THE USE OF MODELLING AND COMPUTER SIMULATIONS TO ACHIEVE AN INCREASED UNDERSTANDING OF COMPETITIVE DYNAMICS

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A thesis submitted in partial fulfilment of the requirements of Kingston University for the degree of
Doctor of Business Administration

March 2009

出る杭は打たれる
Perseverance is a virtue

ACKNOWLEDGEMENTS

When I began this programme of research I was working as the Operations Executive at Zetex plc in Oldham. At that time I received support from my immediate supervisor, the Operations Director Ted Wiggans, who was instrumental in organising sponsorship for me. I thank both Ted and Zetex plc for their help during the early stages of this work

During the first part of this DBA I was informed, enlightened and encouraged by many of the staff at Kingston University. However, I should like to thank two people in particular for their exceptional support, they are Professor Stavros Kalafatis and Professor Robin Matthews. I thank Stavros for his guidance and candid critical reviews, which had a major influence on the final version of this work. I thank Robin for broadening my outlook, exposing me to ideas that were outside my normal realm of thoughts, for challenging my woolly thinking, for opening the door to academic conferences and for his warm friendship.

The thesis would not have been completed without the encouragement and active assistance of Dr. Thérèse Woodward, or without practical help from Professor Phillip Samouel, to them I offer my sincere gratitude.

My final acknowledgement must go to my wife, Julie, whose faith in my ability to create this thesis was total and without whose dedicated help and cooperation I would not have completed it. To Julie, my love and thanks.

ABSTRACT

This research relates to digital software products and the firms that produce them. The approach used to explore these topics is that of modelling and computer simulation within the context of complexity science. A complexity science approach advocates mapping equations from one research area to solve problems in another. In this case, the central features of the models are borrowed from the work of evolutionary biologist Stuart Kauffman.

Logical deductions from Kauffman's work leads to the creation of a quantitative product fitness landscape that does not depend upon allocation of random fitness values. Product complexity is defined in terms of the aggregated quantity of embedded information , whilst product fitness relates to maximising synergies and eliminating redundancy. The assumption that fit products are more valuable than unfit products produces the construct of a market value landscape. This explains how market demand grows and offers an explanation of the economic phenomena of increasing returns. The effect of product lifetime is studied, which indicates that fitter products have to be generated at an ever increasing rate in order to produce continuous revenue streams.

Empirical evidence is presented that shows a positive correlation between software product complexity and market size. The relationship between the size of a firm and its profitability highlights an interesting anomaly relating to Microsoft Corporation, the worlds current dominant software provider. The evidence suggests that Microsoft is experiencing increasing profitability as it grows, which is at odds with the trend for traditional firms.

The research makes contributions to economics, strategic management and complexity science. It does so by creating a product centric model of software firms that provides an explanation of increasing returns and it backs this up with empirical evidence. Computer simulations based upon the models exhibit patterns that give insights into product strategy. A critical feature is that, for digital software programs, increasing returns arise from the integration of features into a single program, not by simply bundling multiple programs together into product package. The success of the Microsoft Windows Product is that, from a user perspective, it appears to integrate multiple programs in a way that releases their synergies.

The models and simulations range from simple conceptual building blocks, through to more complex representations of a marketplace in which software companies are operating. These models provide a basis for further work relating to: exploration versus exploitation and the increasing rate of technological change.

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CHAPTER 1: Introduction

Background

The original impetus for this study came from a series of lectures by Professor Robin Matthews at Kingston University Business School, during the period 1999 to 2003, in which he showed how complexity science can be applied to many kinds of business problems by using computer simulations. The talks illustrated the concept of fitness landscapes as well as some relatively simple, yet illuminating, models of growth. A further development arose from a study of the Polya urn processes, which led to some joint conference publications in this area. Contemporaneously, a puzzling observation emerged from empirical observations of firm behaviour, which is also reported in this document. It is the anomaly between the performance of traditional firms and that of a software archetype of the new economy. The anomaly is described through points a) and b) shown below:

a) Although the absolute profits, and profit per share (equity) of large firms show a propensity to increase as the firm grows, their profit as a percentage of their sales has a tendency to decrease.
b) For more than a decade, an archetype of the new economy, the software provider Microsoft, has seen profit as a percentage of sales increase as its sales have increased.

The apparent inconsistency between these two points stimulated questions about the nature of the firms that make up the new economy and whether their products have special attributes that can explain the discrepancy. This led to a review of the new economy that exposed new ways of defining products and firms, based on evolutionary approaches to biology. The intuition, that is at the root of these observations, is the notion of a *product fitness landscape* on which firms compete. It is also clear that the issues of path dependency and *lock in* effects (Arthur, 1989) are involved in the Microsoft illustration. Microsoft is adept at exploiting its product portfolio to produce supply-side increasing returns and in searching for new products in ways that generate demand side increasing returns.

Issues (a) and (b), were investigated empirically and the results (shown in appendix 6) have been used to validate the central constructs behind a new economic model of software firms.

The paragraphs above describe the circumstances that seeded this research and upon which this thesis it is built.

The Knowledge Gap

This research attempts to resolve a number of unanswered questions relating to digital software products, they include:

1. Is there empirical evidence that digital software products exhibit increasing returns (Arthur, 1994) and if so, how do they achieve it?
2. For a digital software algorithm, of a particular length, there is a finite number of variations, so what are chances the of a particular product being the best amongst its peers, i.e. fittest (Kauffman, 1996), and does this change as the programme length increases?
3. What strategy should a software firm adopt with regard to product development in order to stimulate consumer demand (Lancaster, 1966, 1971) and maximise payoffs, should it launch many small products, or fewer larger ones?
4. In a commercial marketplace for digital software products, how do changes in a variety of business and economic parameters, such as: product lifetime (Packard, 1960; Tamai and Torimitsu, 1992), product desirability (Lancaster, 1971), competitive interactions (Luce and Raiffa, 1957; Lado *et al.*, 1997), market-shares (Urban, *et al.*, 1986) and supply side growth rates (Penrose, 1959; Oulton, 2001; Nordhaus, 2002) effect a firms performance?

5. Can models from evolutionary biology (Kauffman, 1996) be applied to the economic and business environment to explain and predict the performance of digital software firms by using computer simulations?

The Aim of this Research

The aim of this research is to produce conceptual models and computer simulations that apply *complexity science* (Waldrop, 1992) to the analysis of software firms operating in the *new economy* (Kay, 2001), in order to produce models and simulations that give new strategic insights for business and management practitioners. The target sector is software companies. The focus is to understand the effect that the knowledge content of products has in wealth creation (Grant, 1996; Spender, 1996; Shapiro and Varian, 1998; Quah, 2001; Metcallfe and Ramlogan, 2005). Fitness landscapes (Arthur, 1996) and growth (Nelson, 1997; Oliner and Sichel , 2000;Bottazzi and Secchi, 2003) are the central themes of the new models, around which other features coalesce. The outcomes are expected to be extensions to existing academic models as well as novel computer simulations.

Central Features

This research uses computer simulations (Casti, 1997) to discover how and why firms succeed or fail. It takes a cross disciplinary approach, in order to apply methods derived from the biological sciences (Arthur, 1996) to solve similar looking problems in economics and business. The work involves extending a number of well known theoretical constructs (Polya and Eggenburger 1923; Cyert and March 1992; Blanco, 1993) , so that they provide more faithful representations of real situations. The extended models are combined to produce a practical computer program that will aid strategic managers working in real businesses. The combination of academic rigor with practical outcomes is the essence of a DBA and it is hoped that these qualities are contained within this thesis.

Type of Research

In broad terms there are two reasons to undertake a programme of research, one is to solve a specific problem, the other is to contribute to a general body of knowledge in a particular area (Sekaran, 1984). This work falls into the second category. The intention is to make a contribution to the debate on informationalism, through an increased understanding of the competitive dynamics of the new economy. This is achieved by producing computer simulations, based on a synthesis of simple process elements, whose outcomes will be useful to the leaders of software companies. The simulations are representations of models that give a microeconomic account of software firms operating in the new economy. The models are described in terms of digitalisation and the algorithmic complexity of the products.

The Business Setting

The outcomes of this work add to the understanding of the *strategic management* (Hill and Jones, 1998) of *digital software firms,* through a deeper understanding of their products, by using *computer simulations*. These elements define how this research is positioned and they act as pointers towards the literature that needs to be reviewed. At a more fundamental level, there are two underlying themes to the work. They are the *new economy* (Castells, 1996, 1997, 1998) and *complexity science* (Coveney and Highfield, 1995) and both underpin the epistemological and ontological framework (Thagard, 1988; McKinney, 1997) of the research. The new economy provides the real world context for the products/firms being simulated, whilst complexity science is the source of the methodology (Casti, 1997, 1991).

Models and Simulations

The models begin as narratives, which are a synthesis of ideas drawn from the literature review, plus the outcomes of analyses of published databases, which were performed during the research. The narratives contain mathematical formulas, descriptions of processes and parametric data sets, all of which are rendered into flow charts before conversion into computer simulations. Two software platforms are used to present the models and both are manufactured by Microsoft Corporation. The first is an almost ubiquitous spreadsheet (relational database) product called Excel. The second is a widely available, but less common product called Visual Basic.

Models created in Excel have underlying formulas embedded within them in a manner that allows a user to critique and reproduce them in a straightforward manner. However, while Excel offers some degree of transparency with regard to the underlying research algorithms, it cannot easily present dynamic models to the user and is a relatively large and cumbersome program. In contrast, the Visual Basic platform produces fast, dynamic simulations with relatively small quantities of computer code, but having been *compiled* (a process necessary for the wide distribution of a program) the underlying algorithms are opaque.

The Major Concepts

During the formative stages of this thesis, two concepts surfaced that are central features of the most practical, and most complex, simulations of this work; they are *fitness landscapes*[1] and the *logistic growth*[2] equation. Each of these concepts is explored and extended in order to represent processes that apply to digital software firms. Having developed the concepts individually, they are combined into a growth model to simulate software firms operating within an economic marketplace.

The development of a software product fitness landscape and its integration into the core of the logistic growth model (Patrizia, 2001) provides novelty to the thesis. What emerges is a possible explanation of supply side increasing returns (Arthur, 1996) that are driven by development activities from within the firm

[1] See section 3.2 for a detailed explanation
[2] See section 3.3 for a detailed explanation

(Pitelis, 2001) . The explanation of this outcome lies in the linkage within the model of *product desirability and consumer demand.* Consumer demand relates to a parameter within the logistic equation known as carrying capacity, whilst product desirability is defined within the model through the information content of a program, which is a non-linear function of the length of the code making up the computer program.

In addition to fitness landscapes and logistic growth, three further concepts are investigated and developed to simulate some specific processes that are observed in macroeconomic environments. They are: (i) the Polya Urn process[3] to describe the process defining the way that various firms acquire their particular share of a market, (ii) the Prisoners Dilemma game[4] to represent competitive or co-operative interactions between firms and (iii) decision making activities involving exploration and exploitation[5]. These three additions are added to enrich the simulations in a way that moves them away from being purely theoretical illustrations and towards them becoming a practical tool that can inform business practitioners at a strategic level.

A Synopsis of the Results.

Results fall broadly into three areas: a) outcomes from individual modelling components, b) outcomes from multi-component models and iii) outcomes from the analysis of empirical data bases that illustrate increasing returns of the software firm Microsoft.

a) Individual Modelling Simulations

Although all of the main components are described in existing literature, several concepts are re-defined and extended which changes their characteristics.

[3] See section 2.8.1 and appendix 9 for a detailed explanation
[4] See section 2.10 and 3.6 for detailed explanation
[5] See section 3.7 for detailed explanation

The original Polya Urn process is modified and used to mimic the way that market shares are derived. The modification relates to limiting the size of the urn, which is a proxy for the collective memory of consumers in a marketplace. The characteristics of the modified Polya always lead to monopoly (dominance/extinction). A series of simulations show that the small the urn the faster a monopoly arises. The relationship between urn size and the onset of monopoly is shown.

The Verhulst logistic growth difference equation (Patrizia, 2001) is converted from a Markov chain (Howard, 1971) to a semi-Markov chain (Fossett, 1979) by storing the values that are added during each orbit of the difference equation (Goldberg, 1958). The new equation is further modified so that values can be discarded after a fixed number of orbits. When using the extended equation for economic growth of products, the number of orbits is a proxy for the effective lifetime of the product. The relationship between the growth multiplier, the carrying capacity of the systems and the product lifetime is shown through a family of graphical outputs. These results illustrate the consequences of long product lifetime, the need for new product introduction and the patterns that result from sub-optimal control of the firm.

b) Outcomes from Multi-Component Simulations

Two multi-component models were created, one was based on a spreadsheet, whilst the other was an executable program. Both simulations produced graphical and numerical outputs in the form of a time series representing the payoffs from simulated software firms.

In the case of the spreadsheet, data was collected and analysed from one hundred consecutive runs. The graphical outputs produced only six different patterns that gave insights into the pro's and con's of exploring (embarking on new product development) versus exploiting (remaining with a single niche product).

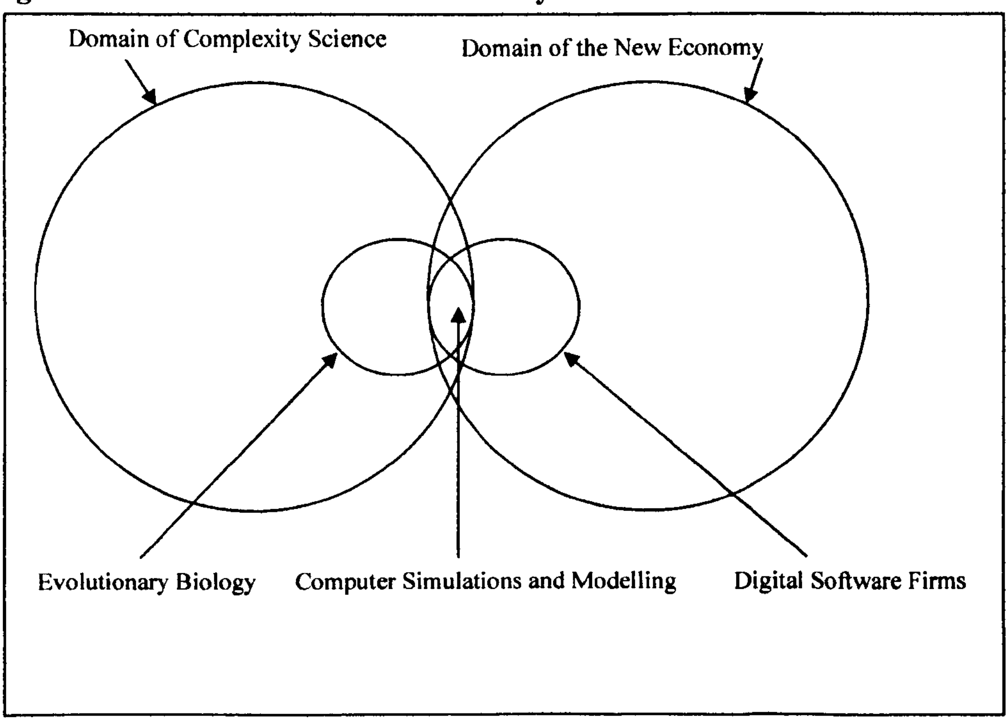
The second multi-component simulation shows the how changes in growth multiplier, product lifetime and the market *carrying capacity* affect each other. The impact of growing and declining markets are explored, as well as instantaneous upward or downward shocks. Patterns associated with particular product lifetimes, growth rates and market demand conditions are also characterised, which leads to an understanding of the symptoms, causes and effects. Of particular note is the quenching effect that short product lifetimes have on systems with rapid growth rates, it implies that frequent new product launches has stabilising effect in as far as they reduce the onset of chaotic supply and demand characteristics.

The next chapter surveys the literature surrounding the research topic. It provides alternative approaches and viewpoints; as well as highlighting knowledge that can be incorporated in the new models.

CHAPTER 2: Literature Review

The topics being reviewed in this chapter can be grouped into three categories: a domain representing economic topics, a domain representing scientific topics, plus a group that is common to both economics and science. A diagram, shown in Figure 1, illustrates this point, so it seems to make sense to partition this chapter into three parts. Part 1 looks at issues relating to the new economy. Part 2 looks at issues relating to complexity science. Part 3 looks at models and processes elements that are specifically relevant to the simulations created for this thesis.

Figure 1 The relevant domains of this study



PART 1

The research focuses on producing computer simulations that could be useful to practitioners of strategic management. The simulations are intended to represent firms producing and selling software products in a free-trade marketplace. It is therefore necessary for the literature review to cover the nature of the *products*, the nature of the *marketplace* and different approaches to *strategic management*. The models could, and arguably should, include rules that reflect government economic policies (Stiglitz, 1988; Barr, 1998), but it was thought that this would extend the scope of the work beyond the available timeframe. So, the impact of public sector policies upon software firms has not been dealt with here.

In the case of firms supplying computer software, it appears that fundamental characteristics of their products set them apart from traditional goods. Features found in software that are uncommon in traditional products include, being virtual, weightless, knowledge based and digital. In addition, there are claims that a new economy has emerged, that can be differentiated from the traditional economy and that software has been a key enabler. For these reasons, Part 1 of the literature review deals with how a new economy has been identified, its features and characteristics, together with issues of strategic management. Themes emerge which indicate that complexity science can play an important role in understanding the nature of software firms and these issues form the basis of Part 2.

2.1 The New Economy

The phrase *new economy*[6] is said to have first appeared in Business Week in 1996 (Kay, 2001). It is a label that epitomises the global marketplace for knowledge based products, such as hi-tech communications devices, hardware and software.

[6] The meaning here relates to computers/information/the knowledge economy/ digitalisation etc, not any earlier usage, e.g. Peck (1943).

It is an environment where virtual products and services exist and where manufacturing supply chains span the globe. One economist put forward a definition of the new economy as one: *'involving the acquisition, processing, transformation, and distribution of information'* (Nordhaus, 2002: p. 201).

Nordhaus (2002) showed that between 1977 and 2000 the new economy massively outperformed the traditional economy in terms of its rapid growth (Javala and Pohjola, 2001; Oulton, 2001). During this period, the total economic gross domestic product of the United States overall economy grew between 1.10% and 1.73%, while at the same time the new economy grew at between 6.25% and 9.98%. Near the end of this period, in 1999, the Chairman of the Board of Governors of the Federal Reserve of the United States gave a speech (Greenspan, 1999) in which he commented on the impact of the new economy. In it, Greenspan (1999) suggested that the recent general improvements in labour productivity were not just cyclical, but due to a quickening pace of technological revolution they were causing a deep seated and still developing shift in the economic landscape.

Productivity and the New Economy

Labour productivity is a facet of wealth creation that manifests itself within the firm and is an embedded feature of growth models that deal with the whole economy. Increasing productivity means achieving more output with the same or fewer man hours of labour and this change in the performance of a firm is usually linked to investment as, for example, in the neo-classical model of economic growth (Solow, 1956,1957, 2000).

The neo-classical model (Solow, 1956,1957, 2000) is built upon three central assumptions: i) constant returns to scale, ii) perfect competition and iii) exogenous technological change. It considers the role of investment through both capital accumulation and a production function, which itself involves output, technology, capital and labour. A key aspect of this analysis, with regard to software firms, is exogenous technological change in which long run growth is driven by the accumulation of knowledge (Romer,1990).

The accumulation of knowledge is especially relevant to software firms, as they are both the users of knowledge and the providers of the enabling technology to access, store and generate it. So, productivity gains in this sector should have long term and meaningful effects on the economy. This is borne out by an analysis of the sources of growth in the US economy during the period 1995 – 2003 (Jorgenson, *et al.*, 2004). The Jorgenson *et al.* (2004) report claims that the production and use of information technology account for a large share of the gains in productivity growth, when compared to the earlier post war period (Jorgenson, 1988).

To economists, substantial changes in productivity and output, like those presented by Jorgenson (2004) and Nordhaus (2002), make a powerful argument for the existence of a new economy. However, not everyone analysed the situation in the same way . For example, Jorgenson and Stiroh (1999), Oliner and Sichel, (2000) and Gordon, (2000) all provided alternative productivity calculations that challenged Nordhaus's (2002) claim of the emergence of exceptionally high levels of productivity.

Jorgenson and Stiroh (1999), arrived at a figure that showed computer inputs during 1990 – 1996 contributed only 0.16% to output growth; they concluded that the use of computers was not ushering in a period of faster growth or higher productivity. Oliner and Sichel (2000) showed that there was a relatively small overall contribution to output growth, by the new economy of 0.5% per year between 1974 and 1995. Whilst Gordon (2000) argued that the impact of the new sector was minimal, with 88% of the economy being unaffected. However, Gordon's assertion was refuted by a study that claimed intense users of *information technology* (IT), in a broad range of industrial sectors, had output levels that were over two percentage points higher than less-intensive users of IT (Baily and Lawrence, 2001).

To traditional economists, the new economy debate pivots on the analysis of productivity and output growth. They are interested in whether a new productivity paradigm has emerged that challenges their existing economic models. In the main, their arguments are about outcomes and symptoms, rather than the fundamental underlying causes of economic growth. Other observers take a different view, one that sees the new economy in terms of its organisational characteristics.

The New Economy as a Complex Adaptive Systems (CAS)

Away from the debate centred on productivity and output, there are others analysing and describing the new economy in a quite different way. One alternative view is to see the new economy (especially the global economy) as a *complex adaptive system* (CAS), with characteristics that include: interdependence, emergence and ambiguity (Matthews, 2001; Metcalfe and Ramlogan, 2005).

Defining the new economy as a complex adaptive system pre-supposes that it exists and there are indications that it does. For more than two decades, cultural and societal changes have been reported upon that can now be viewed as early indicators of the onset of the new economy operating as a CAS. Observations that are claimed to support the CAS view, include the phenomenon of networking (Lipnack and Stamps, 1982) and the change from an industrial economy, to a world economy (Naisbit, 1982). A broad based account of how the world has become a globalised, networked society during the twentieth century, was given by the sociologist Manuel Castells (Castells, 1996, 1997, 1998).

Castells (1996, 1997, 1998) managed to synthesise many of the changes that have taken place in the world into a coherent view of what was changing and why. He

identified the emergence of an *information society* that resulted in a huge growth of interrelationships. These interrelationships formed networks that caused large scale trends in societies affecting the whole world. The patterns that he identified as important are networks comprising of individuals, or tight clusters, linked through information and communications technology. He put it thus:
'dominant functions and processes in the information age are increasingly organised around networks. Networks constitute the new social morphology of our societies and the diffusion of networking logic substantially modifies the operation and outcomes in the processes of production, experience, power and culture. While the networking form of social organization has existed in other times and spaces, the new information technology paradigm provides the basis for its pervasive expansion throughout the entire social structure.'
(Castells, 1996: p. 469).

The networks of autonomous agents identified by Castells (1996) can be viewed as the societal complex adaptive system[7] that makes up the new economy.

Features of the New Economy

Whether it exists or not, the idea of a new economy has infiltrated popular texts with scenarios that encompass various situations, such as: viewing economics as an ecosystem (Rothchild, 1990), advocating mechanisms for increasing economic returns (Arthur, 1996) and identifying *weightless* products and services as high growth enablers (Quah, 1999). Many supporters of the new economy talk of emerging themes and they believe that they are witnessing a complete revolution that is overturning previous norms. Some of those holding this belief have attempted to distil the characteristics that differentiate the new economy from the old. Two such pundits[8], Kelly (1997) and Tapscott (1997) propose that a sets of rules exist which govern the new economy and some of their assertions are summarised in Table 1.

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[7] Complex adaptive systems are discussed in part 2 of this chapter.
[8] Pundit, definition: an expert or learned person (Sinclair, 1993)

Table 1 Kevin Kelly's new rules for a new economy and Don Tapscott's themes that differentiate the new economy from the old

Kevin Kelly's **New Rules for a New Economy**	**Don Tapscott's** **Themes that Differentiate the New Economy from the Old.** ***The New Economy is:***
The Law of Connection- embrace dumb power	A knowledge economy based on human capital and networks
The Law of Plentitude – more gives more	A digital economy
The Law of Exponential Value- success is non-linear	Virtualised
The law of Tipping points – significance precedes momentum	A molecular economy
The Law of Increasing Returns – make virtuous circles	A networked economy, integrating molecules into clusters which network with others for the creation of wealth
The Law of Inverse Pricing – anticipate the cheap	Eliminating middlemen
The Law of Generosity – follow the free	Being created by the new media, a convergence of the computing, telecommunications and content industries
The Law of the Allegiance – feed the web first	An innovation based economy
The Law of Devolution – let go at the top	Blurring the gap between producers and consumers
The Law of Displacement – the net wins	Immediate
The Law of Churn – seek sustainable disequilibrium	A global economy
The Law of Inefficiencies – don't solve problems	Causing discord

(the contents of Table 1 were taken from articles by: Kelly, K. (1997) 'New Rules for the New Economy', Wired Vol. 5, number 9, pp 140-144 and 186 -197, and Tapscott, D. (1997) Strategy in the New Economy. Strategy & Leadership, Chicago, Vol. 25, issue 6, pp 8-15.)

Kevin Kelly's (1997) rules for a new economy are diverse and his phraseology *law of...* is provocative, since his statements have not received any widespread academic approval, or even been tested in a manner that justifies the term. What

Kelly (1997) appears to have done, is to have borrowed ideas drawn from complexity science and reinterpreted them in order to describe his world view of the new economy.

Kelly's (1997) rules will not be individually dissected here, but some of the links with complexity science can be illustrated. For example, complexity science shows how connectivity, expressed through networks, can produce synergies (Matthews, 2004b; Kauffman, 1996 and Arthur, 1989) and this directly links: *the law of connection*, to *the law of increasing returns*, to *the law of plentitude*. The synergies discussed by Kauffman (1996), who is an evolutionary biologist, occur when two genes interact to produce an outcome that cannot be attributed to either of the genes when they are operating independently. For Arthur (1996), economic hot spots arise when networks of firms exchange information and/or employees in a way that creates self-reinforcing growth. Whilst Matthews (2004b) analyses the underlying cause of this kind of exogenous growth and shows that it can be explained by synergies that arise when firms compete or co-operate.

What Kelly (1997) does not mention in his *laws* is anything about the products that are instrumental in creating the new economy; here Tapscott (1997) is more helpful. Five of Tapscot's (1997) themes are indicative of the characteristics found in the products that create the new economy, they are:

- Innovative
- Knowledge based
- Digital
- Virtual
- Created by computing, telecommunications and content industries.

In recent years, many authors have made contributions to defining the attributes, characteristics and terminology of the new economy and yet it was well articulated over twenty five years ago by Arthur (1979).
Arthur (1979) has made significant contributions to economics and complexity science, through his analysis of the traditional and new economies. His tabulation of the differences between the two are shown in Table 2.

Table 2 Old economics versus new economics (a 1979 perspective by W. B. Arthur)

	OLD ECONOMICS	NEW ECONOMICS
1	Decreasing Returns	Much use of Increasing Returns
2	Based on marginality and maximizing principles (profit motive)	Other principles possible (order principles)
3	Preferences given: Individuals selfish.	Formulation of preferences becomes central; Individuals not necessarily selfish.
4	Society as backdrop	Institutions come to the fore as a main decider of possibilities, order and structure.
5	Technology as given, or selected as an economic basis.	Technology initially fluid, then tends to set.
6	Based on 19th century physics (equilibrium, stability, deterministic dynamics).	Based upon biology (structure, pattern, self-organisation, life cycle).
7	Time not treated at all (Debreu) or treated superficially (growth).	Time becomes central (structure, pattern, self-organisation, life cycle)
8	Very little done with age.	Individuals can age
9	Emphasis on quantities, prices, equilibrium.	Emphasis on structure, pattern and function (of location, technology, institutions and possibilities).
10	Elements are quantities and prices	Elements are patterns and possibilities. Compatible structures carry out some functions in each society (c.f. anthropology)
11	Language: 18th century mathematics, game theory and fixed point topology.	Language more qualitative: Game theory reorganised for its qualitative uses. Other qualitative mathematics useful.

12	Generations not really seen.	Generational turnover becomes central; membership in economy changing and age-structure of population changing; Generations carry their experiences.
13	Heavy use of indices; People identical.	Focus on individual life; people separate and different; Combined switching between aggregate and individual; Welfare indices different and used as a rough measure; Individual lifetime seen as measure.
14	If only there were no externalities and all had equal abilities, we'd reach Nirvana.	Externalities and differences become driving force. No Nirvana and system constantly unfolding.
15	Elements are quantities and prices.	Elements are patterns and possibilities
16	No real dynamics in the sense that everything is at equilibrium. C.f. ball on a string in circular motion. No real change happening, just dynamic suspension	Economy is constantly on the edge of time; It rushes forward, structures constantly coalescing, decaying, changing; All this due to externalities leading to jerky motions, increasing returns, structural exclusions.
17	Most questions unanswerable. Unified system incompatible.	Questions remain hard to answer; But assumptions clearly spelled out.
18	Hypothesis testable (Samuelson) assumes laws exist.	Models fitted to data as in EBA); A fit is a fit is a fit. No laws really possible; laws change.
19	Sees subject as structurally simple.	Sees subject as inherently complex.
20	Economics as soft physics.	Economics as high complexity science.
21	Exchange and resources drive economy.	Externalities , differences, ordering principles, computability, mindset, family, possible life cycle and increasing returns drive institutions society and economy.

(Table 2 is reproduced from Collander (2000) *The Complexity vision and the teaching of Economics,* Cheltenham, Edward Elgar Publishing, pp 19-29.)

The views shown earlier, in Table 1, benefit from almost twenty years of new economic growth since Arthur's (1979) contribution and yet they are consistent and tell substantially the same story.

An accumulation of observations supports the notion that a sector of the economy has emerged that acts like a complex adaptive system. If this is the case, then business practitioners need to know which approaches to strategic management are most relevant to this sector. The next section looks for an answer.

The New Economy and Business Strategy

The definition the new economy is vague, yet it is so intimately linked to knowledge that it is sometimes called the knowledge economy (Gill, 2002; Peters, 2006). In tangible terms, two of the underlying enablers of the new economy are digital software and computer hardware, both of which have bought about a revolution in the storage, transmission and creation of knowledge. A century ago, knowledge was primarily stored in books or manuscripts, which were costly to produce and replicate. Today, the contents of a library can be stored on a portable laptop computer system the size of one large book. A century ago, the transmission of knowledge involved substantial time, effort and cost in transferring physical items between locations. Today, knowledge is disseminated globally, at virtually at no cost, with the click of a computer mouse button. A century ago, teams of researchers spent huge amounts of time and effort obtaining and reading books and journals in order to synthesise information into knowledge. Today, an individual researcher has almost instant access to millions of pieces of information that can be sorted, codified and analysed without moving away from the computer work station on his/her desk. The enabling roles that computer hardware and software have played in the new economy are evident in the emergence of a sector referred to as *information and communications technology* (ICT). ICT would not exist, as it is known today, without digital electronic hardware and software.

ICT has been cited as causing structural change in economic dynamics (Carlson, 2004). One attempt at identifying where additional wealth has been created by these new economy enablers suggests that there are four main elements (Quah, 2001), which are:

- Information and communications technology (ICT), the Internet.
- Intellectual assets: Not only patents and copyrights but also, more broadly, brand names, trademarks, advertising, financial and consulting services, and education.
- Electronic libraries and databases: Including new media, video entertainment, and broadcasting.
- Biotechnology: Carbon-based libraries and databases, pharmaceuticals.

The first element identified by Quah (2001) is the primary area where software firms operate and where their products are traded. It is this area of the new economy that relates to this research.

There is a growing recognition that *knowledge* is a critical facet of modern business success, through its role in technological evolution (Cantner and Pyka, 1998). It is a topic that has been growing with the expanding influence of the new economy and its importance is being discussed in academic journals (Shapiro and Varian, 1998). The linkage between knowledge and the new economy is being reflected in academic publications. In the Strategic Management Journal, there were forty-four papers referring to the *new economy* and thirty-five papers referring to the *knowledge economy* between 1980 and 2002. There are also the publications that specialise in the subject, such as the *Journal of Knowledge Management*. Many of the papers relating to this subject concern activities within firms, which aligns them to resource-based theories of the firm (see Connor, 1991, for historical comparisons). The level of importance put upon knowledge management within the last decade is evident from proposals to make knowledge the basis of a dynamic theory of a firm (Spender, 1996; Grant, 1996).

Knowledge Strategies

An interesting aspect of the academic study of knowledge management is that although it embraces many new economy themes it can be applied to both the traditional and new economy. The international consultancy McKinsey (Day and Wendler, 1998) recognises five knowledge strategies, they are:

- Developing and Transferring Best Practices
- Creating a New Industry from Embedded Knowledge
- Shaping Corporate Strategy around Knowledge
- Fostering and Commercialising Innovation
- Creating a Standard by Releasing Proprietary Knowledge

Whilst the McKinsey strategies are aimed at exploiting knowledge, they could apply to any organisation and at any time. The McKinsey model is too generic to be attributed to the new economy and software firms.

A different categorisation, that is more closely aligned to the new economy, identifies six emerging strategies (Haggie and Kingston, 2003) three of which (see below) are consistent with the models being presented in this thesis:

- Knowledge Strategy as Business Strategy : Knowledge is frequently seen as the product
- Knowledge Creation Strategy : Stresses creation of new knowledge through R and D to influence the future of the marketplace.
- Customer-Focussed Knowledge Strategy: Customer needs determine successful products.

A research programme that looked at more than twenty-five firms found that the most important context for guiding knowledge management was the firms strategy (Zack, 1999). This conclusion led to the assertion that : '*... knowledge can be considered the most important strategic resource, and the ability to store, share and apply it the most important capability for building and sustaining competitive advantage*' (Zack, 1999: p. 127).

Zack's work resonates strongly with this thesis and justifies a final quote from his study: '*These examples represent what economists call increasing returns. Unlike traditional physical goods that are consumed as they are used... The more it is used the more value it becomes, creating a self-reinforcing cycle. If an organisation can identify areas where its knowledge leads the competition, and if that unique knowledge can be applied profitably in the marketplace, it can represent a powerful and sustainable competitive advantage.*' (Zack, 1999: p. 129).

Product Strategies

The features that typify the products associated with the new economy have already been extracted from Table 1. They are: innovative, knowledge based, digital, virtual and created by computing, telecommunications and content industries. What has not been addressed in this chapter so far, are the business strategies that firms use to exploit their products and successfully compete within their sector. This topic has been studied by researchers in *strategic management* departments (Cool *et al.*, 1994) and those studying *industrial organisation* (Hunt, 1972 and Porter, 1980, 1998). Several widely known analytical techniques have been identified, three of which will be outlined and then compared. They are strategic groups (Hunt, 1972), typologies (Miles and Snow, 1978) and generic strategies (Porter, 1980).

Strategic Groups

A strategic group is the group of firms in an industry following the same or a similar strategy along the strategic dimensions (Porter, 1980, p.129). The responsibility of managers, when deciding their competitive strategy, can therefore be viewed as making '*the choice of which strategic group to compete in*' (Porter, 1980: p.149).

Since its conception in the early 1970's, the classification of strategic groups has been widely investigated and refined. The dimensions against which firms are assessed vary depending upon the particular industry, with alternative grouping criteria being proposed for: pharmaceuticals (Cool, 1985; Martens, 1988), insurance (Feigebaum *et al.*, 1987), textiles (Porac *et al.*, 1989) and banking (McNamara *et al.*, 2002, 2003). This lack of consistency fuels controversy as to whether identifiable strategic groups are real, or whether they are simply artefacts of imperfect cluster analyses (Barney and Hoskisson, 1990). However, one of the important aspects of the strategic group, and a concept that cuts across sectors, is called the mobility barrier.

