001), Why acquisitions fail: practical advise for making acquisitions succeed, Financial Times Prentice Hall, London.

Reitzig, M. & Puranam, P. (2009), 'Value appropriation as an organizational capability: the case of ip protection through patents', Strategic Management Journal **30**(7).

Reynolds, T. J. & Gutman, J. (1988), 'Laddering theory, method, analysis, and interpretation', Journal of Advertising Research **28**, 11–34.

Rietzschel, E. F., Nijstad, B. A. & Stroebe, W. (2007), 'Relative accessibility of domain knowledge and creativity: The effects of knowledge activation on the quantity and originality of generated ideas', Journal of Experimental Social Psychology **43**(6), 933–946.

Ritti, R. (1968), 'Work goals of scientists and engineers', Industrial Relations: A Journal of Economy and Society **7**(2), 118–131.

Rivkin, J. W. (2000), 'Imitation of complex strategies', Management Science **46**(6), 824–844.

Rivkin, J. W. & Siggelkow, N. (2002), 'Organizational sticking points on nk landscapes', Complexity **7**(5), 31–43.

Roach, M. & Sauermann, H. (2010), 'A taste for science? phd scientists' academic orientation and self-selection into research careers in industry', Research Policy .

Root-Bernstein, R. S. (1989), Discovering, Harvard University Press, Cambridge, MA.

Ross, W. & Shoenfeld, C. (1948), 'W.a.r.f. report', Wisconsin Alumnus **3**.

Roy, D. (2008), A mechanistic model of three facets of meaning, in M. de Vega, A. M. Glenberg & A. C. Graesser, eds, 'Symbols, Embodiment, and Meaning', Publisher details unavilable (in press). Available online at *http* : *//web.media.mit.edu/ dkroy/papers/pdf/canary_oct*17_2007.*pdf* as of Ap. 2008.

Samsom, K. J. & Gurdon, M. A. (1993), 'University scientists as entrepreneurs: a special case of technology transfer and high-tech venturing', Technovation **13**(2), 63–71.

Santos, F. M. & Eisenhardt, K. M. (2005), 'Organizational boundaries and theories of organization', Organisation Science **16**(5), 491–508.

Santos, F. M. & Eisenhardt, K. M. (2009), 'Constructing markets and shaping boundaries: Entrepreneurial power in nascent fields', The Academy of Management Journal **52**(4), 643–671.

Sarasvathy, D. K., Simon, H. A. & Lave, L. (1998), 'Perceiving and managing business risks: differences between entrepreneurs and bankers', Journal of Economic Behavior and Organization **33**(2), 207–225.

Sarasvathy, S. D. (2001), 'Causation and effectuation: Toward a theoretical shift from economic inevitability to entrepreneurial contingency', Academy of Management Review **26**(2), 243–288.

Schneider, H. A. (1973), 'Steenbock, h (1886-1967) - biographical sketch', The Journal of Nutrition **103**(9), 1235.

Schumpeter, J. A. (1934), The Theory of Economic Development, 1911, Harvard University Press, Cambridge, MA.

Schumpeter, J. A. (2000), Entrepreneurship as innovation, Entrepreneurship: The social science view, Oxford University Press, Oxford.

Scott, W. R. (1994), Institutional environments and organizations: Structural complexity and individualism, Sage Publicationsl, London.

Seifert, C. M., Meyer, D. E., Davidson, N., Patalano, A. L. & Yaniv, I. (2006), Demystification of cognitive insight: opportunistic ossimilation and the prepared-mind perspective, in R. J. Sternberg & J. E. Davidson, eds, 'The Nature of Insight', MIT Press, Cambridge, MA.

Shane, S. (2000), 'Prior knowledge and the discovery of entrepreneurial opportunities', Organization Science **11**(4), 448–469.

Shane, S. (2004), Academic Entrepreneurship: University Spinoffs and Wealth Creation, Edward Elgar, Cheltenham.

Shane, S. A. (2008), The illusions of entrepreneurship: The costly myths that entrepreneurs, investors, and policy makers live by, Yale University Press, New Haven, CT.

Sharfman, M. P., Wolf, G., Chase, R. B. & Tansik, D. A. (1988), 'Antecedents of organizational slack', Academy of Management Review pp. 601–614.

Shepard, H. A. (1956), 'Nine dilemmas in industrial research', Administrative Science Quarterly **1**(3), 295–309.

Simon, H. A. (1945), Administrative behaviour: a study of decision-making processes in administrative organizations, The Free Press, New York.

Simon, H. A. (1977), Models of discovery, D. Reidel Pub. Co, Dordrecht, Holland.

Simon, H. A. (1978), 'Rational decision-making in business organisations', Nobel Memorial Speech .

Simon, H. A. (1982), Models of bounded rationality, Behavioral economics and business organization, MIT Press, Cambridge, MA.

Simon, H. A. (1989), The Scientist as Problem Solver, Complex Information Processing: The Impact of Herbert A. Simon, Lawrence Erlbaum Associates, New Jersey.