Mobility Barriers

Mobility barriers are barriers to entry and to exiting the specific market being serviced by the strategic group. They *'cannot be readily imitated by firms outside the group without substantial costs, substantial elapsed time or uncertainty about the outcome of the decisions'* (McGee and Thomas, 1986: p. 150). This concept is sufficiently important that it has been framed as the definition of the strategic group by one team thus. A strategic group is *'a grouping of businesses within an industry that is separated from other groupings of businesses by mobility barriers, barriers to entry and exit'* (Mascarenhas and Aaker, 1989: p.475). So the central feature of strategic grouping is the notion that successful firms within a sector build their competitive position whilst being protected from competition by a barrier that exerts a financial penalty on new entrants.

Mobility barriers are particularly relevant to the software and hardware sectors of the new economy. Both of these sectors have required, and continue to require, massive investment in technological research and development. This has led to a virtual monopoly in personal computer software operating systems (Microsoft Corporation[9]) where three barriers were identified (Church and Ware, 2000). They were: (i) *copyright protection*, (ii) fixed and sunk costs to develop and

[9] In 1998 Microsoft Corporation had a 90% market share. Available from http://www.microsoft.com/presspass/ofnote/9-16mrktshare.mspx [Accessed on 1/11/08]. In November 1999 Judge Penfield Jackson ruled that Microsoft *'had great monopoly power and had illegally abused that power'* (Mankiw and Taylor, 2006: p.341)

operating system and (iii) fixed and sunk costs to develop *application software.* In the complimentary sector of computer hardware, a duopoly developed in the personal computer microprocessor sector (Intel Corporation and AMD[10]). For both of these sectors the situation is further complicated by the rapid technology development that tends to convert investment assets into sunk costs every time there is a change in technology. Industrial market structures like this (Scherer and Ross, 1990) leads to choices of being the high cost *leader*, who has the opportunity to take the largest market share, or taking a less costly *follower* position with all of the potential disadvantages that this could have.

One approach to strategic groups, which should also be mentioned because of its relevance to this thesis, takes an evolutionary perspective whereby strategic groups are equated to biological species (Hannan and Freeman, 1977). In developing this theme, two research teams have adopted an ecological framework to investigate the brewing industry (Boeker, 1991; Carroll and Swaminathan, 1992). Framing the concept in terms of evolutionary fitness landscapes for the purpose of this thesis would mean that, a strategic group would exist on the top of a steep sided, mesa[11], with the products on the top of the mesa being substantially fitter than those at its base.

A criticism of strategic groups, is that it is an historic analysis that identifies the success factors of a group of firms and in so doing it only explains *why* they succeeded, not *how*. It can show the strategic trajectory that put them in an advantageous position and it can illustrate to a potential competitor the difficulties in trying to take them on. It is very useful for those within the group to understand their competitive position amongst its peers, but it does not provide a strategy to circumvent the barriers to entry for those outside the group.

[10] In 2006 the market shares of Intel and AMD were 86.7% and 13.3% respectively. Available from http://www.ibtimes.com/articles/20060727/intel-amd-marketshare.htm [Accessed on 01/11/08]What is more,AMD obtained its original technology from Intel (Church and Ware,2000)
[11] A dictionary definition (Sinclair, 1993) of a mesa is a flat tableland with steep edges, common in the southwestern US

Strategic Typologies

An alterative approach to strategic grouping is that of typologies (Miles and Snow , 1978) which differentiates firms by putting them into four groups -: defender, prospector, analyser and reactor.

> **Defenders** – have narrow product markets and concentrate on improving the efficiency of their existing operations. They strive to keep what they already have.
> **Prospectors** – are driven by innovation, they are continually searching for new market opportunities.
> **Analysers** – maintain stability whilst monitoring, analysing and responding to new ideas.
> **Reactors** – don't really have any strategy other than to react to challenges, change and uncertainty.

The typology methodology of Miles and Snow (1978) was developed to aid the process of strategic planning and has been widely used. More recently it has been extended and modified so that implementation involved completing a multiple choice questionnaire of eleven questions (Conant, et al., 1990).

To a degree the typology approach suffers from the same problem as strategic grouping in being an historical analysis. It may be viewed as being a cruder , more simplistic approach resulting in firms being labelled as one of only four stereotypes. However, it is a simple tool that can be quickly and easily used to understand the way that a firm actually operates, rather than the way it thinks that it operates. This is useful in producing a gap analysis[12] which can provide an impetus for change and progression.

Generic Strategies

Generic strategies are not firm or industry dependent, but are fundamental to free market forms of commerce and they are determined by decisions made within the firm. '*The notion underlying the concept of genetic strategies is that competitive advantage is at the heart of any strategy, and achieving competitive advantage requires a firm to make choices*' (Porter, 1980: p. 12). Porter's (1980) analysis

[12] A gap analysis identifies the actual situation and compares it to the desired situation. Closing the gap between these two positions becomes the target of a firm's goals and activities.

identifies three fundamental strategies: i) cost leadership, ii) differentiation and iii) focus.

A strategy of *cost leadership* is one where the firm sets out to provide the lowest cost products. Porter (1980) suggests some methods to realise this strategy, which include the pursuit of economies of scale, proprietary technology and preferential access to raw materials. In contrast, *differentiation* seeks to embed uniqueness within the product, in dimensions that are widely valued by buyers and which will justify a cost premium. The final strategy is *focus*, whereby the focuser attempts to serve the needs of a small segment, or segments, of the marketplace. Two variants of focus have been defined (Porter, 1980) that align this strategy with the first two, they are *cost* focus and *differentiation* focus.

Porter's generic strategies have a lot of merit:

- They are simple to understand.
- They can be controlled and influenced from within the firm.
- They are not anchored to specific case studies or analyses, but are presented as tools to create success.
- They are cross-sectorial.
- They can be easily described and modelled in simulations.

Integrating Product Strategy into a Business Simulation

The issue of how to integrate product strategies into business models and simulations is complicated. On the one hand, the simulations at the heart of this research are performed by inanimate computers operating based upon mathematical logic. On the other hand, the strategies of real firms are the result of decisions made by business managers, whose motives may or may not be rational. Furthermore, motives cannot be seen and are often inaccessible.
To overcome this problem, an assertion is being made that the motives of business managers do not matter, because whilst motives cannot be seen behaviours and outcomes can. In modelling terms, what matters is identifying the

processes that may result from the various strategic decisions and then incorporating them into the simulations. The following chapter on methodology will provide details of the business activities being modelled and the processes that are used to simulate them.

The literature indicates that knowledge is a key feature of the new economy and that knowledge is an important element of business strategy for firms operating in the new economy. Moreover, virtual products, like digital software, are capable of generating increasing returns through self-reinforcing mechanisms. These themes feature prominently in complexity science and they permeate both the economic and scientific domains, so the role that complexity science plays in business strategy is looked at next.

2.2 Complexity Science, an Holistic Approach to Business Strategy

An important feature of complexity science is that it takes an holistic view of the world. This is not entirely new to the social and business world. During the early part of the last century, a field of research surfaced that sought to explain interrelatedness of organisms and their ecosystems. This life-sciences topic turned out to be the seed for a broader interdisciplinary concept that sought to derive general laws that would apply across academic boundaries. The new, all embracing, subject area was called *systems theory*[13].

Systems Theory

Systems theorists advocated an holistic perspective to academic analysis (Lazlo, 1966) and this was embraced by disciplines including behavioural science

[13] Note: At the time, a contemporaneous field of study called *cybernetics* looked at how entities processed information and how they reacted to information. The two disciplines converged to a point where the terms *cybernetics* and *systems theory* were synonymous.

(Buckley, 1967) and management (Gharajedaghi, 1985, 1999). An early pioneer of systems theory commented upon the emergence of an holistic approach thus: *'surveying the evolution of modern science, we encounter a surprising phenomenon. Independently of each other, similar problems and conceptions have evolved in widely different fields.'* (von Bertalanffy, 1968: p.30).
There are many similarities between systems theory and complexity science, in particular the wholeness of the parts to be analysed and the connectedness of the parts of the whole. The big difference is that systems theory fails to solve any practical or scientific problems (Lilienfeld, 1977). This lack of practical success led to claims that systems theory is not a universal theory of all empirical systems, but is a theory of theories; a meta-theory (Blauberg *et al.*, 1977). In contrast, complexity science has an ever increasing output of successes in solving problems or providing meaningful insights in areas as diverse as weather forecasting (Lorenz, 1963), chaos (Gleick, 1987), economics (Arthur, 1979, 1989, 1990), evolutionary biology (Kauffman, 1996) and management (Wood, 2000).

It is noticeable that many of the success stories within complexity science have involved the use of computer simulations. This began in the 1950's with pioneering work that looked at general circulation of the atmosphere (Philips, 1956). Less than ten years later, a simulation of a climatic weather model was produced (Lorenz, 1963). The Lorenz (1963) model exhibited a number of features that are characteristic of complex systems, two in particular are noteworthy. The first is an extreme sensitivity to the initial set up. The tiniest adjustment to any of the parameters produces a unique output, that in some cases is wildly different to the previous setting. This commonly observed phenomenon acquired the label *sensitive dependence on initial conditions* (SDIC). The second is the production of patterns looking like a butterflies wings (or a bent figure of 8) that are symptoms of what is now known as a strange attractor[14] (Ruelle, 2006). In a different area, Wood (2000) describes the impact that complexity science is having in helping the Citicorp bank in America to achieve some of its best results

[14] A chaotic trajectory is one that describes a unique and non repeating pattern.

and how similar non-linear computer programs have been instrumental in allowing Barclays Global investors to outperform the market (13% return versus 9% on the Standard and Poor index (Wood, 2000).

If systems theory and complexity science have so much in common then why is the former unsuccessful while the latter continues to grow? The answer may lie in the availability of computing power. There is no lack of mathematical rigour to general systems theory. Problems are described logically and in rigorous mathematically terms and yet '*after a promising start, general systems theory began to die on the vine, through lack of nourishment from tangible results*' (Gobet and Simon, 2001: p. 4). One possible reason for this, is that '*you can only understand complex systems using computers, because they are highly non-linear and beyond standard mathematical analysis*' (Langdon, see Lewin 1992: p. 11). So, in the absence of computing power, systems theory atrophied. In contrast, the growing availability and the declining cost of computing power is the enabler for the growth in complexity science.

Complexity Science and Business Management

Within the realm of organisational and business research there are several summaries describing the application of complexity science to strategic management (for example, Thietart and Forgues, 1995; Levinthal, 1997). These summaries typically focus on particular aspects of complexity. Thietart and Forgues (1995) highlight the way that organisations are portrayed as non linear dynamic systems subjected to forces of stability (negative feedback[15]) and instability (positive feedback[15]). These opposing forces can lead to many outcomes depending upon their relative strength. Too much negative feedback leads to atrophy, whilst too little leads to chaos. In contrast, Levinthal (1997) points to path dependency, and the concept of fitness landscapes. Path dependency leads to the recognition that although an organisation's form is

[15] Positive and negative feedback are terms that arise from control theory. For an overview of this topic see Lewis (1992).

transient, it is highly influenced by its initial condition. A widely valued component of this new approach is its ability to deal with dissipative (real world) situations, without needing to resort to simplified approximations that lose the essence of the actual problem.

A survey of the literature on macroeconomic non linear dynamics (Gomes, 2006) identifies five types of model that are being developed using complexity theory. The models have several themes, including: economic growth with increasing returns, strange attractors, business cycles, asset pricing and chaotic outcomes. So which business strategies are likely to compliment a complexity science perspective? The logical starting point to answer this question is to look at the current dominant approach to strategy, which for many years has been *strategic choice* (Hill and Jones, 1998).

Strategic Choice

Strategic choice is a top down planning driven approach (Hill and Jones, 1998), whereby deliberate actions are implemented with an expectation of specific results. The precursor to these actions is an analysis that looks at the internal *strengths* and *weaknesses* of the organisation as well as the external *opportunities* and *threats; a* process known as a SWOT[16] analysis (Clarke, 1997; Frost, 2002). Studies[17] of the impact of a formal strategic planning of this kind on company performance suggests that it has a positive effect (Miller and Cardinal, 1994). Unfortunately, although the majority of businesses that were surveyed (Hill and Jones, 1998) claimed that this technique was the way that they operated, it is incongruent with a complexity science approach. The problem is a fundamental one, since at a philosophical level strategic choice is based on positivism[18] (Lenzer, 1998). The critical issue is that positivism rejects

[16] Strengths, Weaknesses, Opportunities and Threats.
[17] The plural is used because Miller and Cardinal's (1994) paper relates to 26 previously published studies, spanning more than two decades.

[18]The Research Methods for Social Sciences Glossary for qualitative research methods contains a useful short definition of Positivism: A doctrine in the philosophy of science, positivism is

probabilistic events; i.e. all things being equal positivism posits that the same effect will occur for a particular cause, whilst probability theory, which permeates complexity science, allows different outcomes even when all things are equal. Since complexity science strongly supports explanations based upon probabilistic events and stochastic processes, it would be inappropriate to link it to the positivistic doctrine of strategic choice/SWOT analyses. What is needed is an approach with less certainty, possibly underpinned by the philosophy of *logical positivism*[19] (Reichenback, 1938; von Mises, 1964) where probabilistic events, based upon relative frequency in the long run, are legitimate.

Whilst strategic choice is claimed to be the most preferred doctrine of business organisations (Hill and Jones, 1998), it is not the only way to manage a business. There are alternative schools of strategy that are in harmony with complexity science, their usage just happens to be less common. In looking for a strategic planning system that is consistent with complexity science, what is needed is a recognition that strategic trajectories are not direct journeys from *a* to *b*, but bumpy rides in which only a general direction can be imposed by the management. Sanctioning this premise leads to different views; such as strategy being a continuous attempt to reconcile objectives with the opportunities presented by the business environment, within the constraints of available capabilities (Matthews, 2000a). A crucial aspect of this portrayal is the recognition that organisations and their environment are *interdependent*; a change in one effects the other and *visa versa*. At a practical level, it begs the question of how often should conscious adjustments be made to strategic plans and their associated control systems? This is a question that is implicitly answered by strategies based on *muddling through* (Lindblom, 1959) and *logical*

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characterised mainly by an insistence that science can only deal with observable entities known directly to experience. The positivist aims to construct general laws, or theories, which express relationships between phenomena. Observation and experiment will then show whether the phenomena do or do not fit the theory; explanation of phenomena consists in showing that they are instances of the general laws or regularities. . Available from: http://cwis.livjm.ac.uk/bus/busrmccl/aem303/glossql.htm [Accessed 27/07/08]

[19] Also known as logical empiricism

incrementalism (Quinn, 1980). Both muddling through and logical incrementalism schools of strategy are built upon ideas that align with complexity science, as both can be thought of as a search techniques that interact with their surroundings.

Muddling Through / Logical Incrementalism

At the time of its conception, the muddling through approach viewed strategy as a fragmented process of serial incremental decisions made with limited data. There are three key issues in the muddling through system. The first is the recognition that it is impractical, maybe impossible, to have all relevant data associated with any decision. This is in line with the theory of bounded rationality (Simon, 1982) where agents face uncertainty about the future, and the costs of acquiring information limit the extent to which they can make a fully rational decision. The second is that all decisions are value laden (i.e. subjective), and thirdly that decisions (about policy) are iterative: '*Policy is not made once and for all; it is made and remade endlessly. Policy making is a process of successive approximations to some desired objectives in which what is desired itself continues to change under reconsideration*' (Lindblom, 1959: p. 86). Muddling through implies that positive and negative feedback will be reconciled infrequently. On the other hand, logical incrementalism perceives effective strategic management as that of *constantly* integrating the simultaneous incremental process of strategy formulation and implementation (Quinn, 1980).

The difference between muddling through and logical incrementalism is one of timing. Muddling through describes a process involving discrete changes whereas logical incrementalism strives to reduce the time between each adjustment, so that it tends towards a continuous process. In complexity science terms, logical incrementalism it is an attempt to reconcile the interactions between positive and negative feedback, so that they continuously[20] interact and in so doing they reduce the probability of sending the system into chaos[21].

The strategic management approach (Hill and Jones, 1998) of logical incrementalism[22] is consistent with the needs of the new economy and of this thesis. The iterative nature of the process and its acceptance of a dynamic business landscape seem particularly appropriate to computer simulations.

Part 1 of the literature review has covered a number of subject areas. It has set out the epistemological and ontological framework of the research from an economic perspective and looked at the sector of the economy where software firms operate. It has also touched on the way that complexity science influences strategic management. Part 2 will look at a relatively new scientific discipline of complexity, to see what contributions can be found that are relevant to creating simulations of software firms.

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[20] As opposed to interactions composed of discrete events.
[21] Continuous systems with less than two dimensions cannot exhibit chaos (Patrizia, 2001).
[22] As a postscript, twenty years after its conception the originator of the muddling through methodology implied that convergence had taken place, between muddling through and logical incrementalism, by his statement: '*muddling through, or incrementalism as it is more usually labelled...*' (Lindblom, 1979: p. 517).

Part 2

In Part 1, complexity science was shown to have brought a new comprehension to some aspects of business strategy, as well as exploiting computer simulations in new ways. Part 2 explores the domain of complexity science to assess whether it can provide appropriate epistemological and methodological underpinnings for the research.

2.3 Complexity Science

It might reasonably be assumed that an author would be able to define the subject that he was writing about, but in the case of complexity science this is not the case. In a book called *Complexity* the introduction states : *'This book is about the science of complexity – a subject that's so new and so wide ranging that nobody knows how quite to define it, or even where its boundaries lie'* (Waldrop, 1992: p. 9). This view is supported by The Centre for Complexity Science[23], whose web site claims *there is no single definition of complexity science.* Complexity science is a relatively new discipline that is not only difficult to define, but it goes under a variety of different names: Complexity (Nicolis and Prigogine, 1989; Coveney and Highfield, 1995), Complex Systems (Bar-Yam, 2003) and Complex Adaptive Systems (Singer, 1995).

The inability of complexity science practitioners to agree on a definition of their discipline is problematic as it provides ammunition for sceptics, as does its cross-disciplinary nature. A professional sceptic, and founder of the Skeptic magazine, (Shermer, 1997), considers that complexity theory is a pseudo-science attracting writers who use its methodology to give the illusion of science, even though they lack supporting evidence. The phrase pseudo-science is a derogatory term attached to activities like paranormal research (Coker, 2001) and astrology

[23] The Centre for Complexity Science, available at www.ccs.org.il [Accessed 30/03/08]

(Ginzburg, 2005). The distinctions between science and pseudo-science have been collated by several authors (Thagard, 1988; Coker, 2001). Thagard (1988) gives some symptoms of pseudo-science as: neglects empirical matters; oblivious to alternative theories; non-simple theories and ad-hoc hypotheses; stagnant doctrine and applications etc.. Coker's (2001) critique is consistent with Thagard (1988), but with additional indicators including: results cannot be reproduced or verified; failures are ignored, no physical phenomena or processes are ever found or studied.

Let us return to Shermer's (1997) assertion that complexity science is a pseudo-science. In his writing, Shermer (1997) promotes the idea that intelligence is orthogonal to the variables that go into shaping someone's beliefs; in other words highly intelligent people can hold weird (non-scientific) beliefs. He gives an example of what happens when smart people jump from their own field of specialisation into one where they are not specialised. He concludes that weird beliefs may be a result of experts jumping fields, furthermore he states that in most cases any new ideas from outsiders will have been considered and rejected by the experts decades before for perfectly legitimate reasons. Shermer's (1997) scepticism covers many areas, from ghosts, clairvoyants and witches through to various religions/cults and on to advocates of complexity science. He covers a very wide range of topics and does not differentiate, between those taught at reputable universities and those that are not. On the basis of Thagard (1988) and Coker's (2001) distinctions, Shermer's (1997) criticism seems a harsh generalisation. It is the contention here that Shermer's own bias against a cross-disciplinary approach has influenced his judgement of complexity science and that he has unjustly categorised it as a pseudo-science.

The Spirit of Complexity Science

Even without a formally accepted definition of complexity science, different people and/organisations have identified features that they believe capture its essence. In the UK, the Engineering and Physical Sciences Research Council

(ESPRC), a body involved in sponsoring research, described some features of complexity as [24]:

- Emergent Properties
- Adaptation
- Many levels
- Feedback to manipulation

A different, but congruent view to that of the EPSRC is presented by the academic journal called A*dvances in Complex Systems* (ACS). ACS considers that complex systems comprise of multiple interacting components, or agents, influenced by non-linear feedback processes with stochastic components, which may lead to the emergence of new qualities that cannot be reduced to the dynamics of the agents. This assessment aligns with the comment that *'throughout most if its history, complexity science has been focussed on efforts to better understand self-organisation, mainly through close observation of complex systems and through computer modelling'* (Davis and Simmt, 2001: p.141)

A useful taxonomy of the types of complexity being modelled and simulated by complexity scientists (Lucas, 1999) is shown in Table 3.

Table 3 Types of complexity

Type	Label	Comments
1	**Static Complexity**	**Fixed structures , frozen in time** Examples include: visual complexity of a computer chip or a picture, or fractal.
2	**Dynamic Complexity**	**Systems with Time Regularities** Examples include: planetary orbits, heartbeats, cyclic attractors.
3	**Evolving Complexity**	**Open ended mutation, innovation** Examples include: searches of state space, branching tree

[24] These 4 points were taken from a web site, available from: http://www.epsrc.ac.uk/ResearchFunding/Programmes/Cross-EPSRCActivities/ComplexityScience/WhatWeMean.htm [Accessed 30/03/08]

		structures (these are historically contained) and form ergodic strange attractors.
4	**Self-Organising Complexity**	**Self-maintaining systems, aware** Examples include: Autopoiesis, adaptive self-stabilizing organic systems. These systems occupy dissipative , semi-stable , far from equilibrium positions.

By studying the four categories of complexity shown in Table 3, it can be seen that the topic of this thesis falls under the label of *evolving complexity*. The reason for this relates to the nature of digital software programs, which comprise of strings of zero's and ones. This means that:

- Trying to detect the best combinations of zeros and ones to make a useful software program is a *search* amongst all possible strings of zero's and ones.
- Differences between strings of zeros and ones that make up the software programs can be considered as *mutations*.
- A string of zero's and ones can be represented as a *branching tree structure*.
- Branching tree structures produce ever more possible outcomes[25] as they unfold making ergodic[26] searches the only *guaranteed* way to define all outcomes (unless the solutions are already known)

There is an ongoing level of controversy associated with the use of computer simulations in research. Nevertheless, a substantial research community has emerged in the area of complexity science that relies upon it. It is within this school of thought that this thesis is positioned. A further source of enlightenment is a seminal text book relating to complexity where a chapter is dedicated to *'The Vocabulary of Complexity'* (Nicolis and Prigogene, 1989: p. 5). The text book

[25] Mathematically, they are known as *NP hard*. They can also be termed *convex*, meaning that solutions do not converge towards a single answer.
[26] An ergodic search is one that systematically looks at all possibilities, in contrast to a sample search such as a *lazy random walk*.

proposes a number of terms that are indicative of, or associated with, complex behaviours. They include: dissipative systems; nonequilibrium constraints; nonlinearity, feedback and bifurcation. The meaning of these terms is outlined briefly below.

Dissipative Systems are those that give rise to irreversible processes. In the traditional sciences this characteristic can be tested by considering the impact on the mathematical expression of a scientific law if time is reversed. Nicolis and Prigogene (1989; p. 51) give the example of Ficks law of diffusion, where reversing the direction of time by changing the variable t to –t produces a completely different law. This kind of irreversibility is an expression of the second law of thermodynamics (Mackey, 1992; Daintith, 2005) that states that the entropy[27] of an isolated system, which is not in equilibrium, tends to increase.

Non-equilibrium Constraints relate to situations where resources can be added to and/or removed from the system and net gains or losses can be observed. This is in contrast to many traditional scientific approaches, where systems under investigation are viewed as if they are in a steady state where variables sum to zero (i.e. as if they are enclosed in a hypothetical *black box* that completely isolates the system it from its surrounding).

Non-linearity refers to situations that when described mathematically exhibit power law/exponential relationships. These situations can relate to processes where variables are affected in a compounded way through feedback mechanisms.

Feedback describes the linkage mechanism between the input and output of a particular process, such that the current output of the process influences its future inputs. Feedback can take two forms: *positive feedback*, which has a reinforcing effect and a tendency towards ever increasing outputs, and *negative feedback*,

[27] Entropy is a measure of the unavailability of a systems energy to do work (Daintith, 2005)

which reduces future outputs and has a stabilising effect. In extremis, negative feedback can eventually lead to a zero output condition.

Bifurcation is associated with systems that exhibit branching, for example a decision making tree. It is a term commonly used for situations where two equally probably outcomes can arise. Bifurcation features in the outcomes of logistic equations, which are dealt with in more details later in this thesis (see chapter 3).

All of the features described in the five paragraphs above give an indication of the kinds of phenomena associated with complexity, but they do not offer a particularly useful generalisation. A simple, and useful, general description is shown below.

> ***'Complexity science posits simple causes for complex effects. At the core of complexity is the assumption that the complexity in the world arises from simple rules'*** **(Phelan, 2001: p.130).**

The lack of a formal definition has not stopped academics from participating in complexity science and it has not stopped efforts to understand epistemological issues relating to its theory and practice (Richardson et al., 2001). Dillon (2001) points out that a number of Nobel laureates are active in this field and that they are embracing the challenges of cross-disciplinary research. They include: M. Gell-Mann (Nobel prize for physics in 1969), P.W. Anderson (Nobel prize for physics in 1977) and K.J. Arrow (Nobel prize for economics in 1972). These high profile individuals and many others have been promoting complexity science techniques to investigate previously intractable problems.

The complexity science approach underpins this thesis in many ways, but the major aspiration is to produce simulations with complex outcomes, that mimic reality, using models based upon very simple rules.

Contrasting World View Assumptions

The degree to which the term "complexity science" has become linguistic currency is illustrated by an internet search for this phrase, which gave 320,000 results[28], but has this new scientific approach had any impact within the academic literature? One team of researchers who tried to answer this question (Dent and Powley, 1999) analysed forty years worth of articles from two academic journals[29]. The approach that they took was to look for a shift in world view between traditional science and the emerging science of complexity. The aspects that they compared are shown in Table 4.

Table 4 Contrasting world view assumptions

Dimension	Traditional World View	Emerging World View
Level of Explanation	Reductionism	Holism
Causality	Linear Causality	Mutual Causality
Observation	Objective	Perspectival
Interrelatedness	Competition	Co-operation

(Table 4 is taken from Dent, E.B. and Powley, E.H. (1999) 'Worldview Assumptions: Paradigm Shift in Progress?', Lincoln England, proceedings of the UK Systems Society 6th International Conference.)

The results shown in Table 4 were produced using a narrative analysis methodology and the definitions that were used by Dent and Powley (1999) are shown, verbatim, in points (a) to (h).

a) Reductionism - The belief that an entity can be divided into its composite parts and that a cumulative explanation of the composite parts fully explain the entity.

[28] A search for the phrase "*complexity science*" was performed on 09/07/08 using the Google search engine.
[29] The two journals were the Harvard Business Review (HBR) and the Administrative Science Quarterly (ASQ). The archives that were reviewed covered the period 1957 to 1997.

b) Holism - The belief that an entity can best be understood by considering it in its entirety. The entity has characteristics which belong to the system as a whole and do not belong to any of its parts.

The difference between points (a) and (b) are important as the concept of synergy is embodied within holism, and synergies are an explanatory element of increasing returns/exogenous growth within the complexity science paradigm. This issue can be illustrated in many ways, such as : the components of a watch do not measure time until they are assembled; a pop group produces hits in a way that its individual members cannot and the chemicals that make up a human being do not contain a persons soul (Fisher, 2004) unless they are assembled together in a very particular way. This final point is extremely relevant, as neither physics or chemistry have yet explained human consciousness using a reductionist approach (Rosen, 1991).

c) Linear Causality - The expectation that the relationship between two (or more) phenomena is relatively linear (or that, for the relationship, a linear model, using a few variables, serves as a useful approximation) and that temporal precedence of cause prior to effect is clearly distinguishable.
d) Mutual Causality - The expectation that the relationship between two (or more) phenomena is heavily influenced by the presence of feedback loops. In other words, a variable may appear on both sides of the equation(meaning that cause and effect are, at least to some degree, a function of each other).

Traditional science has shown that linear causality works for inanimate objects and this is exemplified in laws of nature such as those derived by Newton (1687) However, there are many situations where linear causality is inappropriate. Take the animal kingdom, for example, where free agents react and interact in ways that are not entirely predictable. In these circumstances, Newton's (1687) laws are inadequate to predict or explain observed behaviours. However, such systems can be modelled as an array of linked nodes (comprising a *network*) that can exhibit characteristics not explained through linear causality. For example, in the latter half of the twentieth century, scientists studying the brain began to formulate models, based upon networks of neurons, that allowed them to explore the role of mutual causality in human consciousness.

The traditional model of consciousness, called *The Standard Cartesian Theatre* model, postulated that there was a place in the brain where '*it all comes together in a way that implies content bearing events, occurring within a privileged representational medium, determines subjective order*' (Dennet and Kingsbourne, 1992: p.183). In other words, human consciousness is a linear process of cause and effect. However, by viewing the brain as a complex network of neurons, an alternative model emerged that began to explain anomalous experimental results (Gelderd and Sherrick, 1972; Kolers and Grunau, 1975). The new model was called the *Multiple Drafts* model and it holds that '*whereas the brain events that discriminate various perceptual contents are distributed in both space and time in the brain, and whereas the temporal properties of these various events are determinate, none of these temporal properties determine subjective order, since there is no single, consecutive "steam of consciousness", but rather a parallel stream of conflicting and continuously revised contents* '(Dennet and Kingsbourne, 1992: p.183). This illustration of the change in scientific perspective from linear causality to multiple causality is central to complexity science.

The comparisons that have been made: point a) with point b) and point c) with point d) are considered sufficient to illustrate the two arguments, so the remaining definitions, *d* to *f*, will be stated without further commentary.

e) Objective Observation - The belief that phenomena or information in the world are independent of the method of observation of those phenomenon or information. Moreover, the phenomena or information are not altered by the act of observing.

f) Perspectival Observation – The belief that phenomena or information in the world are dependent upon the method of observation. Moreover, the phenomena or information may be changed by the act of observing.

g) Competition - *'That the world is hostile , that we are in a constant struggle for survival, that the consequence of error is death, that the environment seeks our destruction'* (Wheatley and Kellner-Rogers, 1996, p.11). Also, situations framed as win/lose.

h) Cooperation – *'to create, not defend...[that we are in] a world that delights in its explorations. A world that makes it up as it goes along. A world that welcomes us into the exploration as good partners'* (Wheatley and Kellner-Rogers, 1996, p.11). Also, situations framed as win/win.

Dent and Powley's (1999) study concluded that there was not much evidence of any migration to an emerging science. In spite of Dent and Powley's (1999) results, there is a growing interest in topics that are being categorized as complex, and universities have[30] and are continuing to[31] create departments to study this field.

Solving Difficult Problems

Topics investigated by practitioners of complexity science include many that were thought to be too difficult to solve, such as problems classified as 'NP' or 'NP complete' (Gary and Johnson, 1979; Papadimitriou and Tsitsiklis, 1986). These types of problems arise when stochastic processes develop in a manner that produce an ever increasing number of possible outcomes, such as in decision making scenarios, and they are known as intractable. Another difficult class of problems that has been targeted is non-equilibrium systems. Non-equilibrium systems, especially ones that embody interacting feedback mechanisms, can give rise to deterministic chaos (Schuster, 1984) and unrepeatable outcomes (Waldrop,

[30] For example, the Department of Complexity Science and Engineering at the Univeristy of Tokyo, http://www.k.u-tokyo.ac.jp/complex/about-e.html [Accessed 25/06/08].
[31] At the time of writing, Strathclyde University are advertising a Chair of Complexity. Advertisement posted in Feb. 2008 Ref JA/14/08.

1992; Baumol and Benhabib, 1989). Incredibly, whilst such systems can be unpredictable and erratic, they can also give rise to self-organising[32] entities (Bak and Chen, 1991; Kauffman, 1993), which has provided an impetus for the field of Artificial Intelligence (Russell and Norvig, 1995).

Self Organisation

Self-organisation is an important aspect of complexity science that arises in a wide range of situations. It is characterised by patterns of behaviour or movement, that to a human eye appear to be orchestrated or co-ordinated at a level above that of the individual components. It is a system level, rather than individual level, phenomenon and involves many, ostensibly independent and individual, components.

At a macro level, self-organisation can be observed in human and animal behaviours, such as the patterns made when cities expand or birds flock or fish shoal. Whilst at a micro level, the morphogenesis of the slime mould organism *Dictyostelium disoideum* is extraordinary example. The *Dictyostelium disoideum* lifecycle begins as a fungal spore, which develops into a single cell animal that aggregates into a worm like organism, before finally turning into a fungal fruit that produces spores for the cycle to begin again[33].

Complexity science has made great in roads into understanding the possible underlying causes of self organizing systems by using computer simulations. The case of flocking birds was simulated by applying just a few simple rules to otherwise randomly moving shapes (Reynolds, 1987), whilst artificial shoals of fish have demonstrated (Terzopoulos *et al*., 1994) at conferences discussing the topic of artificial life. Even events occurring over many decades can provide

[32] A simple definition of self-organisation is: a process where the organisation (constraint, redundancy) of a system spontaneously increases (Heylighten,1997). Available from http://pespmc1.vub.ac.be/SELFORG.html [Accessed 30/06/08].
[33]Available from, http://scholar.lib.vt.edu/theses/available/etd-092199-122025/unrestricted/NWMAINBODY.PDF [Accessed 09/07/08]

evidence for self organisation, such as the patterns seen in cities and regions (Allen, 1997).

When dealing with living organisms, self organisation is considered by complexity scientists to involve autonomous agents making individual decisions that collectively result in impressively complex outcomes. However, it can be difficult for some people to believe that a macroscopic entity is not the outcome of an overseeing controller. Herbert Simon (1996), a Nobel laureate for economics, commented that his students were incredulous when told that the pattern of medieval cities *just emerged* without a central planning department. In fact, Herbert Simon's (1996) students *'reacted to this fact as many Christian fundamentalists do to Darwin: no design without a designer'* (Ball, 2004: p.191). The reaction of the students highlights the area where an active debate about self organisation, and by extension complexity science, is ongoing. It is a debate that specifically relates to events occurring at the micro, rather than macro, level.

Self-organisation and Biological Evolution

At a micro level, the topic of self organisation touches on some deep philosophical issues regarding the evolution of life. These issues could fill a thesis on their own, but the argument boils down to the question: is it possible for life to have begun by accident, through random processes that form living matter from non-living matter? The debate surrounding the answer to this question is not about self organisation *per se*, as it does not relate to inorganic atoms or molecules. Christians are not concerned with the movement of atoms in the mechanical sense,[34] an example of which is the self assembly of nano-particles on a pre-patterned substrate (Zyga, 2006).

The tension between theology and science arises from evolutionary biology, where an assertion has been made that *'if a sufficiently diverse mix of molecules accumulate somewhere, the chances that an autocatalytic system – a self-*

[34] Mechanical self-organisation of atoms is sometimes termed self-assembly (Tetsuo, 2003),

maintaining and self-reproducing metabolism – will spring forth becomes a near certainty' (Kauffman, 1996: p. 50). An alternative, scientific view, to Kauffman (1996) is the theory of biological self-organisation (Pivar, 2004) that maintains that phenotypes[35] arise from simple mechanical forces rather than genomic code (Pivar, 2004). Neither Kauffman (1996) or Pivar (2004) require the intervention of God to explain their views of biological evolution.

On the other side of the debate are Christian fundamentalists whose belief system rejects the notion of life emerging spontaneously through random events. Whilst some Christians simply reject evolutionary biology out of hand, others have attempted more formal arguments to rebut the concept of life being an accident of nature (Overman, 1997).

Overman (1997) does not rail against evolutionary biologists in an irrational way, instead he takes the argument to their door by focusing upon the role of DNA. DNA is often likened to a blueprint that contains all of the information necessary to construct a living organism. Overman (1997) asserts that DNA is not information and that evolutionary biology and the associated sciences of physics and chemistry cannot explain the specific information contained in DNA or where that information comes from (i.e. there are no little packet of information tagged onto oxygen or carbon atoms, that builds into a blueprint, or if there are then it is not mentioned in the scientific literature). There are other Christian alternatives to evolution, that try to make bridges between science and theology. Intelligent Design (Dembski, 2007) is one such example, which attempts to show how God's design is accessible to scientific inquiry.

To date, none of the Christian alternatives to evolution have impressed the established scientific community who systematically reject them as simply affirming prior religious commitments, rather than putting real hypotheses to the

[35] Phenotype is the physical constitution of an organism as determined by the interaction of its genetic constitution and the environment (Sinclair ,1993)

test (Young and Edis, 2004). So the Darwinian approach, which forms an important aspect of the models in this thesis, is taken to be current and valid.

Computer Simulations as an Alternative to Experimentation

So far, section 2.3 has shown that a new scientific discipline, called complexity science, has emerged that has begun to solve problems that traditional science had set to one side. In many cases, these problems had accumulated because of their arithmetic complexity, which was so great that it was considered either impossible, or too costly, to attempt solving them. The tool that changed this situation was the digital computer, which has made huge contribution to understanding self organisation and has led to the burgeoning study of Artificial Intelligence[36] (AI).

The digital computer is eminently suited to the rapid arithmetic computation needed to solve complex problems and as its cost has come down its use as a research tool has gone up. In the period between 1971 and 1999, a study of citations in the physical and social sciences shows that the use of computer simulations has risen by a factor of ten (Henrickson, 2000). However, the growing use of computers as an active part of the complexity research agenda has raised philosophical questions about its legitimacy and this will be dealt with next.

There are a number of reasons for creating models and computer simulations in an economic and business context. They include: testing hypotheses, proving theories and exploring different scenarios. In many cases, the pecuniary value of the simulations arise from their ability to predict future outcomes, as in the case of stock market trends (Beltratti *et al.*, 1996). In this context, the simulations are used as practical tools and the general concern is whether they are reliable,

[36] The on line dictionary http://www.yourdictionary.com/artificial-intelligence [Accessed 09/07/08] gives the following definition of AI i) the capability of computers or programs to operate in ways believed to mimic human thought processes, such as reasoning and learning, ii) the branch of computer science dealing with this

repeatable and accurate; issues that come under the headings of verification, validation and accreditation (Balci, 1997). However, from an academic perspective, the assumed linkage between simulations and reality raises a fundamental epistemological question, which is: can simulations be a credible alternative to traditional experimentation? Before trying to answer this question, it may be useful to look Table 5, which shows some of the differences between the two methodologies.

Table 5 Examples of differences between traditional experimentation and computer simulation

Traditional Experimentation	Computer Simulation
Critical activities occur in the 'real' world	Critical activities occur within a computer (in cyberspace)
Can prove or disprove assumptions/theories/laws.	Cannot prove assumptions or theories relating to the physical world (other than in a purely mathematical sense)
Limited by physical/financial constraints of the experimental system.	Can explore wide ranging aspects of theories and hypothetical systems (almost limitless)
Can be formulated in a narrative or mathematical form.	Must be formulated as a computer algorithm.
Trends indicate increasing costs[37]	Trends indicate reducing costs[28]
Always involves errors	May be error free (but require sensitivity analysis)
Can be difficult to repeat and reproduce.	Highly repeatable and reproducible (through transfer of computer code)

One of the assertions made in Table 5 is that simulations cannot directly prove physical laws. An example of an experiment that illustrates this point relates to the Theory of Relativity (Einstein, 1912). Einstein's (1912) academic work was entirely cerebral and prompted many experiments, one of the which was to prove,

[37] Example taken from US chemical industry (Cummings, 2000) indicated that the cost of and experiment had increased from $50k in 1995 to $100k in 2000, compared to simulations which had reduced in cost from $20k to $5k during the same period.

or disprove, the conjecture that the velocity of light was/is a constant[38]. The critical issue of the Michelson - Morley experiment (Hay *et al.*, 1997) was that it was not to prove Einstein's theory, but to prove his assumptions. With today's computers, it would be easy to simulate the Michelson-Morley experiment such that the results confirmed Einstein's hypotheses. The problem is that such simulations would have to adopt Einstein's assumptions and they would therefore simply illustrate Einstein's theories not prove them. To prove Einstein's theories required that the actual physical entity (i.e. light) should have its speed measured and that could not be achieved using an electronic computer simulation[39].

It is evident from Table 5 that there is not a *one to one* correspondence between simulation and experimentation and that there are instances where simulations cannot substitute for experiments. So are there problems where simulations are more appropriate than experimentation? The answer here is yes. Consider trying to discover the shortest route that a salesman should take in order to make visits to customers each located in many different towns. A straight forward experiment could be set up to drive between the towns using a variety of routes. The difficulty is that there are a vast number of alternative routes that could be taken. In fact, this is a well known, and very difficult, problem of combinatorial mathematics (Lawler *et al.*, 1985) whose solution is completely impractical through experimentation and yet it has been effectively solved by simulation using a genetic algorithm (Goldberg, 1989; Moreno, 2008).

It is clear from the above examples that there are situations where simulations cannot replace experiments, such as when fundamental physical properties need to be discovered. It is also clear, that there are situations where a computer simulation is more effective and efficient than experimentation. Such as when exploring a system whose properties are known but whose boundaries are not, as

[38] Michelson – Morley experiment (see Hey *et al.*, 1997)
[39] Note of clarification: Modern computer components are now designed to utilise quantum effects (tunnel diodes for example), so it might now be possible to use an electronic computer to measure the speed of light by configuring it as an instrument, but not by performing a software simulation.

in combinatorial search problems; but what about problems that fall between these two situations, where causality and prediction is being sought? This is an area where the use of computer simulations is controversial.

The Legitimacy of using Computer Simulations for Causal Research

The desire for prediction implies a model building methodology that should embody causation rather than just explanation or description. Historically, the search for causality has been strongly linked to the scientific approach (Lastrucci, 1963), whereby experimentation links causes to effects through manipulation of the environment and/or system control variables. For some researchers, computers have become tools that aid the scientific process in a more profound way than by simply taking the drudgery out of numerical computation. Instead, computers are being utilised as tools to search and investigate combinatorial problems, in ways that include conditionality that can result in unexpected outcomes. Searching and investigating are activities that are more akin to research than calculation. As such, computer simulations are considered to be compatible with investigating topical issues and developing new theories:

'*The autonomy of the computer model is what enables scientists to gain insights from exploring the space they construct in the modelling procedure. In this sense, the computer is experimental: it provides controlled surprise.*' (Dowling, 1999: p. 264).

Dowling's (1999) assertion that it is legitimate to use computers for experimentation is not as useful as it may at first seem, since he limits his comment to the space they construct within the modelling procedure, without building a bridge from that space to the real world.

Using Computers for Computation

There are few concerns about using computers to take over the chore of long arithmetic calculations: '*The reliability of the knowledge produced by computer* *simulations is taken for granted if the physical model is correct'* (Kuppers and Lenhard, 2005: p. 5). However, using them for experimentation has been contentious.

Using Computers for Experimentation

In the early 1970's, the results of a two year long computer simulation project, based at the Massachusetts Institute of Technology, were published (Meadows *et al.*, 1972). The project, called *Limits to Growth,* focussed upon the issues that endangered the survival of mankind in the twenty-first century. The results stimulated a wide ranging academic debate about the legitimacy of using computer simulations as sources of knowledge, which at an epistemological level is still relevant to this thesis.

Critics of the Limits to Growth project said that the computer model was no more than a mental model in disguise (Streatfield, 1973). In a review of the controversy over Limits to Growth, the following statements summarized some key aspect of the criticism:

'Those who oppose the simulation results claim that the assumptions made by the modellers were such that the expected results followed readily without much computational effort. In their view, the computer is only a humble servant to the modellers, turning the biased assumptions into computational, i.e. apparently objectively derived results. '(Imhof, 2000: p. 10).

'Data of the necessary detail is not available to construct a valid model of global developments. This fact disqualifies all attempts to use a model to make forecasts since detailed empirical data decides future developments.' (Imhof, 2000: p. 13).

The noticeable aspect of both of these two quotations is that the criticism is not directly targeted at the concept of using computer simulations, but at the inadequacies and biases of the researchers who constructed the simulations. The first quotation could easily be paraphrased as 'garbage in garbage out'[40], albeit that the garbage is the computer algorithm as well as the data. So, it is not a criticism of the use of computers as a tool, but is about how the tool has been used. The second quote is not at all specific and could well be a criticism of any piece of research. In neither case is Dowling's (1999) point of view challenged.

Supporters of complexity science recognise the limitations of computer simulations in formulating rigorous generalizations or principles (Holland, 1995), but they have completely embraced their use to push at boundaries of knowledge. This is particularly true for those working in the area of artificial life, who have an ultimate goal of creating a hypothetical self-contained operating system in which new life forms exists (Lucas, 1999, Goldspink, 2000).

Using Computers for Prediction

It appears that when computers are employed in conventional research then they are seen as labour saving devices enacting the wishes of the researcher. In contrast, complexity science promotes the use of computers simulations in novel ways that actively explore uncharted territory; and when claims relating to their outcomes are confined to *the space they construct in the modelling procedure,* as Dowling suggested, then there is not a problem. However, what if the outcomes of novel computer simulations are intended to predict things in the real world? Using simulations for this purpose raises three key issues:

a) the meaning of words and symbols
b) understanding what is going on in the computer
c) accepting that the algorithm and the assumptions behind it are valid

There are two linked parts to point a), the use and meaning of symbols, and of words. Symbols are an integral feature of software products, which in the case of

40 See glossary of computer terms from the University of Leicester. Available from : http://www.le.ac.uk/cc/glossary/ccglg.html#8 [Accessed 27/03/08]

digital software turn out to be 0 and 1. The semiotic, mathematical and logical traits of 0 and 1 are central to this thesis and the relevant issues are covered in section 2.5 of this chapter and in chapter 3. The use and meaning of words is possibly an even larger subject. In commenting upon his rival (Sir Karl Popper), the philosopher Thomas Kuhn wrote: *'Nevertheless, our experiences like those mentioned above convince me that our intentions are often quite different when we say the same thing.'* (attributed to Kuhn, see Lakatos and Musgrove, 1970: p. 3). The importance of the meaning of words is not confined to the topic of this thesis but applies to all disciplines. It is an important and substantial topic, but it is no more important to this work than any other and it will not be discussed here.

The second point, b), relates a practical issue of human fallibility and the difficulties of reading computer code, especially large programs. In 1983 Microsoft's disc operating system (MS DOS) contained 36,000 lines of computer code, by 2003 the Microsoft Windows product contained 50, 000,000 lines of code. To put this in perspective, if a sufficiently able person read and understood one line of code per second, it would take over six years to read the MS Windows code (based on a forty hour week). One documented example of issue b), (Downey, 1998) relates to a lengthy computer program which could not be understood by the programmers who replaced its creator. When the originator of the program was asked how his software worked (which had been providing a company with the information that it required) he was unable to do so. This point has much to do with the practical aspects of writing programs, such as: the inclusion of comments within the code, consistency and the use of proven functional blocks. It also relates to the skill of the programmer in translating what is logically required into what actually takes place in the algorithm.

The third point, c), touches on underlying philosophical and methodological approaches. It falls into the same area as the change in the meaning of the word *prediction* when moving from Laplace's determinism to statistical mechanics (Parisi, 2007) and will be dealt with later in section 2.3.1.

So far, this section has highlighted some of the concerns that have been expressed by those who are against using computer simulations as active elements in research projects. It has also indicated that the computer simulation is an integral part of complexity science. Where computers are simply used to speed up arithmetic calculations, that would otherwise be performed by hand, there is no real concern. However, what is envisaged by complexity science is the use of computers for experimentation and exploration, addressing topics such as: neural networks (Dreyfus, 2005), complex adaptive systems (Dautenhahn and Nehaniv, 2002; Markose, 2005) and artificial life (Langton, 1989; Langton *et al.*, 1991; Adamatzky and Komosinski, 2005) and other associated areas. An example, that illustrates the differences between a conventional scientific approach and that of complexity science, is scrutinized in the paragraph below.

Boolean Networks

Imagine an electrical component that has two inputs and two outputs and a light bulb. This component is also configured such that if both inputs receive an electrical signal, then the light is turned on and both of the outputs then provide an electrical signal. In Boolean terminology this component is called an AND gate. If 100,000 of these units have outputs randomly connected to inputs how many different flashing patterns are possible? A conventional approach is to consider that each component has 2 possible states and that with 100,000 components there is a possibility of $2^{100,0000}$ different states (this is approximately $10^{30,000}$). Exploring all of these possibilities is known as an ergodic search. It used to be thought that performing this search was too great to contemplate. Complexity science sees this situation differently. Whist mathematically it appears as if there is a huge range of possibilities, it may be that other factors are involved whereby some of the possibilities are not allowed. There may be many reasons for this, there might be pathways that become closed, there might multiple identical outcomes reached by different paths, there might be preferred outcomes that appear to attract the dynamic system into a preferred state. For the situation described above, complexity science used computing power and logic to provide a remarkably different answer to the conventional one and determined that the system would settle down into one of 317 different states (not the billions predicted by simple probability theory). For a more detailed explanation see Kauffman (1996: p. 75-83)

The above paragraph relates to a system known as a Boolean network. Investigations of Boolean networks, similar to that described above, have demonstrated emergent order and attractors (Kauffman, 1991, 1993, 1996) as well as the observation of sensitive dependence on initial conditions (SDIC) and strange attractors (Ruelle, 1991; Sprott, 1993).

It turns out that the sensitivity of a Boolean network to produce emergent patterns is dependant on the degree of connectivity between nodes (Kauffman, 1996) which is suggestive of organisational behaviour where individuals form social networks (Van Alstyne, 1997). The contrast between looking at an organisation as a collection of connected nodes and one made up of independent discrete entities provides another opportunity to see methodological differences between traditional science and complexity science.

So far, this chapter has indicated that computer simulations are an integral part of complexity science; it has touched on Boulean networks and mentioned decision making that involves branching (bifurcation). In addition it has classified the research associated with this thesis as falling within the area of evolving complexity. Collectively, these issues point toward a methodology involving digital models and correspondence mapping and these point are dealt with next.

2.3.1 A Mapping Approach to Modelling and Simulation

Discrete Models and Correspondence Mapping

Many studies of *evolving complexity* involve a methodology that is underpinned by two critical components. The first is that they involve computer simulations based upon digital (rather than continuous) functions. The second is the application of a cross-disciplinary technique, whereby knowledge from one academic discipline is used by another. This subsection is an appraisal of these two key issues and so it reviews cases where digital models have been applied in a cross-disciplinary fashion.

Examples of Reductionist Mapping

Several attempts to model the behaviour of living organisms by physicists have treated individuals as discrete entities. In two cases, the organisms were modelled as if they behaved like molecules in a gas (Henderson, 1971; Ben-Jacob and Vicsek *et al.*, 1994) . In the first case, the Maxwell-Boltzman kinetic theory of gases was used to describe the velocities of people moving as a crowd (Henderson, 1971). Henderson's work identified different distributions for men and women and gave good predictions to velocity profiles, it also predicted some kind of phase transition that would freeze the crowd, but there were no really startling breakthroughs. In the second case, a similar *kinetic theory* approach was applied to try and explain the characteristic circular motion of a mutant Bacillus bacteria (Ben-Jacob and Vicsek *et al.*, 1994).

In the above cases, complicated theories were being mapped from a physical setting to a social situation in one case and from a physical to a biological setting in the other. Neither of these transformations were good fits. The idea of mapping from one discipline to another is consistent with complexity science, but in these two examples the results were poor. The problem was that in both investigations an associated reductionist[41] methodology had been retained. Fortunately, a relevant analysis of the issues surrounding reductionism in computer simulation can be found by looking at how theoretical biologists attempt to understand life (Rosen, 1991).

An Alternative Viewpoint to Reductionist Mapping

Rosen (Rosen, 1991) is insightful in the way that he differentiates between the clockwork machine metaphor of Newton (Newton, 1687; Mott, 1729; Berlinski, 2000) and Descartes (Des Chene, 2001) and the electronic digital computers used to create simulations in scientific research. Rosen (1991) asserts that the machine metaphor[42] is not just a little bit wrong, but entirely wrong and must be discarded. Yet he uses machines and mechanisms in an attempt to explain biological life through models and simulation. This may appear to be perverse, or at least ambiguous, but it is not. What Rosen implies is that reductionism and the clockwork metaphor is now impeding progress within the life sciences: *'If we give a physicist, say, a clock, his or her interest will reflexively concentrate on how it works, never on how it came to be a clock'* (Rosen, 1991: p. 15). He concludes that within the study of biology the machine metaphor has conditioned researchers to view their subject through the physicists lens. As a result, biologists believe that their subject is difficult because there are so many parts to be separated and characterised. The consequence of this is a failure to understand emergent properties as synergistic outcomes. What Rosen did, to try and breakout of this situation, was to define the Newtonian mechanistic paradigm that *life is machine like* much more thoroughly and then to look at the relationships and epistemology of the interacting components, for meanings, causes and effects. As he put it, *'... in a clockwork, recursiveness is not manifested in the motion of the visible figures being manipulated by it; it arises deeper*

[41] Reductionism is the belief that any complex set of phenomena can be defined or explained in terms of a relatively few simple or primitive ones. This is a short definition from the University of Oregon. Available from: http://abyss.uoregon.edu/~js/21st_century_science/lectures/lec01.html [Accessed 10/07/08].

[42] Descartes held that non-human animals could be reductively explained as automata.

down, in the springs and gears that actually do the manipulation. If we change the gears, we change the repertoire of the figures. In other words, what the figures themselves are doing now does not at all entail[43] *what they will do next; rather, it is what the gears are doing now that entails what the gears will do next, and what the gears are doing entails what the figures are doing. This apparently trivial remark has in fact a number of significant correlates for systems theory and system analysis, prime among them the germ of the concept of a program.'* (Rosen, 1991: p. 184).

Rosen's (1991)work provides a theoretical underpinning that links the natural world at one end with the outcomes of computer simulations at the other. Critically, his analysis allows the outcomes of the simulations to be more than simple arithmetical calculations. He explicitly differentiates between models and simulations in a way that supports the kind of work mentioned in the Limits to Growth project. In laying out his ideas, Rosen notes fundamental differences between models and simulations: '*...whereas the possession of a common model imposes a fundamental relationship (analogy) between the systems themselves, the possession of a common simulator tell us absolutely nothing about them beyond that fact'* (Rosen, 1991: p. 200) and '*... Insofar as such a distinction is intrinsically meaningful, it is always preserved by modelling relations. It is never preserved by simulations.'* (Rosen, 1991: p. 201).

The outputs from Rosen's (1991) kind of system are not like those from a simple adding machine. Instead, they can produce emergent and or anomalous results like those found in the natural world. In Rosen's (1991) philosophical reasoning, nature can be modelled and simulated, but outcomes from the simulations do not necessarily allow observers to understand the underlying workings.

[43] Rosen uses the word entail in a very prescriptive manner, with an approximate meaning of 'to have as a necessary consequence'.

Mapping for Complexity Science

Earlier in this section, there were examples of the technique of mathematical mapping, whereby a solution in one discipline was mapped into an unsolved problem in another. Both Henderson (1971) and the Ben- Jacob, Viscek team (1994) mapped from physics (kinetic theory of gases) into biology and sociology. Unfortunately, the mapping was imperfect. In Henderson's (1971) case, one critic (Ball, 2004: p.161) commented that *'although it was valuable in establishing the potential connection to statistical physics, Henderson's study did not really contain anything very surprising.* The Ben-Jacob, Viscek's team (1994) recognised the inadequacy of the original mapping and developed their model further. Instead of individual bacteria being considered to be like colliding gas particles they were modelled as self propelled tadpoles to reflect the tails (whip like strands of protein) that they can actually propel themselves with (Czirok, Ben-Jacob, Cohen and Viscek, 1996). Neither of these examples of mapping exhibit a high level of correspondence between the domains of physics and biology, which leaves them open to criticism from sceptics like Shermer (1997).

In contrast, whilst Rosen's theoretical framework allows mathematical mapping, it delves more deeply into the philosophical aspects of computer algorithms used to simulate nature, including how to codify natural systems into mechanisms and/or machines. Taking this more fundamental approach leads to other ways of creating simulations of the natural world that can take a, *bottom up* approach, whereby simple functions are allowed to interact and their collective outcome observed.

The bottom up approach is one that has been used in organisation policy, where ideas are sought from workers lower down the organisation, which is in contrast to autocratic styles where policy is simply dictated from the most senior levels (Sabatier, 1986).

A simple bottoms-up computer program was used to mimic the natural phenomena of flocking birds (Reynolds, 1987) and it produced startling effects. Whilst flocking by birds is a complex behaviour that mesmerises observers, the computer simulation was based upon a very simple set of rules[44]. Although this type of program is sometimes called 'bottom-up', it may be a misnomer since the rules that the agent must adhere to are assigned in a seemingly top-down fashion by the researcher himself (Duffy, 1998). Whether Reynolds program is bottom-up or not, it is based on small set of rules that produced an unpredictable emergent outcome that was recognisably similar to the flocking behaviour of birds.

Over the past thirty years, there have been contemporaneous developments in computing capability[45] and complexity science[46]. These two fields have interacted to produce virtuous self-reinforcing cycles of learning with demonstrably useful outcomes. There is still controversy about the use of computer simulations for active experimentation, but sufficient philosophical support for their use does exist and continues to accumulate (Miklecky, 2001; Merali and McKelvey, 2006; Heylighten *et al.*, 2006).

2.4 A Brief Review of Alternative Methodologies

The focus so far has been a methodology borrowed from complexity science. This is not yet a mainstream approach and a reasonable question is whether there are alternative methodologies that would be more suitable. Four methodologies

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[44] Reynolds program, called Boids, was based upon three rules: (1) Separation: steer to avoid crowding local flock-mates (2) Alignment: steer towards the average heading of local flock-mates and (3) Cohesion: steer to move toward the average position of local flock-mates. Available from: http://www.red3d.com/cwr/boids [Accessed on 24/03/08].

[45] In 1971 the Intel 4040 processor had 2,300 transistors and operated at 108 kHz, by 2007, the Intel Xenon microprocessor comprises of 820,000,000 transistors and operates at 3,000,000 Khz see the Intel data base. Available from: http://download.intel.com/pressroom/kits/IntelProcessorHistory.pdf [Accessed 09/07/08]

[46] A search of the internet for "Institute of Complexity Science .ac" using the Google search engine produced 95 occurrences in July 2008, thirty years earlier this discipline was only beginning to emerge.

will be briefly examined with this regard. They are: inductive analysis, grounded theory, economic modelling and deductive analysis.

Inductive Analysis

The process of inductive research (Heit, 2000) involves many activities. They include the collection of data, its codification, interpretation, aggregation and analysis.

One dictionary definition of induction is: *a process of reasoning by which a general conclusion is drawn from a set of premises , based mainly on experience or experimental evidence* (Sinclair, 1993: p. 582).

The critical aspect of the inductive process is that it draws insights from real life experiences, or empirical evidence, in a manner that is more than an historic account of a series of events. The aim is to produce new and useful knowledge from the experience, as well as to explain the processes and drivers that are involved in the dynamic system being studied. So, for example, an inductive astronomer who studied the sun might well predict longer days in the summer and shorter ones in the winter, which would be useful to farmers. What the astronomer would not be able to report is whether it was the same object being seen each day or if a new sun rose each morning.

Observing the sun is not a good illustration of the benefits of inductive reasoning, which is considered especially relevant when applied to complicated systems, such as those found in economics, management and the social sciences. A particular advantage is its flexibility which encourages exploration. So rather than simply observing a phenomenon, inductive analysis allows the researcher to probe beneath the surface to expose hidden features or unexpected relationships. A second attribute is its focus on qualitative characterisation, rather than simple definition and measurement. This leads to inductive analysis often being synonymously labelled *qualitative research*. One advocate of induction (Cregan, 2005) considered it superior to the *deductive* method, which *'leaves little scope* *for discovery of new clues in the quest to solve a pressing problem'* (Cregan, 2005: p.283).

Whilst induction has many attractive features it is not without problems. An analysis by Sandelowski (1986) identified four issues that complicate the debate about the scientific merits of qualitative research. They are:

1. The varieties of qualitative methods.
2. The lack of clear boundaries between quantitative and qualitative research.
3. The tendency to evaluate qualitative research against conventional scientific criteria of rigor.
4. The artistic features of qualitative inquiry.

In spite of the problems, qualitative research has been applied to the general topic of this research. In the area of knowledge management and business strategy, one group of inductive researchers have taken a perspective based on a socio-cultural view of organizational reality (Alstete and Halpern, 2008). Their belief is that the major knowledge drivers influencing business strategy are knowledge-centric drivers that are mainly influenced by socio-cultural factors. In the Alstete and Halpern (2008) analysis, knowledge is defined as a '*fluid mix of framed experience, values, contextual information, insight, and intuition that provides an environment and framework for evaluating and incorporating new experiences and information*' (Davenport and Prusak 1998: p. 5). A similar approach, with similar definitions, could be used to investigate software firms and they may provide a new and perspective. However, they are not the appropriate technique to study the relationships between the strings of zero's and one's, that make up a digital software program, and the financial payoffs that the programs produce in the global economic marketplace.

Grounded Theory

Grounded theory (Glaser and Strauss, 1967; Strauss and Corbin, 1990) is a special form of the inductive research process where data has to be systematically gathered and analysed in a prescribed manner. The technique was developed in order to advance the canon of knowledge within the field of sociology and it had four goals (Glaser and Strauss, 1967):

1. To enable prediction and explanation of behaviours.
2. Be useful in advancing theory.
3. Be practical.
4. To guide behavioural research.

The Grounded Theory technique is an extension of the basic concept of inductive analysis. It adopts a process that involves analysing and reanalysing the narrative database to discover the variables, categories, concepts and properties, at work in the system. The expectation is that repeated comparisons will give rise to emergent properties of the category being studied. The focus is on behaviours and the role of the researcher '*is not to provide a perfect description of an area, but to develop a theory that accounts for much of the relevant behaviour*' (Glaser and Strauss, 1967: p. 30).

The additional rigour that grounded theory brings to inductive method is useful for projects that produce textural rich data. This is not the case with the research associated with this thesis, where both the empirical and simulated data bases take either a numerical or graphical form. For this reason grounded theory is considered inappropriate.

Economic Modelling

The world is full of economic models. Table 6 shows the results of internet searches for two simple phrases i) 'Economic Model' and ii) 'Economic Simulation'. Both of the searches were performed using the Google search engine and in both cases a second search was made that included the term '.ac'. Inclusion of the term '.ac' was aimed at finding out how many search hits were located on the web sites of academic communities.

Table 6 Internet searches for economic models

Search Phrase	Number of hits
"Economic model"	947,000
"Economic model" .ac	131,000
"Economic simulation"	77.900
"Economic simulation" .ac	4,060

The data shown in Table 6 does not show how many different economic models there are. It might be that there is only one model which appears on 947,000 sites or perhaps there are almost a million different models each occurring only once on the internet. Both of these propositions are unlikely. What the searches indicate is that large numbers of economic models are accessible on the internet, with over 100,000 available from academic sites. But what are economic models and how are they produced? There is no prescribed answer. The Organisation for Economic Cooperation and Development (OECD) offer the following description[47].

An Economic Model is: A simplified representation of economic reality showing the interrelationships between selected economic variables.

The topics of the models tend to fall into two broad categories, microeconomic, and macroeconomic. The micro' category includes the topics of: supply and demand, theory of the firm, theory of the consumer. Whilst the macro' set

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[47] Available from http://stats.oecd.org/glossary/detail.asp?ID=6813 [Accessed on 04/11/08]

contains models with global reach: Classical, Keynesian, Mundell – Fleming etc.[48].

A common theme amongst economic models is that they are, rational, logical and described using mathematics. They encapsulate fundamental truths and provide the knowledge that politicians and governments need to influence their economies and are easy to simulate using computers. They also span from the theoretical to the applied[49].

It is hoped that the models associated with this thesis fall into the category of economic modelling, but they do so from a starting point out with the traditional economic framework and they employ a methodology that is in its infancy.

Deduction

Deduction is at the heart of what is generally termed the scientific method, which is also known as the hypothetico-deductive approach (Carnap, 1935, 1938). It is an approach that is characterised by a number of highly desirable attributes (Sekaram, 1984), some of which are listed below:

1. Purposiveness
2. Rigor
3. Testability
4. Replicability
5. Precision and Confidence
6. Objectivity
7. Generalizability
8. Parsimony

(The 8 points listed above are taken from *Research Methods for Business*, Sekaran, U. (1984) New York , John Wiley and Sons Inc. p.10)

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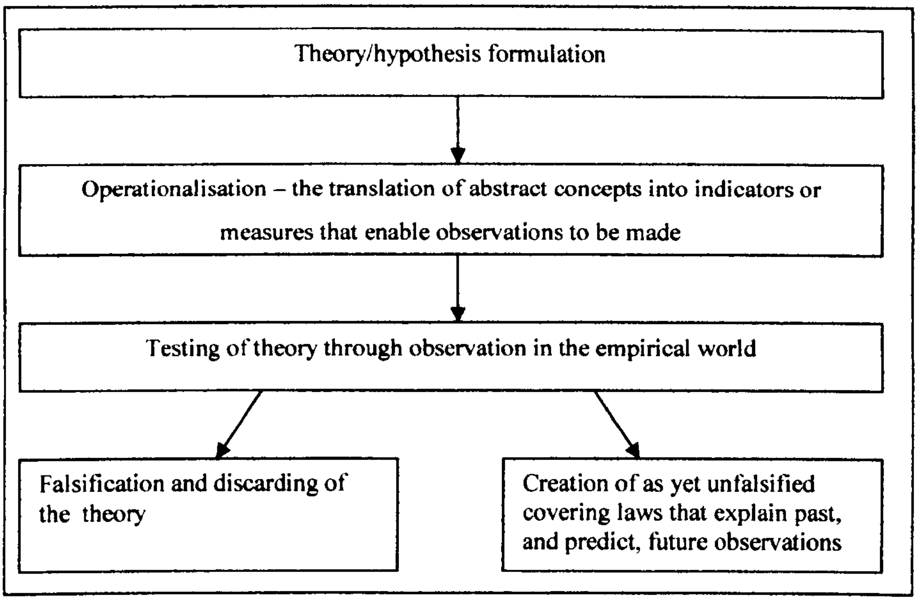
[48] Simulations of these models are available at http://www.econmodel.com/classic/ [accessed on 04/11/08].

[49] An example of the international Journal of theoretical and Applied papers on Economic modelling is available at http://www.sciencedirect.com/science/journal/02649993 [accessed on 04/11/08]

Figure 2 shows a simplified description of the deductive process.

Figure 2 Hypothetico-deductive process



(Figure 2 was taken from *Research Methods for Managers*, Gill and Johnson (1997), London, Chapman Publishing Ltd, p.32)

Deductive analysis is a powerful and credible methodology, that is considered the gold standard by many people. It has proven itself time and again in the physical sciences and underpins much of Newtonian physics; which is based upon a positivist paradigm (Ayer, 1946), requiring direct and specific linkages between cause and effect. However, this success is also an indicator of its limitations. Deductive reasoning is outstanding at identifying fundamental relationships, especially those that involve just a few variables and limited numbers of components. For example, deduction predicted the equations of motion for a pendulum to such a high degree that its position can be predicted with great accuracy. This knowledge led to the development of clocks, which has impacted the world for several hundred years. Yet a double pendulum (two rigid arms that are joined by a low friction bearing) produces such a chaotic movement that empirical evaluation cannot pass the test of falsification (Popper, 1977). The problem is not that its equations of motion are unknown, it is that the outcomes of a real double pendulum experiment are completely unpredictable, due to infinitesimally small differences in the set up of each run.

The difficulty of using purely deductive reasoning for complicated systems lies in the issue of falsification. Scientific falsification (Popper ,1977) states that a single example of a law being broken is sufficient to falsify the law. In the case of complex systems (even something as simple as a double pendulum), the inability to perfectly replicate an experiment and to precisely predict outcomes is low. However, there is a way to increase the usefulness of the deductive process for complex systems. It is by moving from a positivist epistemological position to one of logical positivism. This change in viewpoint allows for probabilistic events and removes the rigidity of Popper (1977). It allows and the direct linkage between cause and effect.

Taking a logical positivist (Hahn et al, 1929; Carnap, 1935, 1938; Hahn, 1980) perspective to deductive reasoning makes it a methodology that is compatible with this research, but it is not a perfect fit. The remaining issue relates to the first stage of the process (in Figure 2), which requires the creation of unambiguous and preferably simple hypotheses. The difficulty is a practical one. It is how to create a theory that is sufficiently rich to apply to real firms without producing so many hypotheses that the research becomes impractical. The solution that was identified was to use complexity science.

Complexity science has developed efficient ways to investigate complex problems that produce useful and practical outcome. It exploits the use of statistical reasoning and graphical rather numerical outcomes. '*When the process of scientific hypothesis testing are cast in hypothetico-deductive terms, we find that both involve tests, predictions, results and conclusions. However, the former involves causal claims , whilst the latter is descriptive. Importantly, connecting the two processes reveals that scientific predictions and statistical hypothesis* *are the same thing* (Lawson *et al.*, 2008: p. 405). For this reason, a complexity science style of deduction was adopted for this research.

Part 2 of the literature review has indicated that by adopting a complexity science approach, models and computer simulations can be viable tools for exploring the strategic characteristics of firms. A methodological framework for creating these modern simulations was not discussed in this section, as it is sufficiently important to merit a chapter of its own (see chapter 4). Part 3 will now look at the literature relating to the creation of business models and their conversion into computer simulations

Part 3

In part 3, the scope of the literature review is narrowed, so that it concentrates only on topics that are directly relevant to producing a business model of software firms. To begin with, the salient aspects of traditional models of firms are scrutinized. This is followed by looking at the two components that will form the core of the new models, which are: i) the virtual representation of software products and ii) an economic growth mechanism. Finally, ancillary modelling components are reviewed whose sole purpose is to make the final models more realistic (i.e. less theoretical).

2.5 Traditional Models of the Firm

This thesis is about simulating the way that software firms operate in the new economy marketplace. Although the final models and simulations are product centric, this research is about the nature of the software firms. It is therefore appropriate to begin this part of the literature review by looking at other models of the firm.