Snchez-Manzanares, M., R. R. . G. F. (2008), 'Designing organizations: Does expertise matter?', Journal of Business and Psychology **23**(3), 87–101.

Sorescu, A. B., Chandy, R. K. & Prabhu, J. C. (2007), 'Why some acquisitions do better than others: Product capital as a driver of long-term stock returns', Journal of Marketing Research **44**(1), 57–72.

Srikanth, K. & Puranam, P. (2008), 'Coordination strategies in the remote delivery of services', SSRN eLibrary .

Steenbock, H. (1924), 'The induction of growth promoting and calcifying properties in a ration by exposure to light', Science **60**(1549), 224–225.

Stepansky, B. K. (1988), 'Coming to terms with ambiguity in science : Case study of the historical aspect of wave-particle duality', Endeavour **22**(2), 48–40.

Sternberg, R. J. (1999), Handbook of Creativity, Cambridge University Press, New York.

Teece, D. J. (2007), 'Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance', Strategic Management Journal **28**(13).

Teece, D. J., Pisano, G. & Shuen, A. (1997), 'Dynamic capabilities and strategic management', Strategic management journal pp. 509–533.

Thagard, P. (2001), How to make decisions: Coherence, emotion, and practical inference, in E. Millgram, ed., 'Varieties of practical inference', MIT Press, Cambridge, MA, pp. 355–371.

Thagard, P. (2002), Coherence in thought and action, The MIT Press, Cambridge, MA.

Thagard, P. & Croft, D. (1999), Scientific Discovery and Technological Innovation: Ulcers, Dinosaur Extinction, and the Programming Language Java, Model-Based Reasoning in Scientific Discovery, Springer.

Tucker, W. T. (1961), 'How much of the corporate image is stereotype?', The Journal of Marketing **25**(3), 61–65.

Tushman, M. L. & Anderson, P. (1986), 'Technological discontinuities and organizational environments', Administrative Science Quarterly **31**(3), 439–465.

Van de Ven, A. (1986), 'Central problems in the management of innovation', Management Science **32**(5), 590–607.

Van de Ven, A. H. & Poole, M. S. (1990), 'Methods for studying innovation development in the minnesota innovation research program', Organization Science **1**(3), 313–335.

van Dijk, E. & Zeelenberg, M. (2007), 'When curiosity killed regret: Avoiding or seeking the unknown in decision-making under uncertainty', Journal of Experimental Social Psychology **43**(4), 656–662.

Von Hippel, E. & Von Krogh, G. (2003), 'Open source software and the" private-collective" innovation model: Issues for organization science', Organisation Science **14**(2), 209–223.

Wallace, D. B. & Gruber, H. E. (1989), Creative People at Work: Twelve Cognitive Case Studies, Oxford University Press, New York.

Wallace, G. (1926), The Art of Thought, Harcourt, Brace, New York.

Weick, K. E., Sutcliffe, K. M. & Obstfeld, D. (2005), 'Organizing and the process of sensemaking', Organization Science **16**(4), 409.

Weinberger, E. D. (1991), 'Local properties of kauffman's n-k model: A tunably rugged energy landscape', Physical Review A **44**(10), 6399. Copyright (C) 2009 The American Physical Society Please report any problems to prola@aps.org PRA.

Weisberg, R. W. (1999), Creativity and knowledge: A challenge to theories, in R. J. Sternberg, ed., 'Handbook of Creativity', Cambridge University Press, Cambridge.

Wernerfelt, B. (1984), 'A resource-based view of the firm', Strategic Management Journal **5**(2), 171–180.

West, M. A. & Farr, J. L. (1990), Innovation and creativity at work: Psychological and organizational strategies, John Wiley.

Williamson, O. E. (1975), Markets and hierarchies: analysis and antitrust implications: a study in the economics of internal organization, Free Press, New York.

Williamson, O. E. (1996), The mechanisms of governance, Oxford University Press, New York.

Wuchty, S., Jones, B. & Uzzi, B. (2007), 'The increasing dominance of teams in production of knowledge', Science **316**(5827), 1036.

Zahra, S. A. (2008), 'The virtuous cycle of discovery and creation of entrepreneurial opportunities', Strategic Entrepreneurship Journal **2**(3), 243–257.

Zahra, S. A. & George, G. (2002), 'Absorptive capacity: A review, reconceptualization, and extension', Academy of Management Review **27**(2), 185–203.

Zeithaml, V. A. (1988), 'Consumer perceptions of price, quality, and value: a means-end model and synthesis of evidence', The Journal of Marketing **52**(3), 2–22.

Zigmond, M. J., Bloom, F. E., Landis, S. C., Roberts, J. L. & Squire, L. R. (1999), Fundamental Neuroscience, Academic Press, London.

Zipser, D. (1986), Biologically plausible models of place recognition and goal location, in D. E. Rumelhart & J. L. McClelland, eds, 'Parallel distributed processing: Exploration in the microstructure of cognition', Vol. 1, MIT Press, Cambridge, MA, pp. 432–470.