Arguably one of the most fundamental reasons for modelling the firm is to understand its potential for growth and wealth creation. It was not until the eighteenth century that the role that firms made to wealth creation began to be analysed through a microeconomic perspective (Niehans, 1994). It was investigated by economists who looked at the transition from farming to factories during the industrial revolution (Smith, 1776). Their approach, which aggregated quantities to look at the economy as a whole, remained popular and was refined and enhanced to create a model relevant for the twentieth century (Keynes, 1936). Other contributions to the search for an understanding of the characteristics and drivers of economic growth took a more focused approach by looking at specific areas. For example, output growth was shown to be dependent upon labour productivity and labour supply (Stiroh, 2002), whilst a stochastic link was made between outputs and profits (Robinson, 1992).

Traditional (neoclassical) macroeconomic[50] theories try to minimise the cost of a given output. However, while costs fall as output increases, the trend bottoms out due to fixed costs and as output continues to increase costs begin to rise again, because of a scarce management factor (Penrose, 1959; Matthews, 2001). The result is a U shaped cost curve. The macroeconomic approach, whilst being very important, treats firms as self-contained entities in their own right and is not of specific interest here, nevertheless an overview of the important concepts is given in Appendix 1.

An early attempt to link the role of firms to the neoclassical model was through an argument that viewed individual firms as merely divisions of one dominant entity (Coase, 1937) . As well as viewing firms collectively, Coase (1937) challenged the prevailing thoughts of the day regarding externalities (such as pollution and other social costs). Externalities were suspected to be a source of inefficient markets and they had previously been addressed by using the concept of Pigouvian taxes (Baumol, 1972). These taxes could be imposed upon capitalists in order to deal with the negative social and environmental impact of their actions.

Coase's (1937) seminal work proposed that the apparently indirect externalities were consequences of doing business and that they could be dealt with through competitive mechanisms within the economy, which he called *transaction costs*. Transaction costs included a broad range business activities, such as: searching, obtaining information, policing and enforcing. These extra, often essential, activities are sometimes categorised as overhead or bureaucracy costs and they

50 Macroeconomics was originally intended to mean the whole economic system in its entirety while microeconomics was defined as concerned with individual behaviour. Unfortunately, this cogent conception has not been followed, and the meaning of macroeconomics has become messy (DeVroey, 2004). Available from: http://www.ires.ucl.ac.be/DP/IRES_DP/2004-17.pdf [Accessed 28/07/08]

involve increasing levels of expensive co-ordination. By bring transaction costs within the firm, Coase's (1937) argument can be viewed as explaining how the size of a firm will be limited through the balance of positive and negative feedback mechanisms. The positive feedback being derived from *economy of scale*, which tends to reduce material and labour costs, whilst the negative feedback is provided through accumulating transaction costs; overheads and bureaucracy. In the context of this study, firms can be seen to be competing on a fitness landscape where peaks of fitness relate to: minimising internal transaction costs, eliminating unnecessary bureaucracy and lowering overheads.

Other issues, internal to the firm, have been investigated through agency theory, such as the ways to incentivise employees and managers to act in the interests of the owners and to take appropriate risks (Ross, 1973; Wilson, 1968; Arrow and Hahn, 1971; Jenson and Mechling, 1976, Jensen and Murphy, 1990). More recently, resource based or competence theories have attempted to provide a practical tool set for managers (Hamel and Prahalad, 1990; Teece *et al.*, 1997).

Further extensions, to both classical and neo-classical models, have been proposed to try and make them appear more realistic. One of these incorporated time delays to try and explain growth business cycles (Goodwin, 1947). The issue of time delays is important when dealing with the new economy as its products are subject to rapid technological change (Mitchell, 2004). The Goodwin (1947) models relied upon differential calculus, but were formulated as non-linear differential equations for modelling aggregative macro-dynamics.

Whilst there have been numerous theories relating to the way that firms operate, the breakthrough that has direct relevance to modelling the new economy relates to the linkage between the microeconomic performance of firms and the macroeconomic understanding of economies. The key argument is that economic expansion is due to processes taking place within the firm (Penrose, 1959; Pitelis, 2001).

The *theory of growth of the firm* (Penrose , 1959) takes a resource based approach to understanding the mechanisms that hinder or help firms to grow. Importantly, the focus of this theory is on what owners and employees do within their firm in order to outperform competitors within the economic marketplace as a whole. This position identifies growth of the firm as success and success is dependent upon internal rather than external factors. At the centre of this model is the view that outcomes are the result of how the internal resources of a firm are exploited. The collection of resources within a firm does not spontaneously appear, they are mustered and shaped by people and therefore in a competitive marketplace it is the human resources that fundamentally make the difference. Possibly the most noteworthy aspect of this Penrose's (1959) theory is that it does not limit the size of firms through a balance competing forces, instead it suggests that growth is possible for any size of firm if its management are capable of managing the necessary changes to achieve it. In the sector of software firms This relationship is the one that is developed upon in this thesis, with regard to software companies, through an assertion that the market values of their products are proportional to their fitness, and that product fitness is a result of decisions made by the firm (i.e. that product fitness can be improved upon through product development).

Earlier, the way that the new economy behaves like a complex adaptive system was evoked, but none of the theories of the firm that have been mentioned so far contain explicit reference to this matter, although it is alluded to with the introduction of idea of fitness, a term drawn from evolutionary biology. This situation is rectified in next section, which explicitly moves the argument into the domain of complex adaptive systems, by proposing the use of fitness landscapes in a model of the new economy.

2.6 Complexity and the Modelling of Firms within the New Economy

This thesis applies the technique of mathematical correspondence mapping in order to draw comparisons between biological systems and business systems. It does so to see whether meaningful parallels exist that can form the basis of a new business model. For example, drawing comparisons between evolutionary biology and evolutionary economics (Kahlil, 1997). In the case of software firms, one starting point is to look at the ways that creatures exploit their environment and compete with each other for the resources that support them and compare this to the way that products proliferate within an economic marketplace. Fortunately, a biological construct exists that has been used to explain evolutionary behaviours of organisms in terms their DNA which has strong similarities to software products. The construct is called a fitness landscape (Kauffman, 1996) and in biological terms it is a representation of the relative success of competing species . A novel feature, that differentiates this kind of approach from traditional theories of the firm, is that fitness landscape models offer the possibilities of firms becoming trapped in a sub-optimal state (local attractor / fitness peak), rather than striving towards an optimum solution as advocated in most traditional theories of the firm.

Fitness Landscapes

A simple landscape can be envisaged as a single peak rising out of a plane, which can be considered as an associated single valley. A more complicated landscape will have multiple peaks and valleys, perhaps resembling an egg crate. However, in general, the topography of landscapes allow for numerous peaks and valleys that vary in: height, depth, size, shape and location. The possibility of a multi-peaked landscapes has generated a significant body of research aimed at efficiently searching them (Kopp *et al.*, 1996; Kimura, *et al.*, 1999). An early technique for searching electronic media was the genetic algorithm (Holland, 1975). As the name suggests, it is a procedure that was developed to investigate genetics and the way that organisms evolve. It is especially effective because it combines both the role of mutation and recombination. So from a particular starting point, combinations of small improvements can be accumulated, which have the effect of improving the efficiency and the speed of finding the optimum, or peak, solution. There is also the issue of efficiency versus effectiveness. To perform an ergodic search, of every position on the landscape, is clearly effective as it must identify the global maxima, but it is also the least efficient. On the other hand, probabilistic searches may vary in both efficiency and effectiveness, depending upon the context. Simulated annealing (Szu and Hartley, 1987; Dowsland, 1993; Carley and Svoboda, 1996) can be used to freeze solutions out of a landscape, whilst genetic algorithms are routinely used when searching for combinatorial optimisation (Rawlins, 1991) and sometimes a combination of both are employed (O'Reilly and Oppacher, 1994).

The Kauffman N-K Fitness Landscape

Fitness landscapes are entities that embody information relating to combinatorial options and competitiveness. Fitness landscapes based upon a digital theme emerged in the early 1990's in some radical proposals, that challenged the Darwinian explanations of evolution (Kauffman, 1996). Kauffman (1996) describes a concept that he calls genotype space, which describes all of the possible combinations of genotypes that could exist .

'*...for an organism with N different genes, each with two alleles, the number of possible genotypes is now familiar: 2^N . The bacterium E. coli, living merrily in the intestines, has about 3000 genes; hence its genotype space might have 2^{3000} potential genotypes...* ' Kauffman, 1996: p. 163)

The genes talked about by Kauffman are, chemical entities. '*Genes correspond to a region on the linear DNA molecule. The DNA of repeating eoxyribonucleotides repeating units where each unit comprises of a sugar (2-deoxyribose) phosphate and a purine or pyrimidine base*'.(Parker, 1982: p. 843)

These highly complicated chemicals interact with each other, and their environment, in ways that allow them to replicate and grow. Replication and growth creates living cells which eventually express themselves in characteristic physical form, *the phenotype*. The processes involved in creating the phenotype are not random ones, they depend upon the precise chemical makeup of the genes, and there are an enormous amount of possibilities.

The large number of possible genes arises from the rule of permutations, which states that if there are n_1 ways to choose a first item, n_2 ways to choose a second, n_3 ways to choose a third and so on; then the number of ways to choose from all items is.

$$N = n_1 \times n_2 \times n_3 \ldots \qquad (1)$$

So if there are three items, each of which have two possible states, the number of possible states is: $2 \times 2 \times 2 = 2^3 = 8$. Kauffman goes on to describe a genotype with only four genes, each comprising two alleles of one and zero. This situation gives sixteen different possible combinations (genotypes), which can be numbered 1 to 16 or in binary 0000 to 1111. This group of sixteen genotypes is then represented pictorially as a Boolean hypercube (this looks like a wire cube within a wire cube, with corresponding corners joined by eight short straight wires see Figure 3). Each node of intersecting wires represents a unique genotype, that Kaufman (1996) allocates random fitness values to, in order to create a random fitness landscape. On this landscape, moving between neighbouring nodes, a situation that represents genetic mutation, can be seen to represent either an increase (moving up hill) or decrease (moving down hill) in fitness. These concepts of genotype space and fitness landscapes are taken further through the creation of the NK model, which introduces the possibility of increasing an organisms fitness through emergent synergies.

Figure 3 A Boolean hypercube

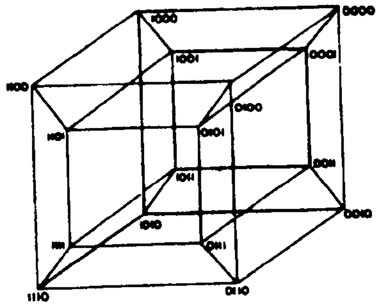


Figure 3 is taken from *At Home in the Universe* (Kauffman, 1996: p.165)

The Boolean hypercube contains all possible combinations for genes with two alleles each, but the linkages between the genes and their fitness values are entirely arbitrary.

Kauffman (1996) proposes that random fitness landscapes are inappropriate for describing evolutionary natural selection and he gives two reasons: i) genes do not operate in isolation, in many cases they exhibit epistatic coupling, whereby one gene influences the fitness of another and ii) random landscapes have large numbers of randomly distributed small peaks, so that an evolutionary strategy of walking up hill leads mainly to sub-optimal low levels of fitness.

The NK model reflects point i) by allowing the fitness of an individual gene to be influenced by a small group of associates. This linkage adds structure to the landscape, which Kauffman (1996) terms *correlated* and results in properties that resonate with observations from real life. Peaks are higher and there are fewer of them, they tend to be clustered together and so walking up hill becomes a good evolutionary strategy. However, each step results in diminishing returns, as well as leading to a position with fewer options to advance.

Kauffman's (1996) model of biological evolution creates landscapes from a small subset of genotype space and this allows a strategy of natural selection to prevail through random mutation. Put slightly differently, currently scientific thinking

has decreed that an evolutionary random search method is the way that organisms evolve and therefore biological fitness landscapes must have low K. This thesis is not specifically about search techniques and so speculation about the shape of a real product fitness landscape is not necessary. In translating Kauffman's (1996) ideas to the new economy, the shape of the product fitness landscape need not be assumed, instead the set of all possible products may be considered. In the case of digital software this equates to what Kauffman (1996) called *genotype space*. Genotype space is a data set capable of providing an imaginary fitness landscape of all possibilities, into which any real software product can be mapped.
On his way to developing the NK model, Kauffman (1996) drew parallels between the genetic programming of living organisms and the strings of zero's and ones that make up a computer program. To illustrate his point he presented an argument that looked at how a computer program could evolve from an arbitrary configuration of zero's and ones, to a program that would perform some specific operation. From the vast number of possible combinations (akin to the genotype spaces) he suggested that there would be many working programs that could perform the task to a greater or lesser degree. These programs could be rated against each other and the resulting figures of merit could be considered to be a fitness landscape for the program. He explained it thus: *'When all redundancy has been squeezed from the program, virtually any change in any symbol would be expected to cause catastrophic variations in the behaviour of the algorithm. Thus nearby variants in the program would compute very different algorithms. Adaptation is usually thought of as a process of "hill climbing" through minor variations towards peaks of high fitness on a fitness landscape.'* (Kauffman, 1996: p. 154)

So a fitness landscape can be thought of as a representation of a utility function for the outcomes of all possibilities. Local peaks on the landscape represent successful configurations while valleys represent failure. At any instant in time a particular type of entity, such as a program or an organism can be represented as a point on the landscape. Changes to the organism's genetic code due, for example, to a mutation will produce a variant that will occupy a new point on the landscape. The new point will reflect an improvement (a move up hill) or a degradation (a move down hill) or it will stay at the same level of fitness. An obvious question is: which version of an entity is associated with which point on the landscape? One way to discover the answer is to realise all possible configurations and compare them with each other. For simple entities, where only a few options exist, this may be possible, but the number of options increases explosively as the number of changeable elements increases, a phenomenon known mathematically as being NP or NP complete (Garey and Johnson, 1979). Knowing the relative fitness of any combination of options may be interesting, but in practical terms, understanding which combinations of options represent local peaks (and, if possible, the global peak) is most useful. In the NK model, Kauffman proposes a disequilibria search process as one that mimics natural selection,

Although the interpretation that Kauffman (1996) gave to his NK model was to challenge Darwinism, this has not been fully accepted (Maddox, 1995), however, it has achieved a resonance within other disciplines, including economics and management, where complicated problems can be framed in a similar manner.

Kauffman (1996) constructed his NK model to explain biological diversity, but it is fundamentally an elegant mathematical model that brings together combinatorial options and a networked feedback mechanism. For this reason it has been found to be applicable in other fields, where similar needs have been identified. Some examples, of where the Kauffman NK model has been tried out, include: the analysis of economic organisations (Westhoff *et al.*, 1996), the development of a *kan ban*[51] system (Haslett and Osbourne, 2000), product architecture and design (Brabazon and Matthews, 2003) and organizational strategy (McKelvey, 1999). Even where the fully integrated model, of an active

[51] Kan ban is a Japanese term for a system where minimum stocks are held at the point where they are used, but replacement of used stock is virtually instantaneous.

fitness landscape, is not articulated, the concept of a fitness landscape has been found to be a useful tool in economic and management disciplines. The question of how to navigate on a competitive landscape has been raised (Ferrier, 2001) together with subsets of this question, such as looking at a competitive manufacturing landscape (McCarthy and Tan, 2000). There are also models, which while not using the phrase fitness landscape, result in outcomes that are aligned to the concept. For example, a three dimension model that began life as a representation of how cities grow, has been adapted into a network model, with feedback mechanisms that generate a landscape showing the way that firms grow within a hypothetical economy (see Ormerod, 1998).

It is worth noting that Kauffman (1996) viewed the appropriate landscape for a computer program to be a random one '*... our random landscape is deeply similar to the fitness of maximally compressed computer programs .*' (Kauffman, 1996: p. 166) His reasons behind this statement are sketchy and his comment '*changing a single bit, making any mutations at all, completely randomises fitness.*' (Kauffman, 1996: p. 166) is considered an unproved assertion.

In spite of fitness landscapes being used in some areas of economic modelling, their application to firm behaviour is relatively sparse. The parallel between animals competing within a natural environment and products competing within an economic environment is an attractive one. It is generally accepted that the genotype and phenotype of an animal species are determined by a set of instructions encoded within its DNA and whilst some alleles allow variations to occur, the theme is a constant one unless the DNA undergoes some sort of mutation. Within the new economy, many of the products consist of no more than a set of digital instructions, which when performed produce a product. On this basis, the instruction set of DNA and the instruction set of a virtual software product are directly analogous. The difference is the media that is manipulated by the instructions. In the case of DNA, the instructions operate within a liquid media that comprises of a soup of biologically complex chemicals. In the case of digital software products, the instructions operate within the solid state media of a computer processor, where the position of an electrical charge or a magnetic dipole, has a meaning. This is an area were there is scope for exploring the concept of fitness landscapes in the context of software products that could be useful to some business strategists.

The NK fitness landscape model developed for evolutionary biology is a construct that is sufficiently abstract to be used by other academic disciplines and it has been. The parallels between animal DNA and the digital strings that are at the heart of software algorithms are very strong and so the NK model is eminently suited to be the foundation of a new business model for software firms.

This section, (2.6) has identified a new way of looking at the economic marketplace using the concept of fitness landscapes. It is an idea that can be refined to embrace digital software firms and their products, whereby the desirability of a particular software program is defined as its fitness. This concept alone is insufficient to create a practical business model and so the next section will look at the process of growth

2.7 Traditional Aspects of Economic Growth

The emergence of the new economy reawakened an interest in growth as the centre piece of economic and strategic thinking (Audretsch, 2003; Kahn and Rich, 2003). This section touches on the neoclassical approach to economic growth in general, and then to growth of the firm. It moves on to a detailed discussion of the growth mechanisms based upon logistic difference equations (Goldberg, 1958).

Economic growth is important to all nations, as it gives an indication as to whether their population's lifestyle is improving, or getting worse. This is of such importance that many people have produced models to try and understand it

(Keynes, 1936; Harrod, 1939; Domar, 1946; Solow, 1956; Swan, 1956). It is not the intention of this literature review to provide an in depth analysis of every growth model, but an overview of some historically important theories is given in Appendix 1.

The neo-classical model of the economy (Solow, 1956; Swan, 1956) introduced productivity as a key driver of growth, but it also implied that an economy has an underlying characteristic growth rate. Furthermore, it stated that when the growth rate is greater or less than the characteristic, or *warranted*, growth rate then forces within the economy surface, which push growth towards its warranted level. So whilst the neo-classical approach allows deviations in growth rate, they are expected to take place around some norm.

When growth in the USA took a leap upwards in the 1990's, the question was raised as to whether it was a permanent shift, or an aberration that would be corrected over the long term. By the turn of the millennium, the United Nations was issuing upbeat reports[52] claiming that the estimated contribution from the new economy was adding about $100 billion USD per year to total output. Those who believed that there was a genuine increase (in the warranted growth rate) like Nordhaus *et al.* (2002), looked for reasons for the emergence of a new economy and they naturally focused on whether a new productivity paradigm[53] could be identified. Evidence supporting a change would imply an underlying change in the processes that drive growth.

The traditional economic models, which have been summarised in appendix 1, show a progressive move towards a macroeconomic perspective. This is useful in controlling an economy and is therefore of interest to governments. In the western world, economic growth rates during the twentieth century have

[52] The United Nations World Economic and social Survey Available from: http://www.un.org/esa/policy/publications/papers.htm#2000 [Accessed 28/07/08]
[53] A productivity paradigm is the economic situation associated with a particular warranted rate of economic growth.

typically been under 10% per annum (Kenwood and Lougheed, 1999 ; Crafts, 2000) and by the end of the twentieth century 3 % was more typical[54]. The output growth rates that are declared by economists and politicians relate to business performance, so it could be argued that the models that generate these forecasts should be of great strategic interest to business leaders as well as politicians, but are they?

The neo-classical model provides practical information to business leaders at two levels. The most important and useful is that output growth depends on increasing labour and/or increasing productivity (Stiroh, 2002). In the early part of the twentieth century, the fixation that firms had with increasing productivity was exemplified by an approach called *scientific management* (Taylor, 1947). Scientific management adopted micro management techniques within the firm to increase the efficiency of workers and their tools. This was achieved by; reorganising work flows, matching operator's capabilities with the demands placed upon them, and by ensuring that every minute of their time was productive. In many manufacturing organisations scientific management manifested itself in departments specialising in *time and motion* or *work study*. The role of productivity in wealth creation and in the growth of actual firms, can be seen to have been critical. In recent years the concept of manufacturing efficiency has been transformed into a business perspective, where matching business activities to customers needs have been emphasised (Hammer and Champy, 1993).

The second practical output from the neo-classical model is to forecast the growth rate of the economy as a whole. This is especially useful to businesses that operate in a saturated market, such as suppliers of office equipment. When the market is saturated and there are no new alternatives, then maintaining market share means growing at the rate at which the market is growing. This link

[54] Between 1960 and 1989, the average growth output per capita of: Canada, France, Germany, Italy, UK, and USA ranged between 2.07 % and 3.74 %. Available from: http://www.niesr.ac.uk/pubs/dps/dp221.pdf [Accessed 28/07/08].

between forward planning and growth is recognised by politicians who use phrases such as '*plan ahead for sustained economic growth*' (Dodds, 2008: p.1)

Although, over the long term, wealth appears to increase with time as economies grow, achieving continuous growth has been impossible (Kenwood and Lougheed, 1999). Instead the world has been dogged by cycles of boom and bust (Glasner, 1997). As the twentieth century progressed, and the new economy emerged, there continued to be a search for new and better economic models that reflect these fluctuations in growth (Romer, 1990; Easterly, 2002).

Economic Growth Dynamics: Continuous versus Discrete

The neoclassical growth model focuses on the way that supply and demand impact upon prices output and income. It assumes that when changes arise the forces within the economy will move it towards a state of equilibrium and these models are formulated using differential equations. The accepted view is that '*problems in economics usually involve discrete variables, but we can treat them as continuous variables and use the tools of calculus*' (Aslaksen[55]). This may not appear to be a problem, but it implies that the parameters that define the economic system are of a continuous nature (i.e. like the flow of a liquid). This is at odds with the complexity science perspective which deals with arrays of discrete entities, linked to form networks.

Within the field of complexity, the differences between the discrete and the continuous are considered important, as can be seen from the following statement made by an academic working in the field: '*Now let us clarify the meaning of time and space that we face in our approach to equations. We think that there is a general problem of defining the meaning of so-called "discrete time and space" appearing when interrelation maps or difference equations are used. The questions arise when we try to make a link between continuous time and space of*

[55] Quotation taken from the web site of Helmer Aslaksen, Department of Mathematics , National University of Singapore, Available from:
http://www.math.nus.sg/aslaksen/teaching/calculus.html [Accessed 04/04/08]

differential equations and discrete nature of our numerical calculations.' (Gontar[56]).

From a modelling perspective, using differential calculus is straight forward as long as the system that the model represents is predisposed to continuous change. This is exactly what traditional economic models assume. This does not mean that shocks cannot be applied to these kinds of systems, but applying a shock does not change the nature of the system (Batt and Ravindran, 2005).

A specific example, of a continuous system to which shocks are applied, is a recent dynamic microeconomic model (Trimborn, 2007). In Trimborn's model, control parameters can jump up or down to apply shocks to the system, but dimensional state variables and boundary conditions are continuous. Trimborn summaries the situation thus: *the relaxation algorithm can solve infinite horizon problems exhibiting anticipated shocks conveniently, since it solves the multi point boundary value problem directly. This is done by implementing the continuous variables as differential variables and the possible jumping variables as algebraic ones. The only input the user has to provide are the time dependent parameter* value' (Trimborn, 2007: p.10).

In their early stages of development, the classical and neo-classical models allowed instantaneous rational change to the economy as a method of allowing quasi-static[57], steady state growth to occur (Keen, 2001). It was as if the participants within the economy had a collective consciousness and were playing by the rules, there was no place for workers in one part of the economy to be paid more than an equivalent worker elsewhere. Wages would go up or down instantaneously, depending upon the balance between supply and demand for labour (Muellbauer, 1981).

[56] Quotation taken from the web site of V Gontar, International Group for Scientific and Technological Chaos Studies, Ben-Gurion University of the Negev. Available from: http://www.bgu.ac.il/chaos/paper10/paper10.html#formula2 . [Accessed 04/04/08].
[57] Quasi-static: slow changing, almost static (definition of quasi – *combining form-* almost , but not really; seemingly (Sinclair, 1992)

Although the neoclassical model viewed the economy as a continuous system, there were alternative viewpoints put forward (Goodwin 1951, 1953, 1967, 1989, 1990, 1993) that gave credible explanations of how business growth cycles arise due to delays and discontinuities in the system. Goodwin's mathematical model of the economy was construed to suggest linear couplings of non-linear oscillators. It combined feedback mechanisms between discrete entities (Vellupillai, 1999) as well as a cross-disciplinary approach based on the Lotka-Volterra (see Minorski, 1962) predator-prey model for fish populations. Goodwin formulated his model to contain variables within the interval [0,1] and in spite of criticism of this (Desai *et al.*, 2003) it has been extended by others (Atkinson, 1969; Desai, 1973; Harvie, 2000) to offer further insights into economic behaviours.

The Lotka-Volterra equation, used by Goodwin, is part of a family of apparently simple equations called *logistic* (Blanco, 1993), which can express a wide range of complex behaviours, including: decay, oscillations, chaos and sigmoidal curves. The flexibility of logistic equations has prompted their use in several areas of economics. For example, a simple quadratic, differential form of the logistic equation, has given a conceptual rationale to an empirical growth model (Fisher and Pry, 1971).

The ability of the Fisher-Pry (1971) model to forecast market size and growth rates was investigated at a micro-economic level (Twiss, 1984) with respect to examples of technological substitution. Twiss (1984) looked at different products and assessed how well they fitted the model. The migration from cross ply to radial tyres fits the model very well, with sigmoidal curves showing a slow introductory phase, followed by rapid growth and finally tailing off to a saturation level representing replacement business. However, other examples, such as the change from monochrome to colour TV's, exhibited discontinuities and inconsistency that were not fully explained.

Supply and Demand

Many economic growth models recognise that both supply and demand are important and a new business software firms should include both of these factors. However, the supply side of the new economy has some aspects that differentiate it from the traditional economy. Possibly its most significant of which are virtual products (Cretu, 2006) and a virtual marketplace (Knights *et al.*, 2007). The virtual nature of software products means that they consume no physical resources to manufacture and can be transported at virtually zero cost, this has lead one commentator to describe them as weightless (Quah, 1999) and to propose that this feature is an important reason for the rapid growth of the new economy.

On the demand side, growth manifests itself in two basic ways: i) consumption of *more of the same* products and ii) consumption of alternative products. Furthermore, if alternative goods have a different unit price, and different utility, then measuring economic growth with regard to the cost of living (Dulberger *et al.*, 1996) and making decisions based upon that measure becomes tricky (i.e. how should flat spending on products, that have ever increasing utility, be interpreted?). In the USA, the Boskin Commission (1996) concluded that properly incorporating advances in variety and quality would add 0.6 of a percentage point to annual growth consumption.

Product Lifetime

How long a product remains serviceable is an important aspect of economic supply and demand (Packard, 1960) and can be thought of as the products lifetime. The impact that lifetime has in economics has long been understood in the insurance industry, where laws of mortality have been developed by actuaries since the early nineteenth century (Gompertz, 1825). More recently, consideration of the roles that both birth and death rates play in biological systems (Leslie and Ransom, 1940) has led to a good understanding of matrix models which deal with age structured populations (Ellner and Guckenheimer, 2004). In the context of this study, a notable observation is that for software firms the rate of innovation exceeds the functional lifetime of existing goods. For example, Microsoft introduced nine new versions of their *Windows* software between 1986 and 2003, an average of one every two years, while the average useful lifetime of software products is approximately ten years (Tamai and Torimitsu, 1992). This issue is relevant to consumer choice and so it is surprising that so few of the biological or economic logistic growth models contain age structure in the populations.

There is a surfeit of academic information relating to economic growth models (Cassels, 1918; Keynes, 1936; Harrod, 1939; Domar, 1946; Kaldor, 1957; Solow, 1956, 1957; Swan 1956), as well as substantial quantities of microeconomic data[58]. This knowledge base offers the opportunity to create new models that describe software firms operating in the new economy. However, whilst the combination of fitness landscapes and growth equations might lead to some interesting academic insights, it may not be sufficiently rich to produce a practical tool for business managers. For this reason some value-judgements were made about what additional features should be included. The additional facets that were added to the new model were: market shares, interactions with competitors and the tensions between exploration and exploitation. The final three sections of the literature review deal with these points.

2.8 Market Share and Self-reinforcing Mechanisms

Complexity models, especially self-reinforcing mechanisms, have a distinct contribution to the discussion of what determines a firms share of the marketplace. A mathematical model to describe market shares has been produced that is impressive in its accuracy (Wagner and Taudes, 1986). It made use of a

[58] For example, in the USA government data is available from www.fedstats.gov [Accessed 29/07/08].UK government data is available from www.statistics.gov.uk [Accessed 29/07/08]

stochastic process, based on the Polya urn process (see 2.8.1), to describe brand choice and purchase incidence.

The Wagner-Taudes (1986) model was based upon three hypotheses: (A1) brand choice follows a zero order process, (A2) purchase timing can be described by a Poisson distribution[59] and (A3) the mean purchasing rate is allowed to be influenced by marketing mix variables and time. The authors point out that A1 and A2 are not generally accepted. They also note support for the effect of memory in brand choices, in so far as prior usages influences future choices (Hauser and Wisniewski, 1982). On the other hand, empirical studies for frequently bought consumer goods, which take account of heterogeneity and nonstationarity, indicate no learning is evident from customers actions (Hauser and Wisniewski, 1982). Results from the Wagner-Taudes (1986) model are impressive in tracking the actual market shares of five branded food products over several years.

Unfortunately, this model is inappropriate to use with new economy products for three main reasons. First, it has been tailored to fit empirical data from seasonal, inexpensive, frequently bought, non-durable consumer goods. The purchasing parameters associated with these products are likely to be quite different from new economy products, in the sense that they are relatively cheap/trivial purchases where a wrong decision should not have a long lasting legacy. In contrast new economy products, such as computer software or hardware, are expensive and relatively durable. Second, the model is too complicated (which is why it is so good at reproducing a complex polynomial output) and finally, it has a very low generalisability. What is being looked for is a model that is simpler and which captures the essence of the process rather than the detail. Stripping down the model to the basic Polya urn process is something worth considering.

[59] Note that a discrete probability distribution is being used here (Rees, 2000)

The Wagner-Taudes (1986) model discounted memory because of the nature of the products. For relatively expensive items like software, that are replaced with moderate frequency, mainly to improve performance, the issue of consumer memory cannot be discounted (Hauser and Wisniewski, 1982; Leefang and Boonstra, 1982).

Products are consumed by people, whose experiences influence their behaviours and future choices. Two factors, that of particular concern with this regard, are learning and memory (Sternberg and Wagner, 1999). Adding memory to a model requires the creation of a process that stores information that can be retrieved and used at some future point. This can be very useful, but it can also be inefficient and complicated. Fortunately, there are processes that modify themselves in a way that takes their own history into account, either implicitly as in a Markov chain (Cinlar, 1975), or explicitly as in a semi-Markov chain (Fossett, 1979). Of these two process types, the Markov chain is the most efficient since at any point in time the status of the system is purely a result of its own history[60]. The semi-Markov procedure retains an audit trail that allows details of its history to be recovered. Simple examples of this process are called self reinforcing processes[61] (Arthur, 1990) and they can produce results that evoke many real life situations.

Self reinforcing mechanisms occur frequently in everyday life. In nature ants mark their paths to food with pheromones and choose paths that are marked most strongly, leading to self reinforcement (Hemelrijk, 2005). Whilst in the Economy, firms with similar needs tend cluster together in one geographical location (Arthur, 1994) to benefit from a pool of talented labour and the shared costs of a common infrastructure (Ottaviano and Pug, 1998). In the case of industry clusters of hi-tech firms, they can arise when a process of change,

[60] Although explicit details of its history are unavailable
[61] An example of a self reinforcing process common to everyday life is compound interest, where positive feedback causes a non-linear growth in savings.

leading towards a particular goal, is repeatedly undertaken as in the Polya urn process (Polya and Read, 1987; Arthur, 1994).

2.8.1 The Polya Urn Processes

Two interesting developments during the past twenty years have been the adaptation of the Polya urn process to create stochastic models of firm growth (Bottazzi and Sechi, 2003) and market share (Wagner and Taudes, 1986). Within the domain of economics and business, a simple self reinforcing mechanism has been borrowed from mathematics in order to explain why industries of a particular type tend to cluster together (Arthur, 1994). The mechanism is the same as the one used by Wagner and Taudes (1986), i.e. the Polya' urn problem. The basic idea can be described in a game (after Polya and Eggenberger, 1923) can be described thus. Think of an urn of infinite capacity, to which are added balls of two possible colours - red and white, say. Starting with one red and one white in the urn, add a ball, each time, indefinitely, according to a rule: Choose a ball in the urn at random and replace it; if it is a red, add a red, if it is a white, add a white.

The characteristic result of this game, is that for low numbers of balls the ratio can vary significantly as balls are added; but as the number of balls in the urn becomes large, the ratio of the colours converges towards some constant value. It is not possible however, at the start of the game, to predict the ratio to which the system will converge. Whilst Arthur (1989: p.117) gives *industrial location by spin-off* as an example of Polya -type path dependence, the issue of market share is another that comes to mind.

An investigation, into the factors that determine the market shares of grocery purchases (East *et al.*, 2000), showed that *first store loyalty and retention* contains elements of serendipity and inertia. East's team (2000) commented that about half of the reasons for switching were related to store accessibility. They also found evidence that brand loyalty is associated with first store retention and concluded that this suggests that a proneness for routine may also be a basis for this form of loyalty. Two situations were discussed by East *et al.*, (2000) relating to customer loyalty, in terms of the percentage of expenditure at the 'First Store'. The first situation considered those shoppers who bought all of their groceries from one store. It was noted that this situation restricts trial and therefore makes any substitution of the first store less likely. The second situation considered shoppers who purchased from three stores. It was pointed out that relatively small changes in share can displace the current dominant store. Both of these scenarios can be modelled using a Polya urn process, where the number of different coloured balls would relate to the number of stores. For the special case of 100% first store loyalty, there could be just one ball in the urn when the process begins. Further evidence supporting the use of a process that involves sensitive dependence on initial conditions comes from studies of order entry on market share. Empirical evidence suggests that early followers can expect to get no more than 60% market share and being a late entrant will place a limit of 40% market share at most (Bond and Lean, 1977; Whitten, 1979; Urban *et al.*, 1986).

The Polya urn process is simple and highly generalisable. It has been used as an component of several models, including ones that account for market shares of firms. It is an appropriate component of a new simulation of the firm, as proposed in this thesis.

The next section looks at how strategy has been informed by game theory and the way that strategic decisions relating to competitive positioning can be modelled.

2.9 Strategy and Game Theory

Throughout any typical day, living entities exhibit a variety of behaviours in order to survive and prosper. These behaviours may be tactical or strategic; they could be random events or the result of learning. Whatever their origin, there is a set of activities that could be analysed on a bipolar scale as exhibiting either cooperative or competitive behaviour. One set of academics have described this situation in the following way: '*Strategic behaviours associated with rent seeking may be arrayed on two distinctive but interrelated continua, reflecting degrees of interfirm competitive and cooperative orientations. Strategy researchers to date have tended to view competition and cooperation as opposite ends of a single continuum.* ' (Lado *et al.*, 1997: p.118).

To produce a simulation tool, that is intended to have practical value to a business manager, without allowing for some degree of competitive or cooperative behaviour would be remiss. On the other hand, there are undoubtedly many facets to this subject and to review all of them would extend this piece of research beyond the boundaries of time that constrain it. A compromise that has been decided upon, is to select a modelling element that can be shown to provide cooperative or competitive forces, without making any claims that it is the most suitable to use. The area that was targeted for selecting this modelling element was game theory (Rasmussen, 1989), a subject area that is highly complimentary to the task in hand: *The great successes of game theory in economics have arisen in a large measure because game theory gives us a language for modelling and techniques for analysing specific dynamic interactions.* (Kreps, 1990: p. 41).

There have been many mathematical approaches used to try and understand interactions in economics, one of them drew parallels between economic behaviours and games (von Neuman and Morganstern, 1944). Von Neuman and Morganstern's (1994) seminal work provided an extensive mathematical framework that covered the principles of zero-sum and non-zero-sum games.

Game theory, as applied to economics, has steadily established itself as a legitimate approach to investigating problems of business strategy (Dixit and Nalebuff, 1991). As electronic computers became more available, simple games were simulated and used as research tools and training aids. One of the simplest digital game, that attracted a lot of academic interest, was called the Prisoners

Dilemma (Luce and Raiffe, 1957; Rapoport and Chammah, 1965). As computing technology advanced, so did game theory and more complex games emerged that could represent many aspects of commerce, such as: the market dominance of a few large firms that result in oligopolistic systems (Dixon, 1988; Lyons and Varoufakis, 1989), welfare economics and welfare comparisons (Dixon, 1988; Gibbons, 1992a), strategies for technological change involving based on leader - follower behaviours (Gibbons, 1992a) and learning based strategies (Mankiw and Taylor, 1998).

These academically framed games could involve individual players, or coalitions, engaging in single or repeated games with each other. An important link between economics and game theory is that in both systems, participants are considered to behave rationally. In general terms this means that they interact with their environment and other participants in a manner that will lead to maximising the benefits that will accrue to them, or a group to which they belong.

The concept of *benefit* has a number of explanations that include utility, money and wealth. In a wider social context the debate about how to define benefit would be wide ranging. In a similar vein, the assumption of rational behaviour is open to challenge. Individuals may behave emotionally, randomly, habitually, altruistically and in many other ways that are not obviously rational. Even when agents wish to behave rationally, their limited access to information can bias their views and influence their actions (Simon, 1982, Rubinstein, 1998).

The definition and meaning of the terms benefit and rational, are interesting and important, but they do not materially influence the way that the models of the firm, in this research, would be constructed or interpreted. In this work, benefit is considered unambiguously in terms of financial payoffs to the firm, whilst rational behaviours will be defined in proscriptive algorithms (for a discussion relating to the linkage between rational behaviour, uncertain prospects and measurable utility see Marshak, 1950).

2.10 Interactions Between Firms and Game Theory

Game theory has been widely used to describe interactions between firms (von Neumann and Morganstern, 1944; Hart, 1992; Gibbons, 1992b; Goeree and Holt, 2001). These games have been played by students of economics in classroom environments[62] or been used in computer simulations for a variety of purposes. They can be static or dynamic and in their most sophisticated forms they contribute to agent based models of competition and collaboration (Axelrod, 1997). The simplest categorisation of these kinds of games is to partition them into either co-operative or non-co-operative branches of the discipline. One of the simplest games and one that could be considered to straddle the categories is the Prisoners Dilemma (Luce and Raiffa, 1957). It is a game where the rational winning strategy is not to co-operate with your opponent and yet it is a game where co-operation, produces the maximum joint benefit. The problem is a lack of bargaining (Hart and Mas-Colell, 2008) and reciprocity (Abdulkadiroglu, and Bagwell, 2005).

Bargaining and reciprocity have been introduced in to more complex games in order to understand co-operative organisations (McCain, 2008) and to begin discover the causes for altruistic behaviours in society through indirect reciprocity, i.e. '*I help you and somebody else helps me*' (Nowak and Sigmund, 2008: p.1291).

Prisoners Dilemma

For the purpose of this research, the Prisoners Dilemma game has been chosen to represent the interactions between firms It is only one of many games that could have been adopted. A characteristic feature of the game, that leaves it open to criticism, is that '*the natural structure of individual players options only admit equilibria that are bad for all players*'. (Myerson, 1991: p.371). In other words,

[62] See, for example, the Society for the Advancement of Games and Simulations in Education and Training

the Prisoners Dilemma is a negative sum game; one where all players loose, but some can loose more than others. In economic terms this could be likened to an inefficient market, with an efficient market being a zero sum game and one exhibiting increasing returns would be a positive sum game. However, the Prisoners Dilemma game can be made more efficient, by applying co-operative transformations, such as adding communication or contract signing options Changes of this nature can produce equilibria that are better for all players (Myerson, 1991).

The model of cooperation/competition that was chosen is very easy to embed within a computer simulation and it is relatively simple and easy to understand. It is called the Prisoners Dilemma (Luce and Raiffa, 1957). One description of the (PD) game is shown below:

PRISONERS DILEMMA

The two players are accused of conspiring in two crimes, one minor for which their guilt can be proved without any confession, and one major crime for which they can be convicted only if at least one confesses. The prosecutor promises that, if exactly one confesses, the confessor will go free now but the other will go to jail for 6 years. If both confess, then they both go to jail for 5 years. If neither confesses then they will both go to jail for only 1 year.

Each time that this game is played each player only has two possible choices, to confess or not to confess. The strategies that are available to the players appear, at first sight to be very limited and this is true if the game is only played once. For a single game the players must weigh the risks of an all or nothing play of not confessing against the guaranteed benefit of confessing. This choice is likely to depend upon each player's knowledge of their opponent, in the absence such knowledge the guaranteed payout that arises from a confession is the rational choice. A situation of repeated games presents the possibilities of more strategies being chosen in order to maximise the benefits of playing the game.

The Prisoners Dilemma has been promoted as a rational explanation of evolution and co-operation (Axelrod and Hamilton, 1981) which can lead to apparently altruistic behaviours among ostensibly competing agents, as in the human race for example. It has also found favour in describing situations that can occur in economics, where it can be framed to produce an *oligopoly game* (Mankiw and Taylor, 2006). Consider the case of just a few firms offering similar products to the market place. Each firm would like to make the most profit and to do so they require a large market share. Lowering prices, or spending on advertising and promotions are all strategies aimed at gaining market share. However, if competitors respond in an equivalent way then costs for both companies will increase, market shares will remain static, profits will decrease and the only winner will be the customer. In the case of an oligopoly, the game illustrates why *'although the monopoly outcome is jointly rational for the oligopoly, each oligopolist has an incentive to cheat.* (Mankiw and Taylor, 2006: p. 331).

In these kinds of situations where repeated games are played out, there are many strategies that improve long term outcomes. An investigation of PD strategies was undertaken by game theorists in economics and the most successful and simplest maximising strategy was tit for tat (Axelrod, 1997a). Whilst being intuitively satisfying, the claim that a tit for tat strategy is the dominant one has been challenged by workers in a range of different areas including the animal kingdom where the behaviour of various living organisms, including primates (Brembs, 1996) has been investigated and in bio-economics (Hirschleifer, 1999).

One final comment on the Prisoners Dilemma game. It is interesting that although this game is generally aimed at overt competitors, it has also been used to explain the confounding behaviours among oil cartels, whose members sometimes exceed their quota in order to realise short term advantages (Matthews and Eshhati, 2000).

2.11 Economics and Exploration versus Exploitation

The relationship between the exploration of new possibilities and exploitation of old certainties has been proposed as a basic issue within economics at a macro level (Schumpeter, 1934). As with many fundamental concepts, it is a topic that has also exhibited the property of scaling, in so far as it has also been successfully developed, modified and applied and to the micro-economic viewpoint of management within a firm. This is particularly well articulated in a behavioural theory of the firm (Cyert and March, 1992). Within the environment of the firm, the tensions between exploitation and exploration have been delved into with respect to learning and knowledge (March, 1991; Oshri *et al.*, 2005) and many of the issues which are presented align themselves to a complexity science perspective. March proposes a model of mutual learning which is: digital, stochastic and iterative; features that fit with the approach needed here.

The issues, of exploitation and exploration, need to be considered in the context of knowledge management and revisiting Zack's Knowledge Strategy (Zack, 1999) is useful here. He begins with a SWOT analysis, to identify where a firm has knowledge that it can make use of and what gaps exist that need to be filled , he then plots a firms strategic position using the two dimensions of Exploration and Exploitation, with due reference to the firm's competitors. The output of Zack's analysis is to indicate the degree by which a firm needs to increase its knowledge through exploration, together with an indication of the existing knowledge capital within a firm that can be exploited. Taking a product centric view of Zack's theory is rather like asking the questions: (i) how fit are the current products compared to the competition and (ii) what opportunities can we see to create fitter products.

Within the general body of the literature about knowledge management, the focus of is often within (rather than between) organisations; where the exploitation processes has the potential to uncover latent utility value and synergies, whilst exploration is associated with novelty and product development. An example, of this has been articulated for a large distributed system of digital government projects (Binz-Scharf, 2004), where the identified need was to combine and reconnect the required knowledge . A similar internal focus can be seen when seeking to understand the role of knowledge in resource allocation with regard to exploitation and exploration in technologically oriented organisations (Garcia, Calantone and Levine, 2003).

In a business environment, the process of exploring can be likened to searching a fitness landscape. In this context, exploration equates to activities like research and development and innovation, (Kauffman *et al.*, 2000). By considering that each peak on an economic landscape equates to satisfying a particular set of consumer needs then it is possible to envisage situations where the attributes of competing products converge as they move towards the peak. It is also plausible that climbing upwards on a fitness landscape may lead to sub-optimisation as 'improved' products move towards local maxima. Exploring such landscapes by manufacturing prototypes and testing them in the market is one solution that firms can take. An alternative, which relates to the contribution of this research, is to include this type of searching process within a business model and then to translate the model into a computer simulation.

2.12 Closing Remarks

The research agenda comprised of a wide variety of themes, from ostensibly disparate subject areas. However, this chapter has indicated that credible rafts of knowledge exists, which supports all of the major arguments of this thesis, including: fitness landscapes, logistic growth, Polya processes, market shares, the game of *prisoners dilemma*, competitive interactions and exploitation versus exploration.

The next section, chapter 3, distils the main concepts that have emerged from the literature review and provides details of how they have been re-interpreted, modified or extended in order to use them to simulate software firms; after which, chapter 4 proposes a framework and methodology to create and use the simulations as a research tool.

CHAPTER 3: Conceptualisation and Operationalisation

3.1 Key Concepts

The literature review identifies a number of concepts that can be used in a new business model for software firms. Two ideas in particular appear to offer a kernel[63] for the model. The first is the concept of attributing evolutionary success, of a biological organism, to the specific combination of genes in its DNA. This led to the representation of different combinations of genes as a fitness landscape. The second, is a biological approach to population dynamics that involves a growth mechanism incorporating three key elements:

- Time delays.
- Positive feedback.
- Negative feedback.

An important theme is the idea that knowledge is embedded within organisms and software products through binary code and this encoded knowledge determines a product's utility or value. The digital nature of the code leads to the realisation that software product development takes place by exploring a product fitness landscape of finite possibilities. The product fitness landscape comprises a very large number of potential products that firms must grapple with when investing resources and making decisions. Combining the concepts of *product fitness landscapes* and *growth* into computer simulations should release new insights into the competitive dynamics of software firms.

After deliberation, it was decided to include several additional facets to the model in order to meet the aim of a DBA, which is to perform research with a practical bias. To make the model more realistic, three additional concepts are identified that address:

[63] The term here is used in its everyday meaning as core or essence, not in the technical sense of learning algorithms (Gartner, 2008)

a) Market share

b) Competitive or co-operative interactions

c) Business activities involving exploration and/or exploitation.

The decision to limit the additions to three features is a pragmatic one. It is based on the time available to produce the models and conduct the research. The choices of the additional three topics can be considered as being entirely subjective.

So in summary, this research generates models and simulations that are a synthesis of five concepts, most of which are mapped into the business domain from elsewhere. It is a combination that provides a high degree of novelty and is realistic enough to offer insights into strategic management. The final five concepts and their original disciplines are listed below:

1. Fitness Landscapes (evolutionary biology)
2. Logistic Growth (population dynamics)
3. The Polya Urn process (mathematics)
4. The Prisoners Dilemma (game theory)
5. Exploitation versus Exploration (economics)

In the following sections each of the concepts, shown above, are explained, and the way that they have been modified and applied to a business application is revealed.

3.2 The Concept and Operationalisation of Fitness and Fitness Landscapes

The previous chapter exposed a number of ideas that can be used to build a new computer simulation that could provide a practical tool for leaders of software companies in the new economy. The seed for this new model emerged from a recognition that the knowledge content of biological genes and that of software products can be analysed in a virtually identical manner. Also, that ideas (codified as quanta of information within a digital software algorithm) can have both intrinsic value and synergistic value. This led to the development of two constructs: a *product fitness landscape* and *market value landscape*. These landscapes encapsulate customer preferences and define the payoffs available to the firms that serve the software market. They are the foundation of a model that can offer insights into business trajectories.

This section begins with further development of the Kauffman (1996) NK model, which was only partly rehearsed in the literature review. In producing the NK model, Kauffman (1996) has provided the basis of a model that can represent software products in the form of a fitness landscape. To complete the task, Kauffman's (1996) concept needs to be mapped into a new scenario that deals with economics and firms, rather than ecological systems and organisms.

There are three key reasons to review Kauffman's model in more detail. The first is that it is an important and seminal piece of work, that provides an understanding of the characteristics of combinatorial instruction sets, albeit in a biological science rather computer science situation. The second is that although much of Kauffman's (1996) mathematics is directly transferable to this research, there are several small, but very significant differences in the way that models have been framed, defined and interpreted in this thesis. The third reason is that by applying novel search techniques, the NK model has already provided insights into economics, through an investigation of product architecture (Brabazon and Mathews, 2003) which is an associated research area.

The Essence of the NK Fitness Landscape Model

The NK landscape model is an explanation of how evolutionary diversity arises in the animal kingdom. Its novelty arises in applying combinatorial mathematics to genetics, within the paradigm of complexity science. Its starting point is the information content of DNA.

DNA is a complex double helix polymer structure, built up from repeating units of complementary base pairs comprising of a purine with a pyrimidine. There are just two kinds of pairings observed, guanine with cytosine and adenine with thymine. This base pairing is extremely important, not only in the structure of DNA, but in the performance of its two functions, replication and transcription. From this building block of two pairs of chemicals a twenty letter alphabet of amino acids are derived which build into a vocabulary of 64 three-nucleotide sequences or codons (Parker, 1992).

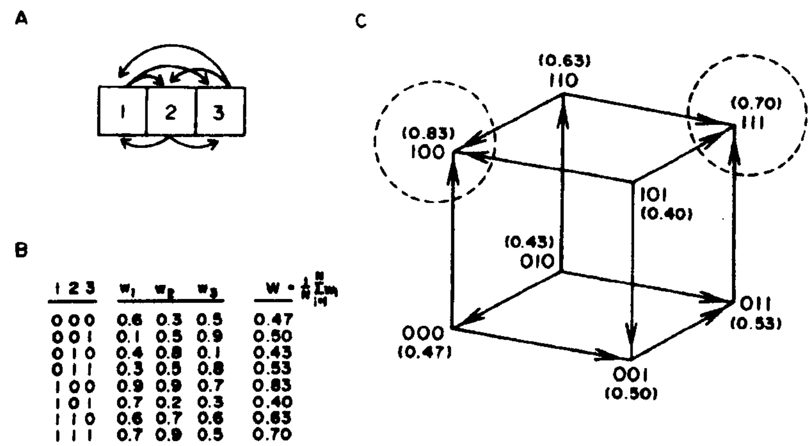
The information that is encoded within a DNA molecule is embedded along its entire length, but it is not continuous. The discrete elements of the code build up into sections that determine specific structural and functional characteristics of an individual (its phenotype). These portions of the DNA are called genes and are the basic currency of inheritance (Parker, 1992). The literature review showed that there is a huge number of possible combinations of genes in a strand of DNA, which Kauffman (1996) calls *genotype space*.

The construct of a fitness landscape results from a process that marries genotype space with an explanation of natural selection, by looking at the impact that an environment has on the rate of reproduction of particular genes. If a population of organisms produce offspring with an unusual phenotype (due to the expression of a particular allele, or some other mutation of its genes) that reproduces at a greater rate than the species that spawned it, then it will eventually become dominant. The new dominant organism will be said to be fitter than the old, in Kauffman's (1996: p. 164) words, '*that is the core of natural selection substituting a fitter for a less fit all*ele'. The process of natural selection produces adapting populations of organisms that flow across genotype space under the drive of natural selection and an assembly of the various different genomes that arise during this journey represent a fitness landscape.

With both genotype space and fitness landscapes articulated, Kauffman (1996) looks in detail at the possible genotypes of an organism with just four genes, each having two alleles. This situation produces 16 possible genotypes, which he randomly allocates fitness values to between 0 and 1 to produce a simple random fitness landscape (see Figure 4). One further issue is drawn into the argument before the NK model emerges and it is epistatic coupling. *'The fitness contribution of one allele on one gene to the whole of the organism may depend in complex ways on the alleles in the other genes. Geneticists call this coupling between genes epistasis or epistatic coupling, meaning that genes at other places on the chromosome affect the fitness contribution of a gene at a given* place.' (Kauffman,1996: p.170).

Kaufman brings epistatic coupling into the picture to produce a new fitness landscape, where the N genes making up a genome, are each epistatically coupled, such that each gene is coupled to K of its *neighbours*. This new fitness landscape is no longer random, but Kauffman (1996) introduces some random fitness values to it in order to illustrate how it works, see Figure 4.

Figure 4 A Fitness Landscape from Kauffman's NK Model



1 2 3	w_1	w_2	w_3	$W = \frac{1}{N}\sum_{i=1}^{N} w_i$
0 0 0	0.6	0.3	0.5	0.47
0 0 1	0.1	0.5	0.9	0.50
0 1 0	0.4	0.8	0.1	0.43
0 1 1	0.3	0.5	0.8	0.53
1 0 0	0.9	0.9	0.7	0.83
1 0 1	0.7	0.2	0.3	0.40
1 1 0	0.6	0.7	0.6	0.63
1 1 1	0.7	0.9	0.5	0.70

Figure 8.5 *Building a fitness landscape. The* NK *model of a genomic network consisting of three genes* (N = 3)*, each of which can be in one of two states, 1 or 0. Each gene receives input from two other genes* (K = 2)*.* (a) *Two inputs are arbitrarily assigned to each gene.* (b) *Each gene in each of the* $2^3 = 8$ *possible genomes is randomly assigned a fitness contribution between 0.0 and 1.0. Then the fitness of each genome is computed as the mean value of the fitness contributions of the three genes.* (c) *A fitness landscape is constructed. Circled vertices again represent local optima.*

The figures in the bottom left hand corner of Figure 4 shows the calculation that Kauffman (1996) defines as the fitness of the organism. It is the numerical average contribution of the N genes.

With the main details of Kauffman's (1996) NK model explained, it is now possible to show how it can be applied to software products.

Mapping of Kauffman's NK Model of Genetic Diversity and Genome Fitness into Software Product Diversity and Software Product Fitness

Many of the mathematical elements of the NK[64] model have a high degree of correspondence with the economic models being proposed, as shown in Table 7.

Table 7 Correspondence between NK biological model and a proposed new economy model

Item	NK model parameters and concepts, plus biological terms	Maps into New Economy Firms providing software products as :
1	Genotype Space	Set of all possible digital software products
2	Epistatic Coupling between genes	Synergies between units of information contained within the software code
3	The concept of Fitness as a competitive attribute that affects growth	The concept of Fitness as a competitive attribute that affects growth
4	Fitness of an entire organism	The average fitness contribution of individual units of code and associated synergies
5	Fitness of an entire organism multiplied by the number of genes on its genome	Product Fitness
6	Guanine -Cytosine pair	The digit 0 in software machine code
7	Adenine- Thymine pair	The digit 1 in software machine code
8	Gene	A digital software information string made up from 1's and/or 0's that is recognised by a computer as an instruction.
9	Rate of growth of a population of organisms	Rate of growth of a population of software products

[64] In this subsection, the NK model is used depict the Kauffman (1996) NK biological fitness model

10	Lifetime of an organism	Effective lifetime of a product (i.e. from time it is bought by a consumer until it is no longer used by the consumer)
11	Ratio of two or more species competing for resources within the same environment	Market Share
12	Competitive behaviour between species	Competitive behaviour between firms
13	Symbiosis	Co-operative behaviour with synergistic value

The strongest link is between the combinatorial assessment of possibilities defined as *genotype space*, and the number of digital programs that are theoretically possible for a given length of machine code. In mathematical terms the mapping here is unity. The NK model also describes the way that epistatic coupling can result in one gene having an increased fitness by virtue of a relationship with another gene. In business terms this is reinterpreted as the emergence of product synergies that increase its value beyond that of the individual parts, conceptually this also is a one to one mapping (although a variation will be proposed later).

Item 4, in Table 7, highlights the most important difference between the biological NK model and its software equivalent. It relates to ratios and normalisation versus absolute values. The issue can best be explained in terms of the differences in definitions. The NK model describes the fitness of an entire organism in terms of efficiency against a relative standard (0 is least fit and 1 is most fit), whilst fitness in the economic models will be described in terms of effectiveness. This means that the biological NK model expresses the fitness of an organism as the average value per gene and this can be interpreted as how efficiently each gene performs its task with respect to competitors in its environment. The implication of this is that a single fit gene with a fitness of 1 can never be bettered. Such a gene would almost certainly rank as having higher fitness than the human genome. The software equivalent would be to allocate maximum fitness to the smallest meaningful line of code, but in economic terms, and in terms of managing real firms this is not helpful.

In economic terms, taking an NK model approach to defining fitness would tend to position all very small software programs as being very fit, whilst the leviathans such as Microsoft Windows would fare very badly. An alternative approach is proposed, whereby individual fitness contributions (including synergies) are summed to give an absolute fitness value, rather than producing an average. Summing the fitness contributions of individual software elements, plus their synergies, in this way produces a different result to the NK model and needs different interpretation. Defining products in terms of the aggregated fitness of their constituent parts, rather than average fitness, will result in small efficient software programs having less value than large inefficient ones. This is the opposite of following the NK model to the letter. Looking at this issue slightly differently, the NK model, strictly applied to economics might measure gross margins, whilst the alternative being proposed here would look at total profit (or perhaps return on capital employed).

A further consequence of redefining the fitness of an entire organism (or a product) manifests itself in the characteristics, structure and meaning of the fitness landscapes. The NK fitness landscapes are related to K in such a way that as K increases, the peaks become smaller but more numerous. The impact that increasing K has in the NK model led Kauffman to suggest that evolution is more difficult on high K landscapes, which would conflict with observations of survival of the fittest. He concluded that his model fitted the facts when K was a low number. In contrast, the redefined, aggregated model for software fitness leads in another direction. If the fitness of a software product is a cumulative quantity, then the more internal linkages that there are, the better, since each one give the possibility of an additional contribution to the overall fitness. Software product landscapes where K is large are therefore desirable and should be allowed.

Product Fitness Landscape and Market Value Landscape

The literature review showed that growth models, drawn from scientific disciplines, have been re-interpreted and modified so that they apply to macroeconomics. These growth models have merit in their own right, by illustrating general situations, but they fail to address some important business issues such as: what determines the size of a marketplace for a particular market sector and what influences the way that different products compete? If the answers to these questions could be incorporated into a business model, then it is possible that it could be tailored to specific sectors of the marketplace. In the previous section, the Kauffman (1996) NK model was mapped into an economic situation with a very high degree of correspondence. In this section, further extensions are proposed that will link fitness and fitness landscapes to economic payoffs through a *market value landscape.*

When considering animals, the blueprint needed to create them is embedded within them in their DNA, for software products it may reside in multiple locations and in multiple forms. For a particular length of an information string, there are a large number of possible combinations of ones and zeros not all of which have been realised as products or animals. Nevertheless, it is easy to imagine that all combinations are possible. For simplicity, imagine grouping information strings of the same length together and then using these subsets as the basis for a fitness landscape. In this situation, the lowest nontrivial combination is represented by two pieces of information, A and B. Now attribute fitness values of one or zero to each piece of information and to their possible synergies. So A can be 1 or 0, B can be 1 or 0, the fitness contribution of A to B can be 1 or 0 and the fitness contribution of B to A can be 1 or 0. If the overall fitness for any of these combinations is now taken as the sum of the components then it produces a fitness landscape with four possible values. The combination: A=0, B=0, synergy AB =0 and synergy BA =0 clearly produces an overall fitness level of zero, whilst the combination: A=1, B=1, synergy AB =1 and synergy BA =1 clearly produces an overall fitness level of four. Table 8 shows all possible combinations of fitness values that can arise from a combination of two ideas.

In the four digit strings, shown in Table 8, the fitness contribution from idea 'A' is shown as the first digit, that of 'B' the second, the fitness synergy contribution AB is the third digit and the fitness synergy contribution BA is the final digit.

Table 8 Fitness values of products, produced by combining two ideas

Fitness Groups	Total Fitness of each member of the group
0000	0
1000 = 0100 = 0010 = 0001	1
1100 = 1010 = 1001 = 0101 = 0110 = 0011	2
1110 = 1101 = 1011 = 0111	3
1111	4

(Note: the fitness values shown above illustrate a landscape where one product has zero fitness and one has a fitness of four. There are three products with a fitness level of one and three products with fitness levels of three. Products with fitness level of two form the largest group and there are six of them)

Thinking about this more generally, a particular piece of information within any instruction set can impact on fitness in a variety of different ways:

a) It might contribute positively to fitness.
b) It might contribute negatively to fitness.
c) It might create a positive, synergistic contribution with another bit of data
d) It might create a negative synergistic contribution with another bit of data.
e) It might be a duplicate piece of information and be redundant.
f) The information may be benign, neither increasing nor decreasing fitness.

Kauffman decided to build up fitness values by attributing variable increases in fitness to different gene combinations. He did so by generating random numbers between zero and one and allocated them randomly. An alternative proposition is being made here, that the smallest digital change to an information string (i.e. the change from a 0 to a 1 or visa-versa) causes a smallest digital change in fitness. So a change in one digit of the code causes a change in one digit in the fitness value. To create a fitness landscape using this system it is necessary to attribute a fitness value to each piece of information using values of zero, minus one or plus one (plus one for 'a' and 'c', minus one for 'b' and 'd' and zero for 'e' and 'f' and for any duplicated information). This system can be simplified further by considering information with a negative or zero contribution to be allocated a value of 0 and positive contributions to be allocated a value of 1.

Attributing the appropriate impact to each component in the blueprint information string is not possible, without actually creating the animal or product and comparing it to others. As with the instruction sets, this does not stop the list of all possible fitness values from being created. Such lists of data are purely mathematical statements and can be used for real animals or real products: there is no difference whatsoever in the list for both situations.

As with the NK model, consider a binary information string containing n pieces of information that represents all that is necessary to produce a particular software product. Here the number of components that must be considered in calculating a fitness value is n individual contributions and $(n^2 - n)$ possible synergistic values (i.e. the total number of values contributing to the overall fitness is n^2). Also assume that each one of the n^2 items could have x possible values; then the maximum number of possible combinations that the product could express is x^{n*n}. This set of numbers captures all possible fitness values for any product described in a string of length n. This is the world set of fitness values for product of complexity n. These values form a product fitness landscape of complexity order n (fitness values for $n = 2$; $x = 2$ were shown earlier in this section). Such a landscape contains elements of connectivity within each potential product, in the sense that each combination represents a set of information that is capable of being connected for the purpose of creating a product. Whether connections are made or not, is not known only the result of the possible connection is implied. So, a connection between two pieces of information may result in a positive synergy, in which case a connection can be implied, but the lack of synergy could be because the connection was not made, or because it was made and no synergy exists. This shows it is not possible to determine whether connectivity exists, without creating the products, making the connections and evaluating the result.

The NK model creates interesting fitness landscapes, which mimic nature. However, the decisions to attribute random fitness values and to limit the number of epistatic couplings, are in a sense arbitrary. Kauffman chose to do so because they produced non-random, *correlated* landscapes that he thought mimicked nature. In thinking about how to calculate the fitness of software (comprising of a binary string of length n, where each digit can be either a 0 or 1) the following thought process is presented.

1/ There are 2^n possible different strings of length n and they are contained within a set called N.
2/ Now consider sets of binary strings, comprising all positive values of n. Let this larger set be called the universal set of digital binary strings, called U_{BS}.
3/ The machine codes of all software products that have ever been manufactured are contained within the universal set U_{BS}.
4/ Some of the strings within U_{BS} represent encoded information that has meaning when presented to a digital computer.
5/ Strings that contain information capable of being run on a digital computer may have a utility (monetary value), which will be decided by the marketplace.
6/ Strings that have a high market value are fitter than those with a lower market value.
7/ Fitness values can be allocated to individual digits and synergies between digits, in such a way that the potential maximum fitness is proportional to the length of the string.

The ideas captured in the above points allow a new landscape to be proposed. It is an imaginary product fitness landscape, where every point on the landscape represents a unique software product. The complexity of the software will be defined as the number of binary digits that make up its digital code (i.e. n).This product fitness landscape contains features which imply the following:

(a) Fitness can continually increase as complexity increases.
(b) That as complexity increases, the fitness peaks get higher.
(c) As complexity (n) increases, so does the numbers of different strings of code that exhibit the same level of fitness (i.e. the number of local peaks increases)

The final point (c) makes finding global maxima increasingly difficult as products become more complex.

A universal product fitness landscape can be created, by combining landscapes for all values of n. This raises issues regarding value for money efficiency, redundancy and value engineering. There is a rational argument that goes; if two products have the same fitness but different values of n, then the lowest n value will be intrinsically cheaper and therefore more attractive. This is a paradox since equal fitness should mean equal desirability. Maintaining fitness, whilst reducing n, is an activity undertaken by real firms and it is called *value engineering* (i.e. removal of features that are not valued by the customer in order to improve value for money).

A simple mathematical model to describe the fitness of a software program can be constructed using an array populated by zeros and ones. In this model, the diagonal values in the array describe the intrinsic worth of each idea taken in isolation, whilst the remaining cells of the array contain the values created by synergies between two ideas. In this situation, individual quanta of knowledge (information encoded in software) can have a value of one or zero and the synergy between two quanta can have a value of one or zero. In this situation the minimum fitness is zero when the array is full of zero's and the maximum is n^2 when the array is full of ones. The number of possible fitness values that can be attributed to a product array containing 'n' ideas is 2^{n*n}. This approach defines the range of fitness levels for a product resulting from two ideas to be between 0 and 4. It also provides a distribution of possibilities. With n = 2 there are four components of fitness each of which have two possible values, which gives sixteen possible permutations. The fitness distribution is shown in Table 9.

Table 9 Fitness distribution of products with low complexity (two quanta of information)

Fitness Level	Possible number of different products with this fitness
0	1
1	4
2	6
3	4
4	1

An assertion is made here, that is built upon in the models, that fitness and complexity are linked. The complexity of a product is being defined as the number of quanta of knowledge that define its blueprint. This means that the maximum fitness that a product can obtain is proportional to its complexity. A further assertion is, that the mathematical product of the number of customers' times the average selling price, will be higher for a fit product than an unfit product. This directly links market value with complexity and fitness, so the market value of a particular product can be taken as being related to its fitness (i.e. the product fitness landscape maps into the market value landscape by a linear scaling factor that links pairs of points). This concept of the market value landscape provides the rationale for firms to search the product fitness landscape for ever fitter products, since fit products offer higher payoffs.

Increasing Returns: linear scaling in a non-linear model.

The detailed explanation of the creation of a fitness landscape and its translation into a market value landscape have profound implications. Product fitness is shown to increase as a quadratic with regard to the length of software code. The linear translation of fitness to market value therefore retains this non-linear characteristic and provides the possibility of increasing returns (assuming that the costs of producing software code is constant).

The linear translation product fitness value into a market value using a simple 1:1 scaling factor relates to the way that the model has been conceptualised. The only purpose of this stage is to convert the dimensionless scalar quality of fitness into a scalar quality having financial value. The process is shown in the Figure 5 below:

Figure 5 Changing dimensions

Create a landscape of all possible different software products with their associated fitness values.
(**Note**: Values on this landscape are dimensionless ratio's)

Create a demand landscape that mirrors the product fitness landscape (which is already non-linear in nature) such that the total available income for every unique product is directly proportional to it associated products fitness value. This landscape is called the ***market value landscape*** and is derived through a linear scaling transformation of the *product fitness landscape*.
(**Note**: Values on this landscape are **potential** financial payoffs- in principle they are £'s $'s ... or some multiple thereof)

Create a growth model that derives its maximum level of market demand (the carrying capacity) of a specific product being sold into the marketplace by referencing the appropriate point on the market value landscape.

Include in the growth model functions that modify pay offs based upon diminishing returns and/or competitive pricing behaviours. Diminishing returns are modelled such that payoffs per unit of sales decrease by a fixed percentage for every time period (orbit of the difference equation) that elapses. A time decay, rather than volume decay, is chosen because technology advances make software products perishable over time. There is justification to reduce payoffs as output increases to represent increasing transaction costs, but this would increase the programming time and effort needed for the research and it was not performed (it can be seen as one of the limitations/compromises of the simulations).

Present the outcomes from the model in numerical and graphical formats

This chapter has described in detail the Product Fitness and Market Value Landscapes for digital software products that are central to the thesis, as well as Kauffman's (1996) biological NK model from which they were derived. These landscapes provide platforms that sustain software firms and with which they interact.

The primary interaction being explored in this work is that between fitness landscapes and population growth. The next section links *growth* with *fitness* through the concept of a market value landscape.

3.3 The Concept and Operationalisation of Logistic Growth

The growth mechanism known as the logistic equation was originally derived to account for changes in animal populations. It's premise is that the future population of a group of animals depends upon two issues: i) how many there are now and ii) the level of resources in the ecosystem that are available to sustain them (known as the *carrying capacity* of the system). The logistic equation is constructed so that when a population is small, and resources are large, then the population can grow very rapidly, but as the population approaches the carrying capacity then the growth in the population slows down, due to scarce resources.

The logistic equation takes many forms and can be expressed as either a differential equation (Duff and Kaplan, 2000) or as a difference equation (Kaplan and Glass, 1995). The form of the equations that are of interest here, are those which are constructed as difference equations.

Logistic difference equations can be interpreted as describing punctuated, iterative, processes that have a rich diversity of outcomes. The significant difference, between the differential and difference forms of the logistic, is that the differential equations do not, necessarily, produce chaos whilst the difference equations can and do (Kaplan and Glass, 1995). The importance of this issue cannot be understated: chaos arises in logistic equations when they are representing phenomena that behave discontinuously. Remarks on the website of the University of Tuebingen, relating to the discrete logistic equation, make this point very strongly. '*One of the crucial differences between discrete system and continuous systems, in one and two dimension(s), is the fact that it is plainly impossible for the dynamics of the differential equation to be chaotic! For the difference equations the situation is different: for maps it is possible even in one dimension to* *obtain chaotic (or seemingly chaotic) orbits'* (Patrizia[65]). Mathematicians have simplified the discrete logistic equation into a parsimonious form that can be expressed as:

$$P_{t+1} = X\, P_t\,(1-P_t) \qquad \text{for } 0<P_t<1 \qquad (2)$$

Where:
P_t is the population at time t
P_{t+1} is the population at time t_{+1}
X is a growth multiplier

The difficulty in using the expression in (2) is that it is too abstract , which limits the set of people who can understand it to those with a relatively high understanding of mathematics. This unnecessarily reduces its accessibility. For example, all outcomes of equation (2) are contained within the interval [0,1] and so 1 represents the maximum population, even if its actual value changes between each orbit[66] of the difference equation. In the opinion of the author, a wider group of business practitioners will understand the logistic by using real numbers, together with a maximum population figure that can increase or decrease depending upon the situation. The way that the logistic is built up is explained in the following paragraph, using the biological terms from which it is derived and this results in an equation that deals with real numbers, rather than ratio's.

Most animals reproduce in a manner that generates discrete increases to their population, due to the time effects of their characteristic gestation period and climatic cycles. Furthermore, a particular species tends to have a particular fertility level (i.e. the number of offspring per pregnancy cycle). If, for example, a pair of animals produces four offspring per pregnancy, then the logistic equation incorporates this fact by saying that the future population at time t_{+1} will be three times what it was at time t (i.e. three equates to the two offspring plus one parent) . If the population expansion occurs in an

[65] Patrizia, N. (2001) The Verhulst Equation. Available from, http://gris.uni-tuebingen.de/projects/dynsys/latex/dissp/node15.html [Accessed 26/09/08].
[66] The term orbit is used by mathematicians to describe the process of calculating the value of the equation for a particular value of t.

environment with no predators and plenty of resources then it is a plausible proposition. If it occurs in circumstances where resources are sparse, then not all of the offspring will survive and so an additional term is incorporated into the equation that takes this issue into account. Expanding equation (2) gives two terms XPt and - XPt^2. The first of these terms is called a growth multiplier and it provides positive feedback to the system, and because it is repeatedly applied it produces a non-linear self reinforcing process that is similar to that of compound interest. The second term provides negative feedback in the form of a quadratic, which also has a non-linear influence.

Changing equation (2) slightly to deal with whole numbers gives a new version logistic equation know as the *logistic difference equation*, which is shown below (3):

$$P_{t+1} = X\,P_t\,(C - P_t)/C \qquad (3)$$

Where:

P_{t+1} is the future population at one time interval into the future

P_t is the current population

X is a growth multiplier

C is the maximum capacity that the system can support (carrying capacity)

The families of outcomes that (3) produces fall into patterns as follows:

For X<1, the outcomes decay asymptotically towards zero.

For 1<X< 3.0, the outcomes transition from a smooth sigmoidal habit to one that exhibits 'ringing' oscillations .

For 3.0<X< 3.569946, the system moves into the realm of chaos with bifurcations arising at an ever increasing rate[67] .

So, the logistic equation is capable of producing an S shaped curve, whereby a stable

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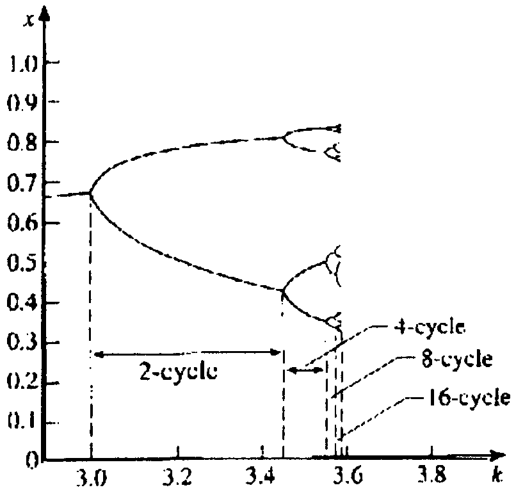
67 The values of the bifurcation points shown above and the method of calculating further points are taken from work by Cross (2000).

population is reached at a point where the resources that it consumes equals the rate at which they are replenished. This seems intuitively satisfactory, but an S shaped curve is only one of many possible outcomes that are observed in the natural world. Other patterns include: modest cyclic variations that decay towards an asymptote, ongoing cycling between high and low population levels and, in extremis, chaotic population levels like those observed in locusts. These patterns can also be generated from the logistic equation, if suitable values of X and *C* are selected.

The values of X, where outcomes change from one type of pattern to another, are special types of discontinuities called bifurcations. To see why this name is relevant, it is useful to graphically represent the equation in a slightly different way to normal. For a particular value of P_t, pick a value of X and some integer t; now calculate P_t and note its value; repeat the process with as many different values of X as possible and then plot the results of P_t versus X, as shown in Figure 6. No matter how many different times this analysis is performed the shape of the pattern it produces will always be the same for any value of P_t or X. This analysis shows how the number of possible outcomes for a particular value of X doubles, as X crosses the bifurcation points from one region to the next. Furthermore, as X increases the intervals between these bifurcation points gets progressively smaller. In fact, the gap between the points are inversely proportional to a constant, F, known as Feigenbaum number (Feigenbaum, 1978). The approximate value of F is 4.6692.

Figure 6 Period doubling and bifurcations



Growth multiplier X

The logistic equation is used here as a growth mechanism to represent the way that software products are launched and accepted by the economic marketplace. The growth driver on the supply side of the equation is represented by the growth multiplier, X, which reflects an increasing product availability from the supply chain. The demand side is represented by the carrying capacity, C. The parameter C represents the total number of products that the marketplace could absorb, if all customers and potential customers owned on unit of the product. The values of X and C are set at the start of the simulation and can be altered during the operation of the computer program. The next section will elaborate on these issues in the context of fitness and fitness landscapes.

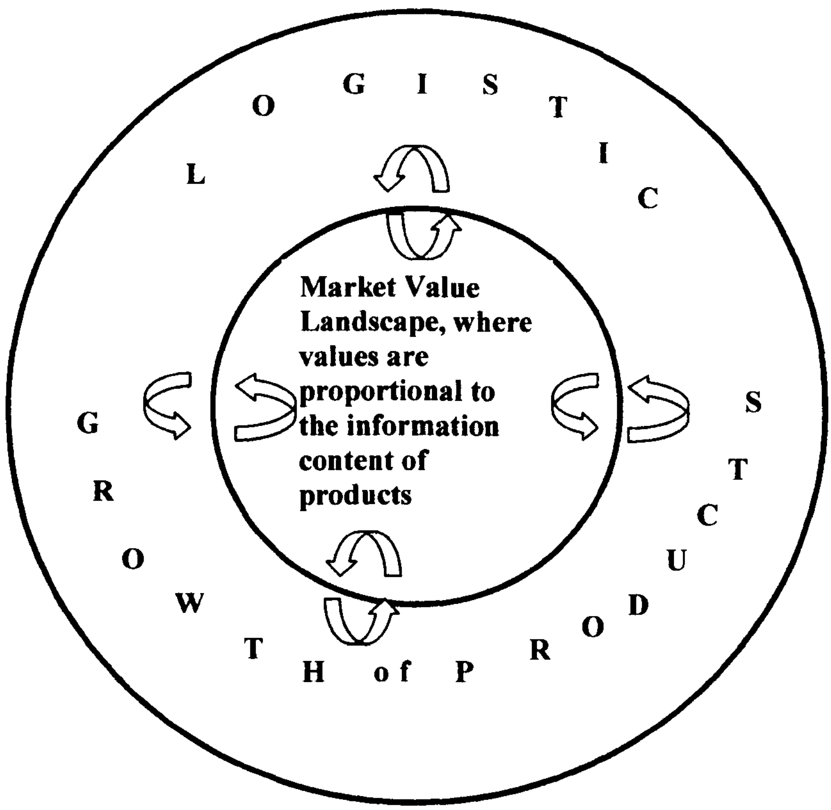
3.4 The Integration of the Product Fitness Landscape and Logistic Growth

The literature review showed that key elements of the new business simulations have been constructed from models borrowed from the biological sciences. At the core of the new models are two landscapes which are embedded within a growth equation. The first, called the *product fitness landscape*, represents relative fitness values for all potential digital software products that could ever exist. The second landscape, called the *market value landscape*, is a simple linear scaling of the Product Fitness landscape to represent the latent market values for each of the products (the differences between the product fitness and market value landscapes were explained in 3.2, as was their role in providing the value for the coefficient C). The scaling mentioned here relates to the *conversion of the supply-side product fitness landscape into a demand-side market value landscape* by attributing financial values to the products. In this system, the market value of a product is based upon its fitness and this defines the level of consumer demand.

With consumer demand at the heart of the models, the question is how it impacts firms? The answer is that it provides two interdependent facets of the economic environment. They are: the positive feedback that stimulates growth, and the negative feedback that limits it. Positive feedback manifests itself initially by motivating firms to produce products, in order to service an unsatisfied latent demand. Having entered the market, a firm continues to receive positive feedback, in the form of payoffs, as its products are purchased by consumers. If demand is large, compared with supply, then the firm will experience ongoing positive feedback that produces a self-reinforcing mechanism driving growth. On the other hand, each point on the market value landscape is finite, and so as ever increasing numbers of products enter the marketplace there will be a time where the potential supply could exceed the latent demand. In this situation, a negative feedback process is possible whereby the growth multiplier (within the positive self-reinforcing mechanism) is progressively reduced until supply equals demand, at this point the net growth multiplier will be unity.

Issues raised in the literature review suggest that, the new economy is reliant on innovative technologies (Tapscott, 1997) and can generate non-linear payoffs that are capable of producing increasing returns (Kelly, 1997). The technology is digital; the products are digital versions of earlier ones, as well as new products that can only be realised through digital technology. It also emerged, that non-linear biological growth models dealing with discrete entities, such as fish, could be equally well applied to economic products (Goodwin, 1967) such as software for example. Combining these thoughts with the concept of a product fitness landscape offers the possibility of creating a business model that contains parameters, over which an individual firm has some control, by searching the product fitness landscape for fitter products than their current offering. When discovered, a fitter product repositions the firm to a new position on both the product fitness landscape and market value landscape. This represents a new opportunity for the firm; one where the carrying capacity of the marketplace has increased. A move of this kind is reflected in the growth potential of the firm through the parameter C which defines the carrying capacity of the marketplace (i.e. the maximum number of products that the market can absorb) in the growth equation (3). In this way, product fitness and firm growth are explicitly linked. This relationship forms the core of the new model as shown in Figure 7

Figure 7 The Core of a new model of software firms



Note: The Arrows illustrate feedback loops between interdependent parts of the system, with the existence of firms implied by a population of products.

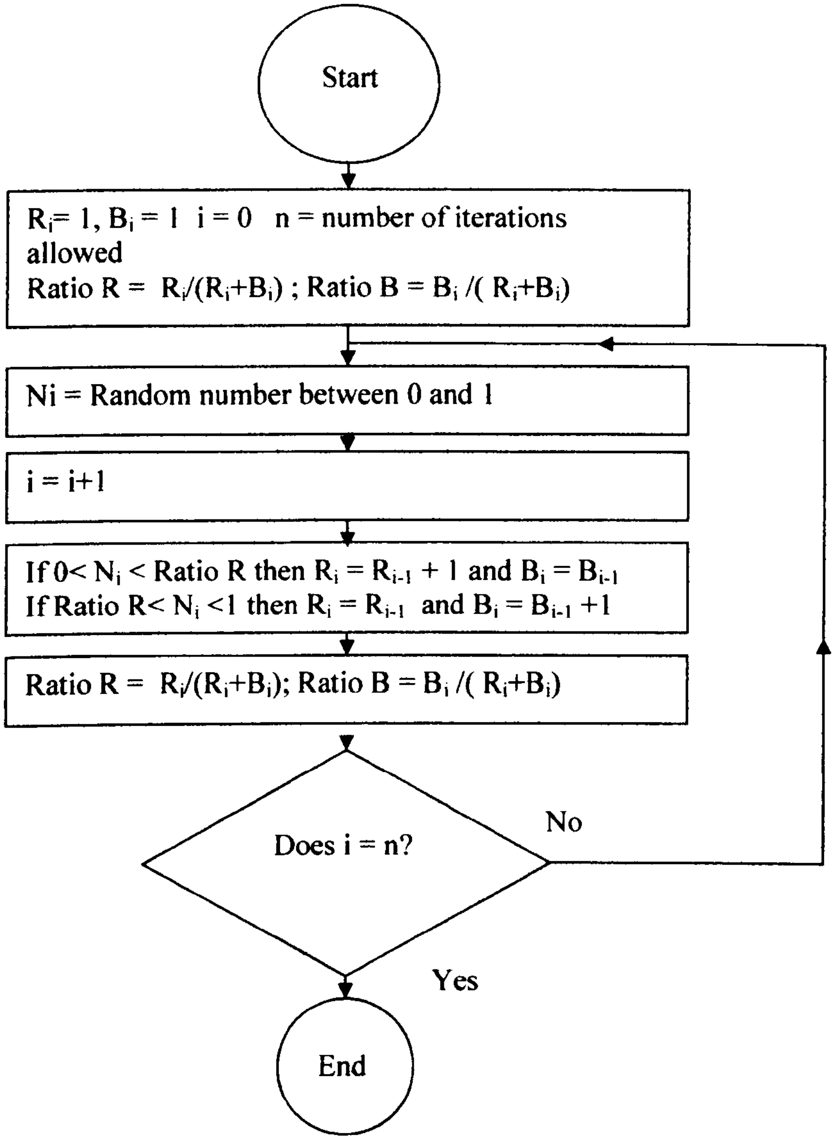
3.5 The Concept and Operationalisation of the Polya Urn Process

The Polya urn process is a self reinforcing stochastic mechanism. It describes the changing fortunes of a particular parameter over a period of time. The parameter can relate to a physical object, such as the percentage of coloured balls in an urn or the percentage of a particular brand of products in a marketplace, or they can be ideas or psychological values or de-facto standards. The parameter can relate to any number of things. There are three main characteristics of the process that make the Polya urn system a candidate for modelling market share. They are:

1. During the initial phase of the process, when there are only small numbers of entities with the particular parameters, the stochastic mechanism is influenced by the vagaries of random selection (which most people call luck). In terms of complexity science, this situation is termed sensitive dependence initial conditions (SDIC).
2. The stochastic mechanism is one where future success depends upon present availability.
3. As the process continues, the proportions of the various parameters settle down to stable ratio's that are increasingly difficult to change.

The flowchart shown in Figure 8, on the following page, represents a Polya urn process. It was converted into a stand alone executable program (.exe) written in Microsoft Visual Basic, that generated a visual and graphical output. The flowchart was also used to produce a Microsoft Excel spreadsheet version that only produced graphical outputs.

Figure 8 Flowchart representation of the Polya urn process



In business terms, the first point resonates with the launch of two competing products, which is a time when advertising departments try to influence the stochastic balance through high levels of promotion. It can be both in real terms, of making products more readily available, and in virtual terms of obtaining *share of mind* through advertising. In terms of the Polya process, firms try to bias the urn with their own coloured balls at the start of the process, in order to end up with the dominant market share in the future. The second point relates to the importance of product availability at every stage of a products lifetime. The final point relates to the difficulty of gaining market share in a mature market, where the problem for a new firm is that consumers have already formed a habit of buying from a competitor, or buying an alternative product.

In operationalising the Polya urn process, the urn is considered to be the economic marketplace for software products and the colours of the balls are taken to be different brands of software. The computer simulation is constructed such that whenever a new software product is launched, an arbitrary number of software units are introduced into the urn. If there are already competitors units in the urn then the market shares of the next periods output are distributed between the brands following a Polya urn process.

An extension to the original Polya urn process is developed[68] that limits the capacity of the urn. Limiting the size of the urn represents the memory of customers and/or the marketplace, which reduces the anchoring effect of the process and illustrates the way that monopolies can arise.

3.6 The Concept and Operationalisation of the Prisoners Dilemma

One of the aspirations of this research is to produce simulations that lean in a practical rather than academic direction. To achieve this, three additional features are incorporated with the central core of the model (which integrates a growth equation with a fitness landscape). The first, which has just been discussed, is the Polya urn process to represent the attribution of market share. The second is drawn from *game theory* and relates to the way that firms interact. For simplicity, firm to firm interactions are taken to be either competitive or cooperative and the game of *prisoner's dilemma* is adapted to represent these choices.

Game theory is attractive, in so far as it has been used in both evolutionary biology (Hammerstein and Selten, 1994) and the evolutionary economics (Hansen and Samuelson, 1988; Lomborg ,1992).

[68] See appendix 9

The key features of the Prisoners Dilemma (PD) are:

(a) Participants receive payoffs that are dependent upon their own and others behaviour.
(b) Payoffs can be symmetrical or asymmetrical
(c) Repeated cycles of the game allow learning to occur and maximisation strategies to emerge.

The prisoners dilemma game allows individual firms to either compete (H) or cooperate (D), so when two firms interact there are four options that can arise: HH; HD; DH or DD. In making choices during operationalisation, these options have been reduced further, to just HH or DD, i.e. the firms either compete against each other or they both cooperate. Cooperation in this work is not meant to imply any form of cartel arrangement, it simply implies that the firms act independently of each other and do not cut their prices if a competitor emerges. In contrast, when two simulated firms compete it results in reduced payoffs for both firms.

Participants are taken to be independent and without the means or desire to collude, except through their moves when playing the game. At each cycle of the game, each of the participants A & B, must make a selection H or D. They must declare their choice in ignorance of the other participant. When the choices have been made, the payouts are issued in line with Table 10 as shown below.

Table 10 Prisoners dilemma payout scheme

Participants Choice		Value of Payout	
Participant A	**Participant B**	**Participant A**	**Participant B**
H	H	Low	Low
H	D	High	Very Low
D	H	Very Low	High
D	D	Very High	Very High

A simulation of the PD game has been produced (called complex.exe) as an interactive demonstration and is contained in the c.d. at the rear of this thesis. The algorithm that was used to produce the PD demonstration was also used in simulation number 3 (Three Agent Model.xls), the results of which are described in chapter 6.

A further operational decision compels simulated firms to cooperate, unless they are occupying exactly the same place on the fitness landscape as another firm. However, when two or more products have the same fitness (i.e. products with the same fitness offer equal benefits to potential customers) then the simulated firms always compete.

3.7 The Concept and Operationalisation of Exploration and Exploitation

The final feature that is included in the simulations is the concept of *exploration* and *exploitation*. These two activities are intended to have the meaning ascribed to them by Cyert and March (1992) in their behavioural model of the firm. In this context, the act of exploration relates to a wide range of measures that present a firm with new opportunities. For example: performing research and development, developing new products, seeking new markets etc. Exploration in this sense is an investment decision; it is a spending rather than earning activity and may involve high levels of uncertainty. On the other hand, whilst exploitation may involve expenditure, it is fundamentally intended to produce payoffs. Exploitation uses the full range of a firms assets in order to generate profits. These include: manufacturing , distribution, and selling of products, licensing intellectual property, collecting royalties from brand names and patents etc. In comparison to exploration, exploitation represents a low risk set of activities.

Within the simulations, exploitation is the default mode whereby simulated firms receive payoffs from fixed positions on the market value landscape. The motivation to explore other positions on the landscape is contrived to be a function of reducing profitability (based upon decreasing returns). In one of the simulations, firms are divided into two types, ones that are allowed to explore and ones that are not. A parameter is introduced for both types of firm that represents profitability[69]. So, as payoffs increase, the simulation steadily decreases the percentage profitability in an asymptotic manner towards zero. Where firms are allowed to explore, a trigger point exists which causes the firms to reposition themselves on the product fitness landscape when profitability falls below a certain level. Repositioning in this situation is a random jump on the product fitness landscape.

3.8 Time Delays, Finite Memory and Finite Lifetime

Time delays are an integral aspect of the models. The use of difference, rather differential, equations means that outputs are series of discrete values separated by finite time intervals, rather than a continuous variable (although the graphical representations of models throughout this documents are shown as lines for ease of interpretation). Each outcome, in a series of outcomes, is made up from an aggregation of modelling elements and this leads to consideration of the issues of finite memory and finite lifetime.

Finite memory is a concept that is used to extend the Polya urn model when applied to determining market share. It is explained in Appendix 9. Finite lifetime is a concept used to extend the logistic growth equation when applied to products. It is explained in chapter 5. Many approaches could be adopted to operationalise these concepts, they range from a digital approach of a memory or product either being there or not, through to one where a memory decays or a products is used progressively less and less.

A choice has been made to use a digital approach to modelling finite memory and finite lifetime. This choice leaves the option open for future research to investigate the impact of asymptotically based functions, such as half life or exponential decay.

[69] Profitability is calculated as a percentage of the payoffs derived from the market value landscape.

3.9 Summary of the Basic Concepts and their Translation into a Model and Computer Simulation

Table 11, below, summarises the concepts used in the models and simulations and the ways that they are operationalised.

Table 11 Representational equivalents of the Kauffman NK model

Original concept	Represents the business phenomena of:	Operational comments
Biological fitness.	Relative product desirability in the eyes of customers.	A parameter representing the sum of all desirable features of a software product.
Evolutionary Fitness Landscape N-K model.	A representation of relative desirability of alternative software products.	A combinatorial set of all possible digital representations of zero's and ones and all possible attributions of values to those combinations using a prescribe set of rules.
Biological population growth based on the logistic equation.	Growth of commercial software products in an economic marketplace.	Organisms are replaced by products. Products imply firms and payoffs. Initial introduction is the creation of small arbitrary number of units of the product (under 1% of the carrying capacity of the marketplace). Payoffs represent the product cost to the customer. Profitability is a percentage of the payoff. Profitability reduces as the population of products increases[70]. Maximum carrying capacity represents market saturation of the total available market. Product lifetime was introduced to enrich the output information relating to new product sales.
Polya urn process	Market shares of competing products.	Coloured balls replaced by product brands. Limited urn capacity introduced to represent customer/marketplace memory.

[70] Reducing profitability has been shown empirically in this thesis through an analysis of a Fortune 500 data set. Although the analysis indicated that the software firm Microsoft may not be subject to diminishing returns, the general rule of diminishing returns was included in the simulations.

Prisoners dilemma	Competitive/cooperative Behaviours.	Firms only compete when they have products with the same fitness (benefits). Competing results in lower profitability.
Exploration And Exploitation	Exploration and Exploitation.	Exploiting equates to realising the payoffs associated with a particular product as represented by a point on the market value landscape. Exploring equates to launching a new product in place of a previous one. It is a random jump on the product fitness landscape.

3.10 Integrating the Basic Concepts

The computer simulations will explore the strategic trajectories of simulated software firms, in terms of their payoffs over time and yet there are few explicit references to firms in the models. The reason for this is that the models are product centric. They will show the way that populations of products colonise the economic marketplace and in so doing generate payoffs to the firms that provide them, so there is an a priori assumption that *products* imply *firms*. Figure 9, shows two views of the new economy, it is followed by Figure 10, which gives a visual representation of a simulated *software firm* as defined by this thesis.

Figure 9 Contemporary view of the new economy (L) compared with this research (R)

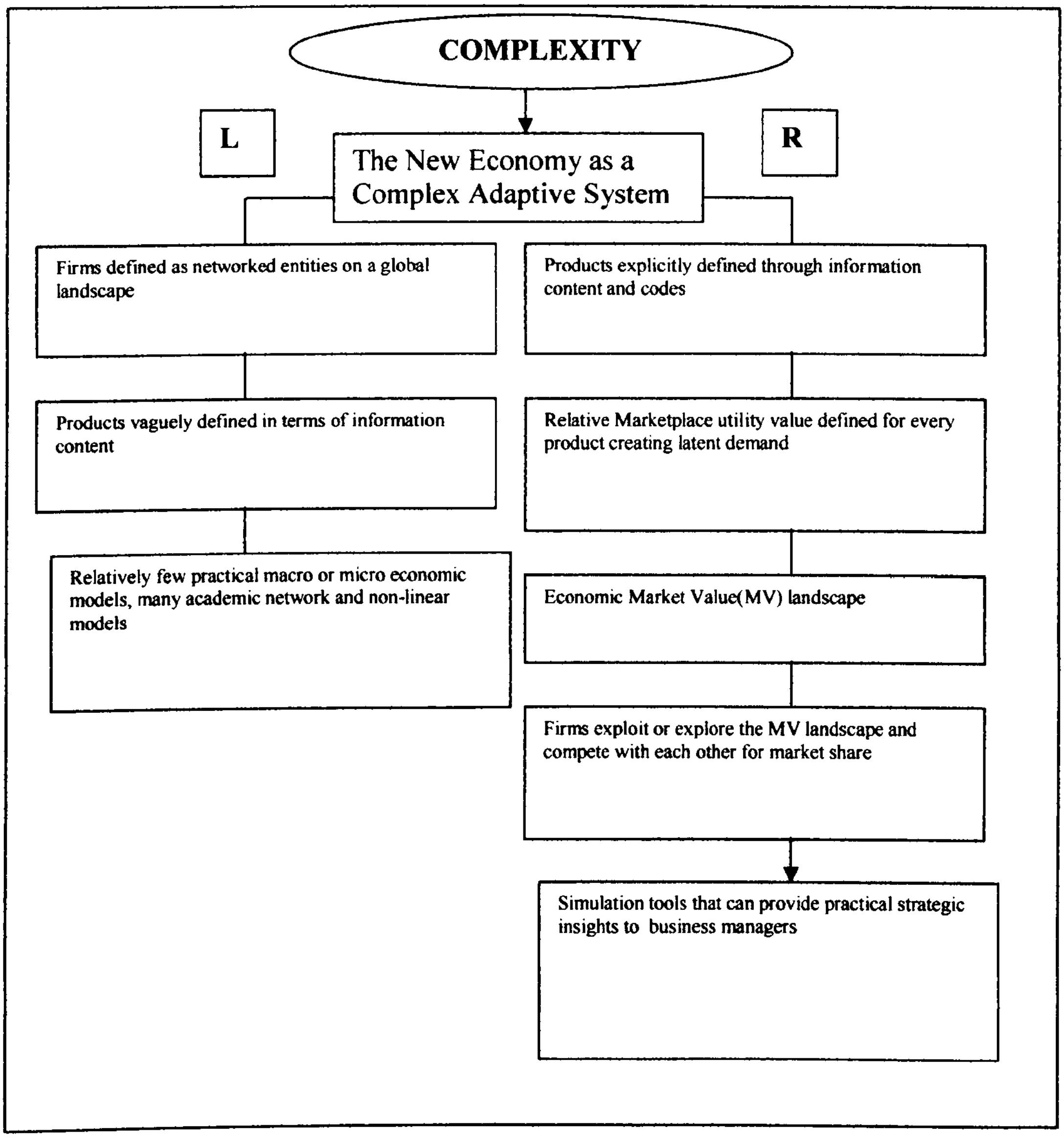
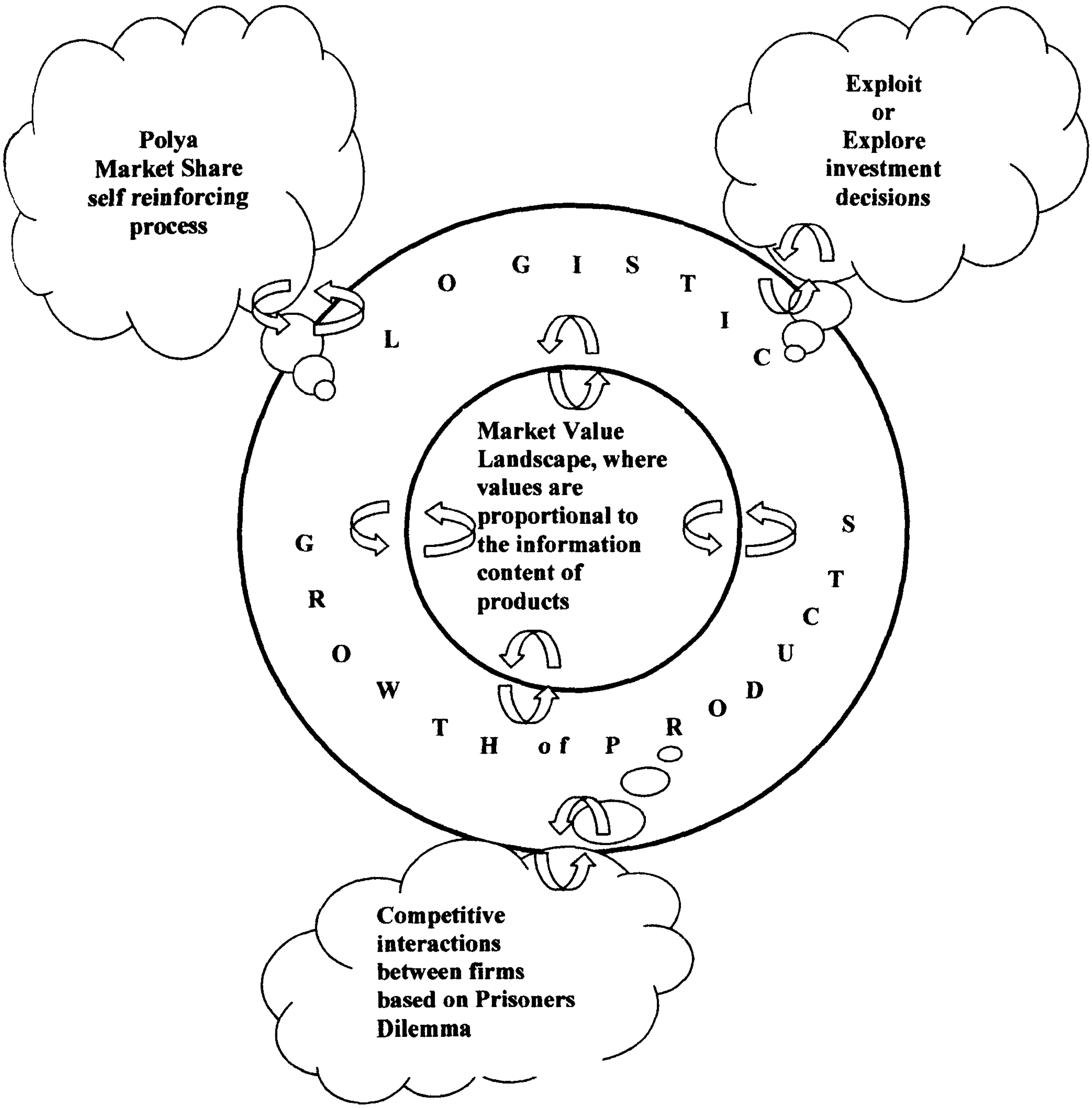


Figure 10 Outline of a simulation to describe a software firm operating in the new economy



Comments Relating to Figure 10

The core of the thesis is an adapted Kauffman (1996) fitness landscape drawn from his NK model. Products take the place of organisms and the demand from an economic marketplace, rather than the resources of an ecosystem, provides the stimulus for their growth. The market value of software products in the marketplace is represented by a landscape called a market value landscape. The market value landscape arises out of a discussion of what knowledge content means in the context of software and the new economy. The thesis defines the economic utility of a software product in terms of the useful knowledge that it contains and this is in turn is derived from the length of its digital code. Novelty arises in the way that fundamental units of binary code and the synergies between them, are built into a quantifiable landscapes, which are shown to express all possible potential product utility values.

Finally, it should be noted that this work is part of a research programme that includes publications and other more detailed analyses (involving search techniques and games) by a team from Kingston University. Each element of the programme can be thought of as building nodes in a knowledge network. Each node can be viewed individually, or combined to produce outcomes with greater value than the sum of the individual parts. So, it can be envisaged that the search techniques developed by Tony Brabazon[71] could be introduced into the core of the above simulations, as an improvement to the random leaps that have been used. Similarly, the valuations of simulated firms could be estimated from the work of Stefan Richter[72] and so on.

[71] A former member of Prof. Robin Matthews research group at Kingston University
[72] A former member of Prof. Robin Matthews research group at Kingston University

CHAPTER 4: Methodology

4.1 The Methodological Framework

The aim of this research, as stated on page 3, is to produce conceptual models and computer simulations that apply complexity science to the analysis of software firms operating in the new economy, in order to produce models and simulations that give new strategic insights for business and management practitioners. The methodology that has been adopted to achieve this aim has three components They are:

- **Complexity,** which copes with large numbers of interacting variables and is capable of providing solutions to seemingly intractable problems.
- **Simulation,** which offers the possibility of finding general solutions to NP complete types of problem, through its ability to expose patterns and strange attractors.
- **Empirical Observation** of a specialised kind (*Epidemiology*) that views everyday life as a myriad of potential experiments waiting to be properly analysed.

The rest of this chapter deals with the way that the above interdependent components support the research.

4.2 Complexity methods

Previous chapters have indicated how complexity science has been successful in applying techniques used in one discipline to solve difficult problems in another (for example biological models applied to economics). The methodological framework is dictated by the key issues of the thesis, which were exposed in the literature review and are summarised below.

a) The derivation of a competitive business landscape for software products.

b) The use of product fitness as a measure of relative desirability[73].
c) The relationship between product fitness and competitive landscapes.
d) The impact of legacy and path dependent effects upon competitive dynamics in (a) and (b).
e) The inclusion of a growth dynamic, specifically the Verhulst growth equation, linked to product fitness via a market value landscape.
f) The new economy, which explicitly embodies and exemplifies complex adaptive systems in action and which provides the backdrop to the thesis.

A substantial element of complexity science consists of finding solutions to NP hard problems. The solutions to such problems are necessarily incomplete, since they involve large numbers of variables and the context of the interactions between these variables is continually changing. One method of tackling these situations is to use computer simulations that map real problems into a virtual world, in a way that embodies the interrelatedness of the variables. This mapping can never be entirely objective or even completely representative but learning comes from examining sensitivities to changes in underlying variables.

Complexity and Probability

A broad class of problems in business management fall into the algorithmic class that is amenable to simulation. In this case, modelling of the economy is proposed, using ideas from biology that have also been adopted by complexity science. It is an approach that is relatively modern, but, as shown in section 2.3 of the literature review, it has already provoked significant philosophical debate regarding the epistemological fundamentals, some aspects of which are not entirely settled. Many basic definitions have been proposed, such as those relating to vocabulary and grammar where useful and practical distinctions have being made (for example, between the denotative model *of* and exemplary model *for*). However, positivists still question the legitimacy of simulation as an investigative technique, where it is

[73] Desirability relates to the customers perspective of ranking different products.

not, or cannot be, followed up through experimentation and especially when it involves probabilistic decision making algorithms.

Probability theory forms the basis of many scientific theories, but not everyone accepts it as a valid explanation of nature. Albert Einstein's famous remark that the gods do not play dice with the universe (Dokovic and Grujic, 2007) captures the disquiet that exists with regard to this issue. Einstein's approach was based upon a traditional scientific tradition , yet ironically it was the theory of relativity (Einstein, 1912) and Einstein's students (for example, Reichenbach, 1920) that played a major role in combining probability theory with positivism in what became to be known as logical positivism . The fundamental tenets of this philosophy relate to the sources of knowledge. Logical positivism asserts that there are only two sources of knowledge: logical reasoning and empirical evidence. This approach also takes the view that there cannot be different kinds of knowledge and that ultimately all knowledge is based on sense experience.

The LP perspective leads to an acceptance of probabilistic reasoning, which differentiates it from the rigidly unambiguous causality of positivism and produces a setting that embraces multiplicity and ambiguity. These differences create tension between positivists, relying upon deconstruction within a paradigm of falsification (Popper, 1977), and logical positivists (Hanfling 1981, Lakatos and Musgrove, 1970) who follow a constructivist approach within an exploratory paradigm (Kuhn, 1970). There is no doubt that complexity science is congruent with the latter.

Complexity science takes its strength from an argument for structural similarities between sociologies, which, through rules of correspondence, allows mapping to be established between two domains from different subject areas (Ziman, 1978). This issue is extended to three domains, by an argument that suggests that when considering the limits of scientific knowledge three worlds should be considered: the physical, the *mathematical* and the *computational* (Casti, 1997: p. 31).

The central idea of a mathematical model is to mirror the observable quantities in the real world in the abstract structures making up the world of mathematics. This idea leads to encoding which establishes a dictionary we can use to translate real-world observables in to mathematical objects. (Casti, 1991: p. 32-22)

The issue of correspondence between two different disciplines is an interesting one when looking at the historical relationship between biology and the physical sciences. For a long time, biology used the positivistic machine metaphor to try to explain life. This took the science quite a long way by using reductionist machine metaphors for explanations of how and why organisms functioned. Recently this approach has been challenged, with the suggestion that when posing the question *what is life?* the position should be that *' the machine metaphor is not just a little bit wrong; it is entirely wrong and must be discarded'* (Rosen, 1991: p. 23). The emergence of complexity science has reinforced this view and promoted a reversal of the mapping process, so that instead of physical systems being used to explain biology, it is biological systems that are being used to explain the physical.

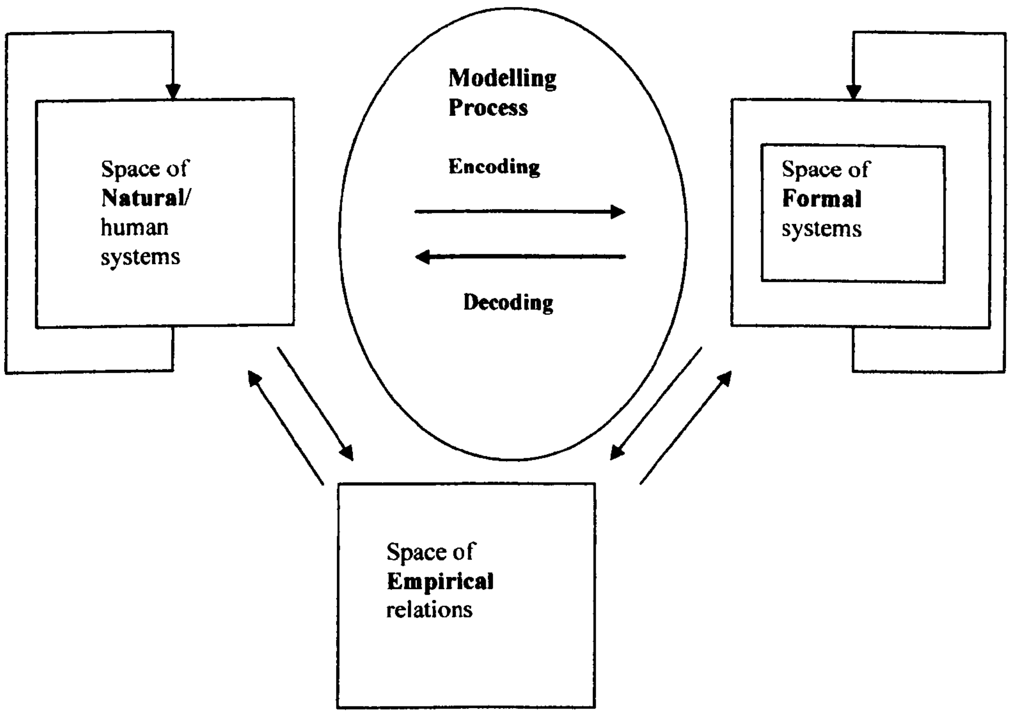
Mapping, in the mathematical sense, is central to simulation. It is mapping that allows an investigation to be transferred from one domain, where experimentation is difficult or impossible, into another where it is easier or possible. This is very relevant for investigations involving evolutionary economics, where simulations tend to be more prominent in the work of evolutionary economists than the mainstream (Marney and Tarbert, 2000).

4.3 Simulation methods

Simulations are especially useful when looking at complexity models. Complex models are problematic in that they deal with emergence, generally arising from interdependence, which makes it difficult to elicit direct causal effects. Computer simulations offer a solution. This is achieved by repeatedly executing an algorithmic representation of the complex model and then analysing large numbers of outcomes. It is a technique can produce qualitative results, in the form of visual representations, as well as quantitive solutions by looking at the frequency and /or the similarity of different outcomes. This can lead to probabilistic predictions and claims of generalisability to be made, where previously an inductive reasoning was prevalent, as in the case of solving NP and NP complete problems.

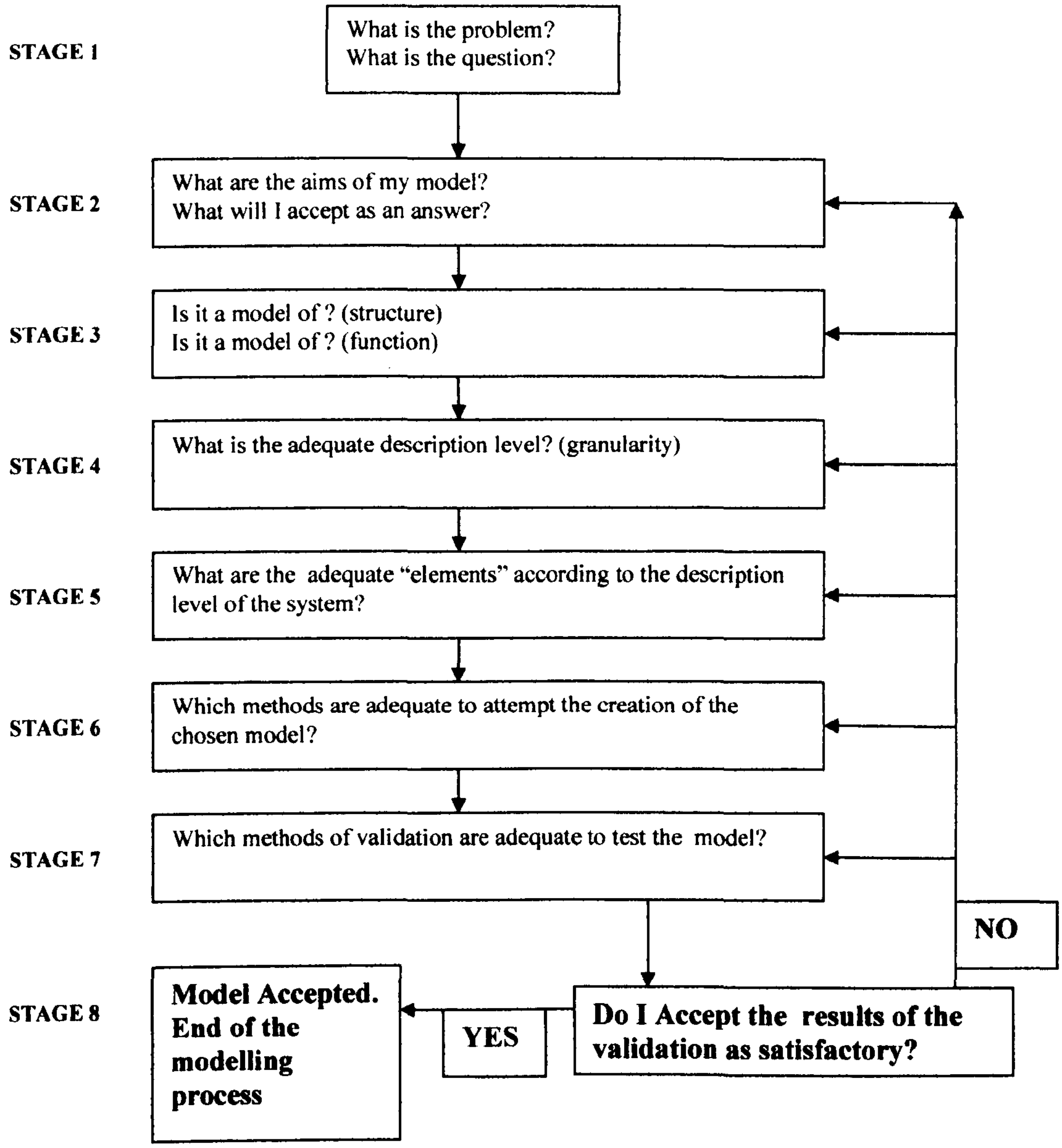
The framework that supports this methodology is based upon the concept of iterative mapping between different domains. It describes a situation where solutions emerge through progressive refinement, rather than a *eureka* moment. Figures 11 and Figure 12 provide important guidance during the practical stages of the research. They offer workable structures and operational processes and so they were adopted in full.

Figure 11 A framework for modelling processes



Figures 11 is taken from a working paper called : Contributions to the Epistemology of Modelling, by Leonhard Meirer, Manfred Paier, Andreas Restetarits, Harald Schuster and Julia Zink, with contributions from John L. Casti and Johannes Lenhard., Available at www.complexityscience.org [Accessed on 17/02/08]

Figure 12 Operational sequence for model building and model validation



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Stage 1 The problem and the question

The *problem* and the *question* are facets of the gap in the knowledge base and the aim of the research, which were articulated on page 3 in chapter 1.

The Problem

The problem is a gap in the knowledge base of economic and business models and simulations that are aimed at practitioners of strategic management. Specifically, no examples of models or simulations have been found that describe digital software firms in terms of the detailed knowledge content of their products (as defined through algorithmic strings of 0's and 1's).

The Question

Can useful conceptual models and computer simulations, that apply *complexity science* to the analysis of software firms operating in the *new economy*, be created that give new strategic insights for business and management practitioners?

Stage 2 Acceptable outcomes

Outcomes, from the models and simulations, are intended to inform strategic managers and so they will be considered acceptable if they can be interpreted as achieving any, or all, of the following:

1. Show how changes to the fundamental attributes of software products, such as the length of the computer code, relate to the ongoing viability of the firm that produces them.
2. Show how changes to a firms internal *management and decision making systems*, such as frequency of capacity planning, competitive decision making, new product launches etc., relates to the ongoing viability.
3. Show how steady changes to the marketplace, such as slowly increasing or decreasing demand, effect firms whose products have particular characteristics (for example, products that are perishable versus ones that are long lived)

4. Show rapid changes to the marketplace, such as an instantaneous increase or decrease in demand will effect firms whose products have particular characteristics (for example, products that are perishable versus ones that are long lived)
5. Demonstrate the existence of *strange attractors* within a virtual system whose modelling elements include random and/or stochastic elements, as these features can be used to steer strategic decisions that might be counter-intuitive.

Stage 3 Type of model

One of the requirements of a DBA research programme is that it should be relevant and useful to the active business community and not focussed upon purely theoretical advances. So, '*rather than viewing research as an end itself, DBAs have placed research at the service of the development of professional practice and the development of professional practitioners* (Bareham *et al.*, 2000). The models reported in this research were undertaken in this spirit and are aimed at strategic business managers working in software firms. The broad categorisation of models can be judged by using Table 12, which identifies features that distinguish practical models from theoretical.

Table 12 Classification of models by objectives

Practical Models	Theoretical Models
1. Main goals are management, design and prediction. 2. Numerical Accuracy is desirable, even at the expense of simplicity. 3. Processes and details can be ignored only if they are numerically unimportant 4. Assumptions are quantitative representations of system processes 5. System and question specific	1. Main goals are theoretical understanding and theory development 2. Numerical accuracy is not essential; the model should be as simple as possible. 3. Processes and details can be ignored if they are conceptually irrelevant to theoretical issues. 4. Assumptions may be qualitative representations of hypotheses about the system adopted conditionally in order to work on their consequences 5. Applies to a range of similar systems

(Table 12 is taken from Ellner, S.P and Guckenheimer, J. (2004) *Dynamic Models in Biology.* Princeton, Princeton University Press.)

Assessment of the models associated with this research and the *practical* side of Table 12

Point 1 The models in this research are designed to show how software firms will perform under different situations, their purpose is to help managers predict outcomes and guide their organisations towards high levels of business performance.

Point 2 The simulations are numerical and have at their core a representation of virtual software that exhibits perfect mathematical correspondence mapping with real software. There are many limitations to the amount of numerical inputs that were possible and this is commented on in section 7.1 (Limitations).

Point 3 The models are based upon detailed and fundamental process description with especial focus upon process interdependency.

Point 4 Parameters within the model are quantitative representations of products and quantitative constructs of the economic marketplace in which they are sold.

Point 5 The models are specific to software firms operating within the new economy.

Assessment of the models associated with this research and the *theoretical* side of Table 12

Point 1 The models are not presenting a new theory.

Point 2 The simulations are a synthesis of five different inter-related and dynamic stochastic processes. They are highly complicated and produce outputs that, in many cases, are completely unpredictable. An embedded sensitivity to initial conditions, means that small changes in numerical values can have a large effect.

Point 3 As much process detail has been included as possible within the time limitations of the research. If more time had been available further details would have been added.

Point 4 There was no conscious attempt to include any qualitative information in the models/simulations.

Point 5 The models are specific to software firms and do not purport to represent any other kind of firm.

The assessments of the models against the template described by Table 12 indicates that the models are of a practical nature.

Stage 4 Granularity

The granularity of the simulations has involved several facets. For a particular model, granularity can be seen in terms of the way that programmable input and output variables are defined, as explained below.

Program Granularity: Inputs

Granularity was considered in terms of two attributes (a) entities and (b) time. Considerations of time was relatively straight forward in being defined in terms of chronological order (ordinal events) and/or parametric time, as per the scientific SI units of seconds. Entities were seen as all things other than time, such as products or lines of code etc.

Entites

The most basic input parameters are the encoded instructions that are made up of quanta of information. Each quantum is defined (in software machine code) as either a zero or one. Each of these quanta of information are attributed with *fitness values* that can also only be either a 0 or 1. The next level of granularity in the simulations represents a software application (a program comprising of an information string of zeros and ones). The application has an associated fitness value, which determines the maximum value of this product in the marketplace. The final level relates to 'the firm', which receives payoffs from the sales of its products.

The models show changes in the populations of products within the marketplace where additions or losses are made in terms of single units (i.e. the sale of one software program). The payoffs to firms are viewed as being a function of the number of units sold but they are not explicitly expressed.

Time

There are two time elements to the simulations. One relates to the time taken to operate the program when it is being used. This is not of interest, as it is purely an issue of convenience and plays no role in the modelling, other than determining how long each simulation will take to perform. The other time elements relates to the model itself. As has already been stated, the models are based on difference equations and this means that they will produce time series outputs that are ordinal in nature.

Program Granularity : Outputs

Entities

As far as the entities are concerned the output granularity has a one to one correspondence to the input.

Time

The time granularity of the outputs, also has a one to one correspondence to the inputs. However, the output can be interpreted in different ways to try and 'calibrate' the intervals between the ordinal time series output and real situations. The interpretation of the outputs are likely to be subjective, approximate and prone to errors, due to inexact mapping between the simulation and the real world. The proposal here is to redefine the growth constant k that resides within that element of the model being driven by the logistic (Verhulst) equation. In a recursive difference equation, the growth coefficient (k) is simply a dimensionless multiplier, but in the real economic marketplace the growth of a firm, as well as internal feedback intervals, can be measured against time. So, if a firm routinely adjusts its operating plan every three months and finds that the growth of its shipments during that quarter is 10%, then setting the growth coefficient to 110% (i.e. 1.1) would allow an assumption to be made that the time series granularity was in intervals equal to three months.

Granularity: Validation

Entites

The later paragraphs of this chapter, that outline stage 7 of the operational sequence, reveal that the granularity of validation data is significantly coarser than the models. The finest details of the models are building blocks of ideas represented by strings of ones and zeros, and these translate into fitness values and fitness value landscapes with similar granularity. Validation with this level of granularity was not readily available and instead a proxy measure called *lines of code* was used. The assumption is that the number of ones and zero's in a line of code follows a normal distribution. In granularity terms, a line of code may represent hundreds, possibly thousands, of binary digits. The granularity of 'product' output, between the model and the validation data is considered to be comparable, although the model deals with units of production whilst the validation data are shown as sales revenues in dollars.

Time

The granularity of the validation data time intervals were periods of twelve months.

Stage 5 Elements of the model

The new models have many components, as described in detail in chapter 3 but they can be seen as involving just two themes.

Theme 1

The first theme is about possibilities, choices and alternatives. It is based on the relatively recent knowledge base on phenotype diversity that has accrued since the discovery of DNA. In particular it looks at the combinatorial mathematics that describes the total number of possible combinations of genes available to a particular species and draws a direct parallel with software products. A key feature of this, is that the basic elements of a software code can combine to produce instructions that define functionality and form, in the same way that genes do. These issues lead to the mapping of evolution of the fittest, from species to software products, with a proposal of how fitness values can be computed, see Table 13. The proposal is that high fitness is associated with large numbers of genes (or lines of code) with an even larger number of cross-linked synergies between them.

Fitness values are the building blocks of a fitness landscape across which a firm might travel. An assertion is made that the monetary value of a software product is directly proportional to its fitness, and this leads to a new concept of a market value landscape that represents the latent potential wealth available to firms servicing this sector. The market value landscape is the driving force for growth.

Table 13 Mapping from biology to business

Biological Feature	>>>>>>Maps into>>>>>	Business Feature
Adenine –Thymine bond in DNA		Software machine code 1
Guanine - Cytosine bond in DNA		Software machine code 0
Gene		Line of Code
Strand of DNA		Software program
Phenotype		An operating computer program
Species		A type of software program
Ecosystem		Economic marketplace

Theme 2

Theme two is about the ways that firms respond to, and interact with, their environment as well as the influences that theme number one has upon their performance. It is not specifically about how to navigate to the high ground on the fitness landscape, although it does look into the impact of exploring future possibilities compared to exploiting the current situation. In essence, theme number two is about the different processes that move firms forward. The selection of the processes that were included in the research was subjective, four have been chosen, but it could have been forty or four hundred, they are:

- Growth
- Self reinforcement
- Competitive interactions
- Exploration versus exploitation

The final simulations are based on bringing the two themes together.

Stage 6 Creating the Model

A fuller description of the concepts and operationalisation of the modelling elements is described in chapter 3. These ideas were then translated into simulations using Microsoft Excel and Microsoft Visual Basic. The cd attached to the back cover contains the final models which will run on any IBM style pc (but not on Apple Mac's).

Stage 7 Validation Through Empirical Observation: An Epidemiological Approach

This research is about simulation, not experimentation. It is dealing with subject matter whose complexity mirrors that of the social sciences, where the numbers of alternatives appears immense and experimentation is not always appropriate. Although identifying causation is universally attractive, it is not always possible and in social science causes are more properly thought of as reasons (Williams and May, 1996). Having said this, there is a technique that claims success in identifying causality without resorting to experimentation. It is the epidemiological method that has become widely accepted practice in medicine. The technique is based on an analysis of historic data, which removes the need for complex experimentation. It relies on there being sufficient data already available for the analysis to take place.

An alternative validation process, of the kind proposed by the *hypothetico-deductive* process,[74] would be to make observations after obtaining outputs from the models and simulations. Unfortunately, to perform such a process would involve a longitudinal study of one or more software firms over a number of years and this is impractical. A second alternative would be to perform a case study of one or more software firms that included a review of their historic technological and financial performance. This would be a more practical proposition, but is not without problems. For example: getting access to appropriate data, gaining access to sufficient firms to claim a representative sample, deciding on the criteria to select the panel, funding the study, performing the analysis in a timely manner. Neither alternative was considered a practical option within the scope of this DBA.

Empirical observation through epidemiology

Firstly some background, from a philosophical perspective, medicine is normally thought of as positivist, having absorbed many aspects of knowledge from basic sciences like genetics, biochemistry, immunology, psychology, pharmacology and so on. However, the difficulties in performing potentially life threatening experiments, upon large groups of people was and is problematic. It has led to medicine broadening its philosophical base to include practices based upon probabilistic outcomes. A key system that has been evolved and been refined by medical researchers, is a technique of non-invasive observation, modelling and analysis, known as epidemiology.

The crux of epidemiology is that: 'the investigator gains insights through exploration of data (Herman, 1992) and is based upon the philosophy of *learning while doing* (Thacker and Buffington, 2001). In this kind of investigation, the investigator gains insights through exploration of data, after which a hypothesis may be proposed. The researchers have at their disposal a full range of statistical analysis tools, but context is critical and the aim is to understand causality, not simply to demonstrate correlations. The statistical nature of this technique locates it on the edge of the

[74] See Figure 2 on page 65.

positivist paradigm and gives rise to other moral questions regarding the use of statistical data when applied to medical intervention (Dagi, 1993). Nevertheless, a growing body of important medical knowledge exists because of the use of epidemiological studies. An early, and seminal, example of this type of research, that solidly demonstrated its ability to draw conclusions about causality by studying data and context, was the discovery that smoking tobacco was a cause of lung cancer (Doll and Hill, 1950). More recently, epidemiology has brought about a consensus view point, that the HIV virus is a necessary cause for AIDS.

With the increasing availability of powerful computing tools, the epidemiological approach is expanding its use of models and simulations. This situation has led to some biomedical researchers, concerned with non-linear relationships, to recognise an overlap with complexity science : *'It is concluded that the complex conceptualisation required by the public- health paradigm will entail epidemiologists to develop new theories and to familiarize themselves with approaches more akin to those used in the study of complex systems* (Phillipe, 1999: p. 474).

In many cases, the benefits being sought by modelling health issues, are attempts to move medical intervention upstream, away from diagnosis and cure and towards prediction and prevention. The moral and practical difficulties of medical experimentation on human beings were the driving force behind epidemiology and although it took quite a long time to gain acceptance, we are now in an age where epidemiology is generally considered a legitimate approach to scientific discovery. Generalising the epidemiological method and applying it to economics leads to the possibilities of new discoveries by analysing historical data. The internet and the digitisation of knowledge are the key enablers. Huge quantities of high quality data now reside in virtual libraries that are widely available to researchers, albeit at a cost. The consequences of this situation means that data can be used and reused, sorted and manipulated by many more people than those who complied it and in ways that were not thought of at the time of its collection. Like modelling, epidemiology is a technique of low risk and low cost and both techniques can be seen to compliment each other as research tools.

Taking an epidemiological approach requires that relevant historical information is accessible, either within the public domain or from other repositories of knowledge. In this case the core topic is digital software, so ideally the knowledge base being sought would relate to details of the code (zero's and ones) that make up commercially available software. Unfortunately, this data is not readily available, but studies of software complexity offer the possibility of a proxy measure.

Use of a Proxy Measure

In the early 1970's questions were being raised relating to the complexity of software programs (Van Emden, 1971, as quoted in Belady, 1979) and at around that time attempts were also being made to measure productivity using lines of code (Wolverton, 1974). Counting the lines of code (LOC) became one of the first measures of program complexity, but as applications grew larger other techniques were investigated. A more sophisticated tool was developed that counted the number of linearly –independent paths through a program (McCabe, 1976). The McCabe (1976) method produced a single ordinal number that described the cyclomatic complexity of a program and this was attractive in allowing programs to be compared directly in terms of their complexity. An alternative approach (Halstead, 1977), which was not appropriate here, computed a figure of merit for complexity, by counting the numbers of operators and operands in the source code.

The interest, in measuring software complexity during the 1970's, related to the kinds of products that were being produced. At the time, large amounts of programming was being done for industrial users, such as airlines, supermarkets, the military and big business in general. The programs were often bespoke and issues of maintainability, reliability and cost were serious concerns, so although there appears to be a number of metrics to choose from it turns out that LOC is most widely available. Although LOC lacks the fine granularity of machine code (zero's and ones), it does have the benefit of being relatively simple to define and simple to understand; and it is probably as close to a raw measure of complexity for software as can be found.

In seeking to validate the main construct of this research, empirical evidence relating to *lines of code* was gathered and analysed using an *epidemiological* approach. The major linkages being looked for were between program complexity, product fitness and realisable market value.

An Empirical Study to Validate the Core Constructs

The central constructs, that underpin the new simulations of the firm, relate to the Product Fitness and Market Value landscapes. The theoretical explanations and arguments that support these constructs were made in chapter 3 whilst evidence of their legitimacy is presented in Appendix 6.

Stage 8

Stage eight is a decision making step that hinges upon the word satisfactory. Two common situations that result in the work being considered as unsatisfactory are:

a) The model may not work properly, due to a software error, or a programming algorithm that does not do what was intended.
b) The simulation may run perfectly, but may not provide a sufficient answer to the question for which it was intended.

Situations described by a) are unsatisfactory, because of what could be called inexperienced or poor workmanship. They did arise, but are not being reported here as they do not help to answer the research question. Situation b) also arose; mainly through design in as far as building blocks of a practical model were created and tested before being synthesized into a larger simulation. Outcomes from the building blocks as well as progressively more complicated models are shown later in the appropriate chapters.

This section has described a modern methodological framework that specifically addressed the use of simulations in research. The eight stages of its design provided a useful template that allowed corrections and fine tuning to be undertaken as the research progressed. In the next two chapters (5 and 6) the main simulations are presented together with their outcomes.

CHAPTER 5 : Computer Simulation 1

This chapter describes a simulation comprising of a Verhulst logistic growth with lifetime component, interacting with a market value landscape . It includes two novel features. The first is the effect that a dynamic market landscape has on an iterative, logistic growth process. The second is the impact that a finite lifetime has on new additions, for a population characterised by logistic growth. These features move historically interesting theoretical models towards the domain of useful business tools. They do so by introducing a demand function that firms have control over (the product fitness - PV and market value - MV landscapes) through their success in product development, as well recognising and accommodating for, the impact of finite product lifetime. Further refinement and customisation of these algorithms offers firms a way of predicting future revenue streams, as well as showing the impact of launching new products.

In its original form, the Verhulst growth model assumes a neutral landscape capable of sustaining a particular population of organisms. The size of the neutral landscape is determined by a constant C[75],which forms part of the negative feedback term. For every orbit of the original model the value of C remains constant. In this model C can grow, decay or be shocked upwards or downwards from one orbit to the next. This feature represents a situation where the amount of resources provided by the sustaining landscape can change. In biological terms it is as if the food supply is changing, in economic terms it is if the market demand is changing.

The addition of a lifetime component is a parameter that enriches the growth equation by enabling new additions to be properly quantified. In standard logistic equations having the form of a Markov chain, there is no way of determining how many new additions make up the population. The inclusion of a lifetime component identifies the portion of the population that are carried over from the prior orbit, and this allows the number of new additions to be calculated.

[75] See equation 3 on page 116

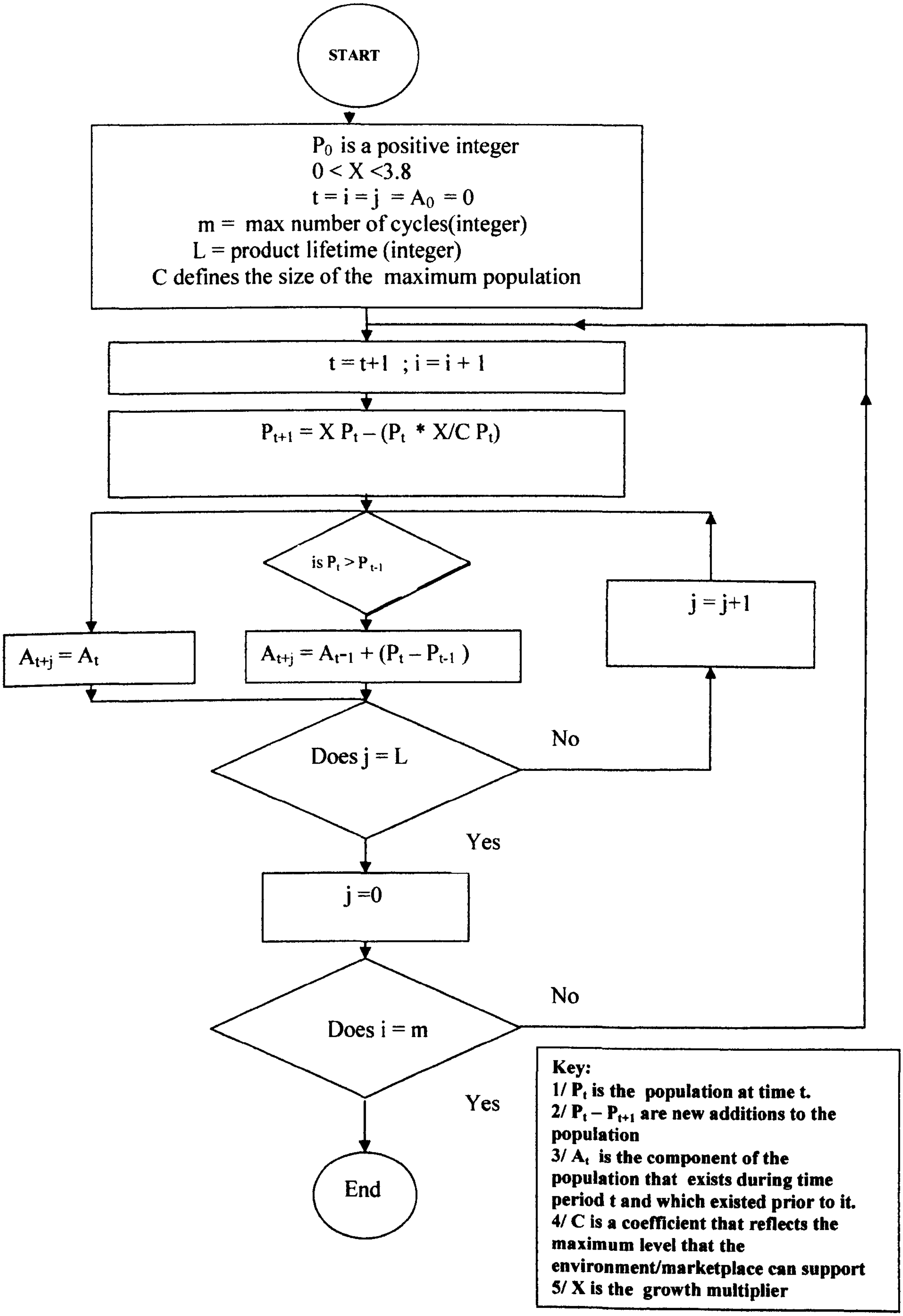
5.1 Verhulst logistic growth with lifetime component

All of the logistic growth equations discussed in chapter 3 (section 3.3) have limitations, in so far as they do not indicate how many new additions are made to the population during each orbit of the iteration, they just show the net change.

The number of new additions may not be very important for biological population dynamics, but it is critical for firms since new additions equate to sales of products and therefore to payoffs. The literature review indicated that software products have a limited lifetime and so it is clear that this attribute needs to be included in new simulations.

The number of new additions to the population can be computed if the standard Verhulst equation is modified to include a time structured matrix that keeps track of new entrants and removes them from the population when they die. In this case, where iterative difference equations are being used, the lifetime is defined in terms of number of orbits. The inclusion of a lifetime term indicates that additions to the population are temporal, existing for a fixed number of process cycles. The consequence of having a lifetime term, is that populations where individuals have a long lifetime have infrequent additions of small quantities, whilst populations where individuals have a small lifetime experience frequent additions of large quantities. A flow chart is shown in Figure 13 which forms the basis of an algorithm that builds lifetime into the Verhulst model.

Figure 13 Flowchart of Verhulst model with lifetime component



5.2 Market Value Landscape

For a population to grow it requires a landscape to sustain and nourish it. In all of the standard logistic growth equations a neutral landscape is implied, through a simple constant contained with in the negative feedback term. This does not seem to be a major problem for biological systems where the landscape is often literally a physical environment of fixed size. In mapping the growth equations into an economic context however, the landscape becomes an economic marketplace, which may or may not be of constant size. One of the constructs that has emerged from this research is the MV landscape which provides the demand function for products. In Figure 13, the MV landscape is the source of the value for coefficient C, at any particular instant in time.

By making the coefficient C a variable that can increase or decrease[76] after each orbit, it was possible to create a new simulation that accounted for both a finite product lifetime as well as a dynamic marketplace.

To explore the characteristics of the *Verhulst model with lifetime* interacting with a *dynamic market value landscape*, a visual Microsoft Basic programme was written, known here as simulation number 1. It was based upon the flowchart in Figure 13, and included five market situations. They were:

1. A flat market
2. A market growing each orbit by a set amount [76]
3. A market decaying each orbit by a set amount [76]
4. A market that is shocked upwards on one orbit[76]
5. A market that is shocked downwards on one orbit [76]

5.3 Comments on the simulation in the context of the new economy

Chapter 3 contained the proposal to limit the size of the urn, in the Polya urn process, in order to represent the *limited consumer memory* within an economic

[76] The values are set by the simulation operator at the beginning of each run.

marketplace[77]. There are similarities in the adaptations that were made to the Polya urn process and those made to the Verhulst, in as far as both equations required a modification that turned them into semi-Markov chains. However, the impact of the change from Markov, to semi-Markov were different in the two cases. For the Polya situation, the new, semi-Markov equation gave radically different patterns of outcomes compared to the original, whilst in the case of the Verhulst equation, the transformation could give the same set of patterns as the original, plus a further set, which were different. More succinctly, the original Verhulst Markov chain produced patterns that were a subset of the extended, semi-Markov model.

Although there are similarities between the extended Polya model and the extended Verhulst model, especially in the technicalities of the mathematics, they also exhibited a fundamental difference in what the constructions were trying to achieve. In the Polya case, the additional part of the process was looking backwards in time. The additional elements of the equation determined which, of all the memories that have existed, still exist. In the Verhulst case, the extension looks into the future and asks which elements of the population that exist today will still be present in the future. There is a complimentarity, a kind of symmetry, about the two processes, in so far as they offer restricted views looking forward and looking backwards from the perspective of the present. These two views can e contrasted with a pure Markov processes, which is parsimonious in the extreme, by retaining no information about past or future events and yet being inextricably linked to both.

It might be thought that the main impact of adding the lifetime term to the Verhulst equation is not to change the pattern of the trajectory, but to provide more detail of how it is made up. The simulation will show that there are situations where a more active effect occurs. The original Verhulst model produces a series of outcomes that may be interpreted as a snapshots of a population at different points in time. The series of outcomes may be presented as a chronological scatter plot, but he information content is rather sparse, and

[77] Appendix 9 gives full details of the extended Polya urn process and a simulation of this process is contained in the cd attached to the rear cover of this thesis

whilst such plots give a picture of a changing population they do not give any real information about the total (accumulated) numbers of animals or products that have contributed to the population profile.

The series of Figures, 14a to 14bi (shown in appendix 8[78]), are the results of running a simulation based upon the flow chart shown in Figure 13, that included a variable X term. The terminology relates to products and customers. The initial conditions allow the marketplace to be defined in terms of:

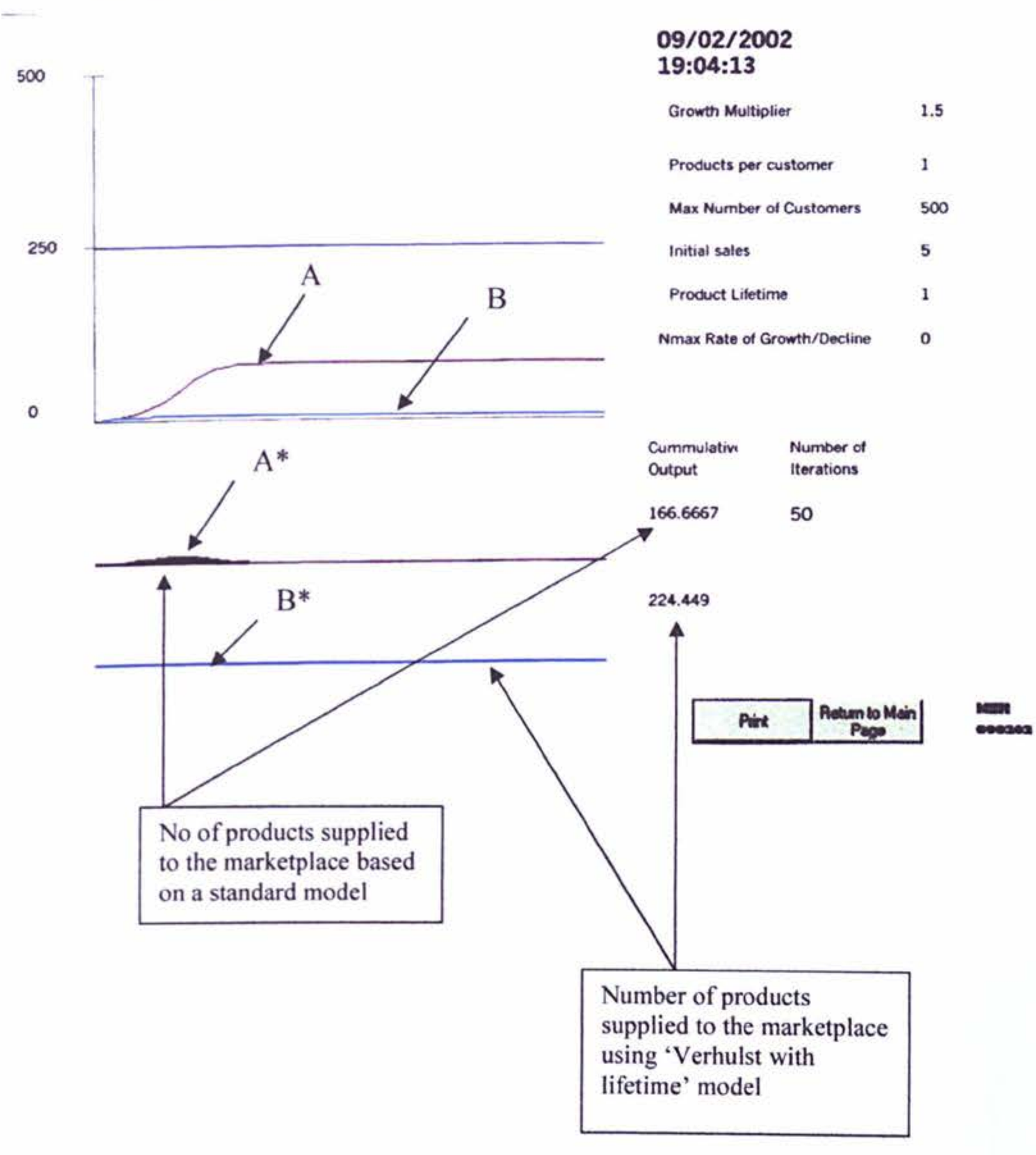
(a) The coefficient, C, which is proportional to the total demand.
(b) The average number of products desired by each customer at any instant in time.
(c) The initial quantity of sales, P_0, at the start of the process.
(d) The growth multiplier, X, by which output can be increased between each cycle of the process.

Figure 15, on the following page, is an example of the actual output from simulation number 1, in which the output labelled 'A' was generated from a Markov chain logistic difference equation (i.e. equivalent to having an infinite lifetime). In contrast, the output labelled 'B' was from a semi-Markov logistic growth equation with a time structured matrix that allows for a finite lifetime. The outputs labelled with stars (A* and B*) show the net new additions to the population during each orbit of the iteration.

78 Read the remainder of this chapter before viewing appendix 8

Figure 15 Example of an output from simulation 1, relating to a marketplace that has a constant, fixed level, of demand

LT1_G1.5



Each result in the series of Figures 14a to 14bi, relates to simulation that ran for fifty cycles of the process. The outputs from the simulation show the total population at a particular instant in time, together with the proportion of the population that constitute new additions. Since the resolution of the printed graphical output is poor, Table 14 and Figures 16a-c are a set of data that has been contrived to illustrate this point,

Table 14 Illustrative data set for simulation 1

Time (t)	Additions to Population During Interval	Losses from population During Interval	Net Additions	Population at time (t)
0	10	0	10	10
1	25	6	19	29
2	32	10	22	51
3	18	6	12	63
4	7	3	4	67
5	3	2	1	68

Figure 16a Illustrative data set for simulation 1

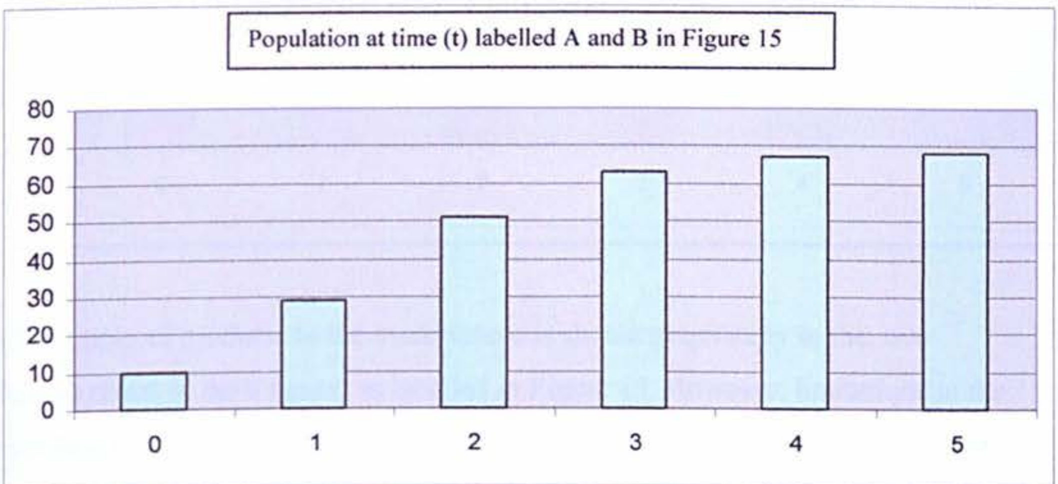


Figure 16 b Illustrative data set for simulation 1

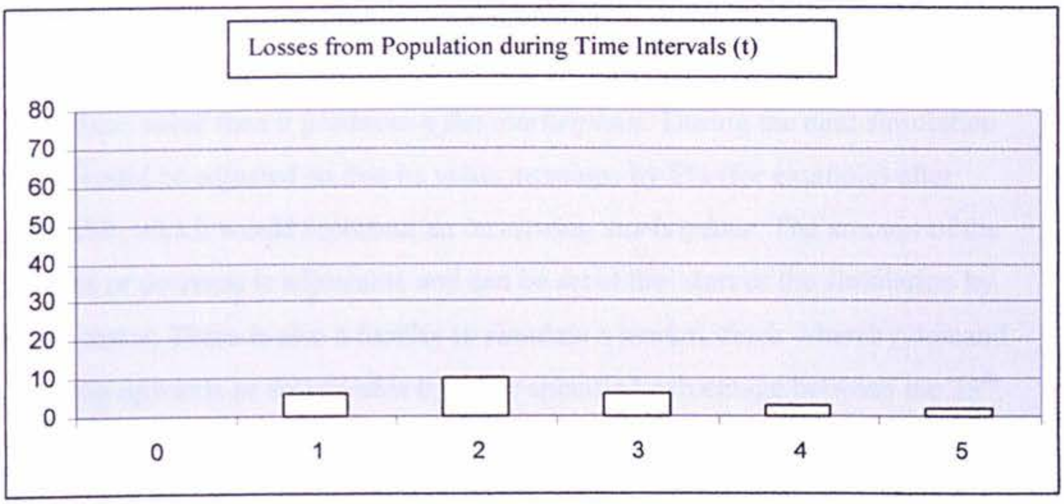
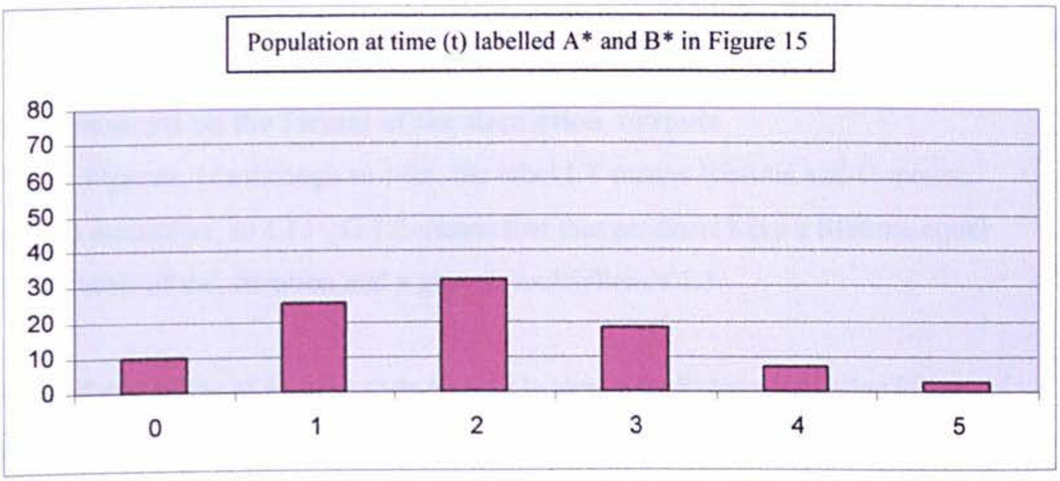


Figure 16 c Illustrative data set for simulation 1



The supply of products to the marketplace is shown graphically in the two lowest charts in each figure, as labelled in Figure 15. However, limitations in the resolution in the graphics do not clearly represent the differences between them but this van be overcome by comparing the numerical values for the accumulated output.

5.4 Shaping the virtual marketplace

The coefficient *C* (carrying capacity) is interpreted as defining the size and shape of the marketplace. It can take on many forms within the simulation and be manipulated in a number of ways. So if at the start of a simulation run, C is set to some fixed value then it produces a *flat marketplace*. During the next simulation run, *C* could be adjusted so that its value increases by 5% (for example) after each orbit, which would represent an *increasing marketplace*. The amount of the increase or decrease is adjustable and can be set at the start of the simulation by the operator. There is also a facility to simulate a market shock whereby demand can jump upwards or downwards by some specified percentage between the 25th and 26th cycles producing a *shocked marketplace*. The simulation was executed repeatedly for each of these market conditions to create families of outputs. Within each family group, changes were made to other parameters to demonstrate the impact of other variables. The main changes were to the growth multiplier and lifetime coefficient.

5.5 Comments on the format of the simulation outputs

For all Figures, 14a through to 14bi, the label LT means lifetime and G means growth multiplier, so LT1 _G 1.5 means that that products have a lifetime equal to one orbit of the iteration and a growth multiplier of 1.5.

Each of the series of Figures (14a to 14bi in appendix 8) have a similar format and contain numerical and graphical data. The numerical information in each Figure relates mainly to set up conditions, whilst graphs show the contrasting outputs of the standard (A – without lifetime component) and modified (B – with lifetime component) Verhulst models. These graphs refer to the quantity of products occupying the marketplace, at any particular stage of the process (scatter plots) and the numbers of new products that enter during each cycle (bar charts at the bottom of the figures).

The scatter plots show a series of instantaneous snapshots relating purely to the overall quantity of products in the marketplace. This is typical of a Markov chain growth model. The additions to the populations during each cycle are shown graphically in the bar charts A* and B* (as labelled in Figure 15).

It is assumed that for the standard Verhulst model, new products only enter the marketplace when the population increases. This means that for a marketplace containing a constant population of products no new sales occur, which is a disaster for the firms supplying the products. In contrast, a marketplace exhibiting a constant population of products, in a *Verhulst with lifetime* model, implies that old products are being lost from the population, but that the losses are being replaced at the same rate by new ones. The two bar charts at the bottom of each figure in appendix 8 illustrate this point.

A commentary on the results from simulation 1, including deliberations and findings is given in chapter 7 (section 7.4).

CHAPTER 6: Computer Simulation 2

Simulation 2 is intended as an applied model of the firm with multiple features including: three firms, logistic growth, a Polya with memory market share algorithm, Prisoners Dilemma competitive interactions, exploration, exploitation and profitability decay.

6.1 A brief descriptive overview of simulation 2

There are two significant differences between simulation 1 and simulation 2. The first difference is in the software tools that were employed to create it. The second is the diversity and quantity of modelling elements that it embraces.

Simulation, 1 was an efficient and fast executable (.exe) program produced using a programming language (Microsoft Visual Basic) that is not commonly found amongst business managers. This means that the models cannot be modified by the user in order to make it a closer fit his/her circumstances, except through the adjustments already built into the simulation. In contrast, simulation 2 was built on a Microsoft Excel platform that is widely used in business which offers the opportunity for it to be modified and improved by future users.

Simulation 2 illustrates the way that empirical information and subjective value judgements can be incorporated into a computer program that tailors it to a specific business situation. It shows the way that many modelling elements can be synthesised into a hybrid application that could meet the needs of a particular firm seeking insights into the possible trajectories of firms in its own situation. This synthesis of established and new models into practical a business simulations is one of the achievements of the study. The features of simulation 2 include:

a) Logistic growth
b) Three firms
c) Profitability decaying as the process progresses

d) Two firms adopting an exploitation strategy only by remaining on a single position on the product fitness landscape
e) One firm that exploits a single product position on the product fitness landscape until profitability falls below a set level, which triggers a random leap to a nearby position on the product fitness landscape.
f) Competitive interactions, based upon the Prisoners Dilemma game, between any firms occupying the same position on the product fitness landscape. This manifests itself as increased rate of decay of profits.
g) Market shares determined by a self reinforcing process based on the Polya urn process whereby early entry tends to lead to market dominance.
h) A demand function based upon the market value landscape concept.

The relationship between the Product Value landscape and MV landscape has already been discussed. In simulation 1, the market value landscape was derived from a product value landscape that was limited to a low level of complexity. For illustrative purposes, the product fitness landscape for simulation number two reflected all possible products and a firm randomly selected a product to manufacture. For simplicity, the fitness values that differentiate the products in this second simulation was created from a narrow set of random numbers (within the interval 0,10) which is intended to indicate that the firms have products which are broadly competitive.

The initial conditions of the model allows for three firms to *seed* the market value landscape at random positions. One of the firms is able to move to a new position on the landscape if its profitability falls below some trigger point. The other two firms are destined to remain on one position on the landscape throughout the simulation.

Whereas simulation 1 produced a large number of different outcomes which justified an appendix, those from simulation 2 could be grouped into just a few categories and so they remain in this section.

6.2 A descriptive analysis of the outcomes of simulation 2

Simulation 2 was run one hundred times without making any changes to the program or to any parameters within the program. The outcomes of each run are presented graphically as a sequential bar chart, the first bar representing the outcome of the first orbit, the second bar represent the second orbit and so on.

The program included both random and stochastic elements and no two outcomes were identical. However, it was clear that the graphical outputs formed patterns that contained common features. Just five patterns are needed to describe all of the one hundred outcomes. The patterns are defined below:

1. **Hilly (A)** - characterised by having erratic outcomes with large and small values following each other in an apparently random fashion, often there would be periods where there was virtually no output at all.
2. **Saturated (B)** - patterns exhibited an initial period of steady growth followed by a plateau where these was relatively little change between each cycle.
3. **Spiky (C)** -patterns appeared to exhibit only one, two or three bars. These bars represented outputs, which were so great, that all other outputs from the simulation appeared insignificant.
4. **Growth then decay (D)** - is characterised by steady growth followed by steady decay towards a plateau.
5. **Hilly then decay (A/D)** - is characterised by an initial hilly region followed by steady decay towards a plateau.

The emergence of patterns was hoped for, but it could not have been guaranteed from a new model that incorporated so many stochastic and random events. If patterns had not arisen and the outcomes had appeared to be random, then the simulations would only have provided a tool for inductive analysis. However, by recognising and categorising patterns in the outputs, it has allowed more general observations and predictions to be made, which is a crucial aspect of the complexity science approach.

An analysis of the results, together with examples of the patterns described above (1 to 5), is shown in Table 15 and in Figures 17a to 17f. Each simulation included three virtual firms supplying products to the marketplace and receiving payoffs in return. One of these firms, *company 1*, followed a strategy of both exploring and exploiting, whilst the other two, *company 2* and *company 3*, choose only to exploit a single product throughout the course of the simulation. Company 1's strategy resulted in a payoff trajectory that exhibited only two patterns, being either 'hilly' or 'spiky'. In contrast , company 2 and 3 had outputs that fell into all five categories of pattern.

Table 15 A Cluster analysis of simulation 2

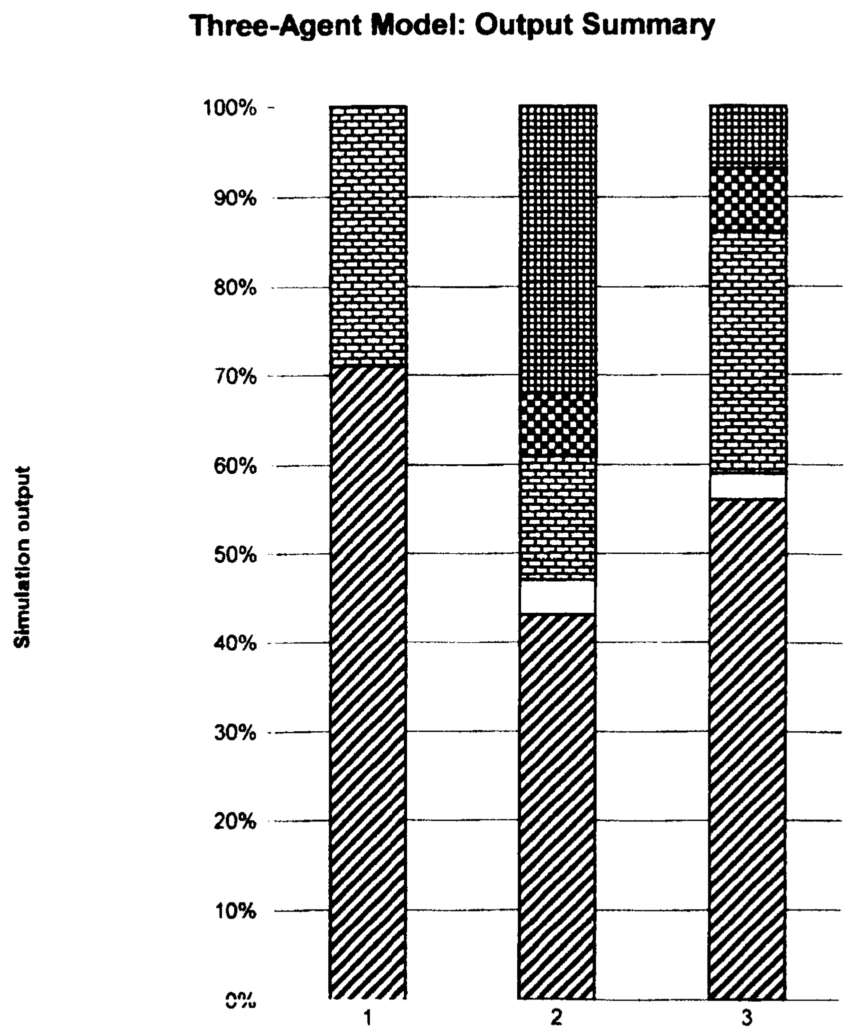
Cluster type output analysis for 100 simulation runs

Run Number	Company 1	Company 2	Company 3
1	A	B	B
2	A	C	C
3	A	A	A
4	C	A/D	A/D
5	A	A/D	B
6	A	A	A
7	A	A/D	A
8	A	A	A
9	A	A	A
10	A	A/D	A
11	C	A	D
12	A	A	C
13	A	A/D	C
14	A	A/D	C
15	A	A/D	A
16	A	A/D	A
17	A	A	A
18	A	B	A
19	C	A	A
20	A	A	A
21	A	A	C
22	A	B	A
23	A	A/D	A
24	C	A/D	A/D
25	C	A	A
26	A	A/D	A
27	A	A	C
28	A	D	A
29	A	D	C
30	C	A/D	A/D
31	C	A	C
32	A	A	A
33	A	A/D	A
34	A	C	A
35	A	A	A
36	C	A	C
37	C	D	D
38	A	C	D
39	C	C	C
40	A	D	D
41	C	A/D	A
42	A	A	C
43	C	B	B
44	A	A/D	A/D
45	C	A	A
46	A	A	A
47	A	A	C
48	A	A/D	C
49	A	A/D	A
50	C	A	A
51	A	A	C
52	A	A/D	A

53	A	C	A
54	A	A	A
55	A	A	A
56	C	A/D	A
57	C	C	A
58	A	A	A
59	A	A	C
60	C	A	C
61	A	A	C
62	A	A	C
63	A	A	A
64	A	A/D	A
65	C	C	A
66	C	A	C
67	A	A/D	A/D
68	C	D	D
69	C	C	A
70	A	C	A
71	A	A/D	A
72	A	A	C
73	A	D	A
74	A	D	D
74	A	A	A
76	A	A	A
77	A	C	A
78	C	A	C
79	C	A/D	A
80	C	A	C
81	A	C	C
82	C	C	C
83	A	A	A
84	A	A/D	A/D
85	C	A	A
86	A	A/D	A/D
87	A	A	A
88	A	C	A
89	A	A	C
90	A	A/D	A
91	A	A	A
92	A	A/D	A
93	A	A/D	A
94	A	A/D	D
95	C	C	A
96	A	A	C
97	C	A	A
98	C	A/D	A
99	A	A/D	C
100	A	A/D	A

Summary			
Hilly	71	43	56
Saturated	0	4	3
Spiky (under 3 bars)	29	14	27
Growth then decay	0	7	7
Hilly then decays	0	32	7

Figure 17a Simulation 2 output summary



	1	2	3
Hilly then decays	0	32	7
Growth then decay	0	7	7
Spiky (under 3 bars)	29	14	27
Saturated	0	4	3
Hilly	71	43	56

Figure 17b

Example of Growth then decay.

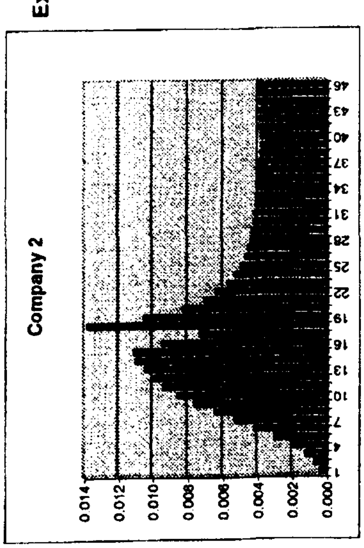


Figure 17c

Example of Hilly behavior.

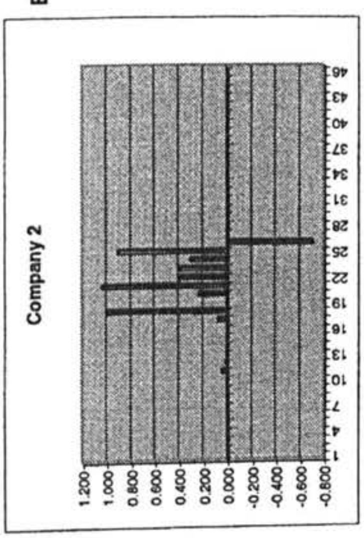
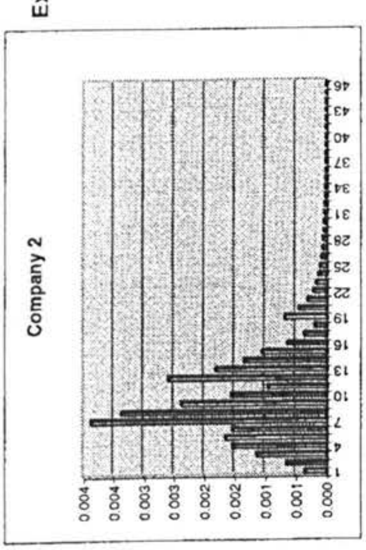


Figure 17d



Example of Hilly then decays.

Figure 17e

Example of Saturated behavior.

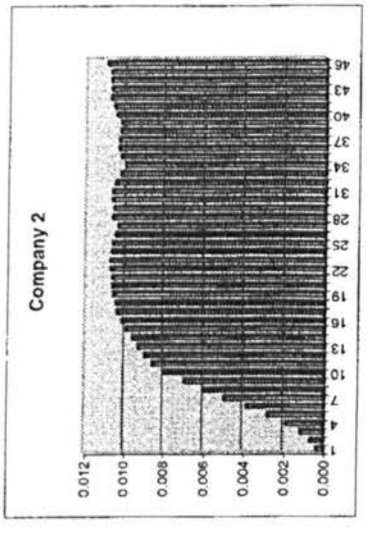
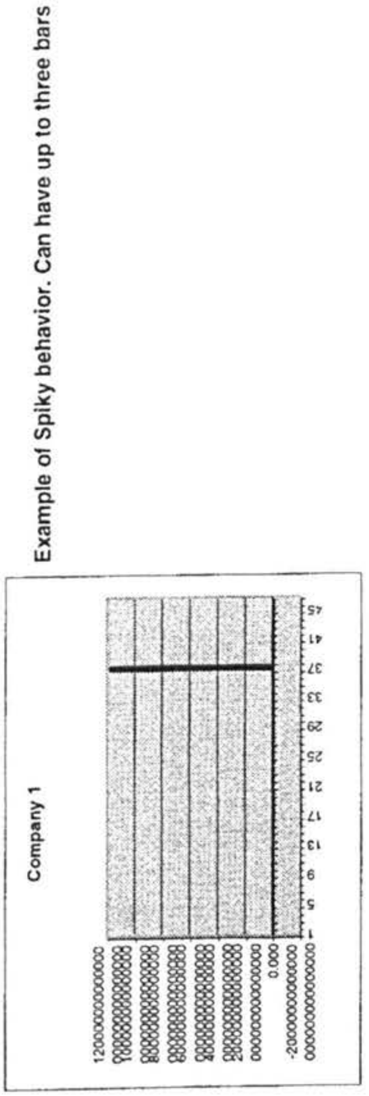


Figure 17f



The results from simulation 2 are discussed, and findings are presented, in chapter 7 (section 7.5).

CHAPTER 7 : Discussion of Findings and Applications

This chapter contains seven sections, whose contents are listed below:

1. Empirical analyses, discussion and findings
2. Simulation 1 discussion and findings
3. Simulation 2 discussion and findings
4. Application of the research
5. Contribution to knowledge
6. Limitations of the research
7. Suggestions for future research

7.1 Empirical Analyses, Discussion and Findings

The Purpose

Chapter 2, showed that all of the individual modelling elements, except the Kauffman (1996) NK model of biological fitness , had been used in economic models in the same way that they were planned to be used in this research. The Kauffman (1996) NK model had been applied to other disciplines, but not in the way being proposed here, where it was the source of a non-linear supply-side function feeding into a logistic growth equation. So, the purpose of the empirical analyses, described in Appendix 6, was the validation of the Kauffman (1996) NK model as a representation of software products capable of supply-side increasing returns.

The Validation Template

For digital software products to be characterised using the Kauffman (1996) NK model, the empirical analyses needed to confirm that software was capable of increasing returns as a function of program length, whilst showing that other products in ICT the sector did not.

The Empirical Analyses

To test the validation template three analyses were undertaken. The first looked at Microsoft Corporation (a software firm with global reach) to see whether increasing returns could be observed as a function of software length. The second looked at, Intel Corporation (the current globally dominant microprocessor firm) to see whether its products were exhibiting signs of increasing returns. Finally, an analysis of the worlds top 500 firms (by sales revenues) was undertaken, against which the performance of a software firm (Microsoft) could be compared.

The data set

No empirical experimentation took place. All of the data existed within in the public domain. The approach was considered to fall into an epidemiological tradition that is widely used in the field of medicine. The data was drawn from four sources:

- The *Fortune* 500 business magazine
- The internet web site of Microsoft Corporation
- The internet web site of Intel Corporation
- From general internet searches, using the *Google* search engine

Observations and Results from Empirical Analyses 1 and 2: The analysis of, and comparisons between, Microsoft and Intel Corporations

Both Microsoft and Intel experienced strong, non-linear growth in sales revenues over the periods being analysed. Both firms invested in technology and made dramatic improvements to their capabilities. Microsoft increased the numbers of lines of code per program from 24,000 in 1985 to 50,000,000 by 2003. Intel increased the numbers of transistors per microprocessor chip from 2,200 in 1971 to 42,000,000 by 2002. However, there is a noticeable difference in the trends of revenue per active component[79] for the two firms.

For Microsoft, each new software platform that it introduced had more lines of code, and every time it performed one of these technological leaps the *revenue per line of code increased.* So, not only did Microsoft revenues increase as a function of the length of its programs, but each additional line of program

[79] The term active component is referring to a *line of code* with regard to Microsoft and a *transistor* with respect to Intel

commanded a greater price in the marketplace than had previous lines of program code (Figure 20, page 229).

In contrast, there are two identifiable phases of the Intel business history (Figure 28, page 235). In the first phase, Intel made nine technological leaps and each was rewarded with increased value per transistor. In the second phase, Intel made three progressively greater leaps forward in terms of numbers of transistors per product and yet the revenue per transistor remained flat. In this second phase, Intel were having to run ever faster simply to stand still. There is a *prima face* case that the phenomena being exhibited by Intel appears to be the *red queen effect* (Derfus, *et al.*, 2008) '*whereby a firm's actions increase performance but also increase the number and speed of rivals' actions, which, in turn, negatively affect the initial firms performance*' (Derfus, *et al.*, 2008: p.61). In spite of this, Intel was an '*incredible profit machine*' (Church and Ware, 2000; p. 111) with an 86.7%[80] market share, and in the year 2000 (even though revenue per transistor had stagnated) it was still returning a 31% net profit, on revenues of $36B[81]. However, it should be noted that during the same year Microsoft turned in a 41% profit, on revenues of $23B[82].

Similarities and Differences between Microsoft and Intel

The two contemporary firms that were analysed (Microsoft and Intel) are both dominant within their specific segment and they both operate within the same high-tech information and communications technology sector. Yet one has experienced increasing returns, as it added more and more functional components to its products, whilst the other has not. Although the analysis only compares two firms, they are both globally dominant players and the observations should therefore be considered relevant, if not conclusive.

[80] In 2006 the market shares of Intel and AMD were 86.7% and 13.3% respectively. Available from http://www.ibtimes.com/articles/20060727/intel-amd-marketshare.htm [Accessed on 1/11/08]
[81] See Appendix 6
[82] See Appendix 4

7.1.1 Finding #1: Microsoft's exhibits increasing returns as a function of the lines of lines of computer code in its products

Commentary

The comparative analysis of Microsoft and Intel suggests that Microsoft (a digital software firm) was benefiting from increasing returns, whilst Intel (a microchip hardware firm) was not. This observation is offered as evidence that software firms are fundamentally different from traditional firms who make and sell tangible goods.

The conjecture is put forward that a plausible explanation for Microsoft's increasing returns can be found in the Kauffman (1996) NK model, when mapped into an economic/business context and that the mapping is applicable by virtue of Microsoft's products being made up of digital information strings. This conjecture aligns with the idea that product development within the firm through technology advances (migration over a product fitness landscape) drives supply side growth and it is consistent with the concept that economic wealth generation has its roots within the firm (Penrose, 1959).

Observations and Results from Empirical Analysis 3: The comparison of Microsoft Corporation with the top 500 largest firms in the world (by sales revenues)

The third empirical analysis looked at the profitability (profit as a percentage of sales) for the worlds top 500 firms over a period from 1991 to 2002. This analysis involved the following steps:

i) The conversion of all sales revenue data, so that it represented values in the year 2003, by inflation indexing.
ii) A calculation of the profitability of each firm, by dividing its *net profit* by its *gross sales* and multiplying by 100.
iii) The plotting of all profitability data on one chart with the x axis representing sales and the y axis being profitability.
iv) The discarding of all negative values of profitability.

v) A visual analysis of the chart, mentioned in point iii, to look for patterns.

vi) The superimposition of Microsoft performance data (1985 -2003) onto the chart mentioned in point iii, and a comparison of the result.

7.1.2 Finding # 2: A parametric description of profitability decay for the worlds 500 largest firms, covering the period 1991 to 2002

Commentary

At stage v) of this analysis a pattern had emerged. For the firms within the data set, a profitability envelope could be observed. The envelope constrained the profit performance of the firms in such a way that as revenues increased there was a tendency for profitability to fall. The profitability envelope indicated that, those firms whose sales revenue was in the bottom ten-percentile of the data set were constrained to a maximum potential profitability equal to 45% of sales. Those firms in the top ten-percentile of sales revenue were constrained to a maximum potential profitability equal to 15 % of sales. Although the trajectories of individual firms was not followed, the pattern of the outcomes implied that as sales increased there would be a tendency for profitability to decrease. The equation shown in (12) closely fits the decay envelope and is one of the findings of this research

$$y = 100 \times 0.53\, e^{-(0.0000093355\, x)} \qquad (12)$$

y = The percentage return on sales profitability of a firm (i.e. net profit as a percentage of net revenue)

x = Net revenue ($M).

An empirical description of the profitability decay envelope is shown in Table 16. Plotting these data on a graph and joining points with straight lines describes the revenue profitability envelope of the worlds top 500 firms during the period 1991 to 2002.

Table 16 An empirical description of a profitability decay envelope

Rank during year	Year	Firm	Revenue ($M) Indexed	% Profit
413	1994	Standard Life Assurance	11537	46.70%
315	1999	Cable & Wireless	16346	38.84%
110	2000	Intel	35978	31.24%
32	2000	Verizon Communications	69029	18.23%
13	2002	Citigroup	102915	15.16%
3	1998	Ford	162756	13.90%
2	2001	Exxon Mobil	198726	8.00%
1	2000	Exxon Mobil	224446	8.42%
1	2002	Wall Mart Stores	251726	3.26%

The decrease in profitability amongst the worlds largest firms is not a surprise, as the phenomena of diseconomies of scale (Mankiw and Taylor, 2006) is a recognised feature of large firms.

7.1.3 Finding # 3 Microsoft exhibits increasing profitability as sales revenue grow

Commentary

The final stage of the analysis (vi) involved superimposing the performance of Microsoft onto the chart[83]. This showed that the historic performance of Microsoft is at odds with the general tendency of decreasing returns. The data for Microsoft shows an overall upward trend of increasing profitability as revenues have increased and the firm has grown. Furthermore, there were two instances where Microsoft broke through the profitability envelope that seems to constrain other traditional firms in the data set.

The observation, that Microsoft has exhibited a trend of increasing profitability as it has grown, is put forward of further evidence of *digital software products* being especially capable of producing increasing returns. This supports the use of the Kaufmann (1996) NK model, when mapped into an economic/business context, which can be rationally explain the phenomenon of increasing returns.

Finding #3 lends weight to those who believe the new economy has been outperforming the traditional economy (Jorgenson *et al.*, 2004). It also supports the belief that the higher performance is due to accumulation of knowledge

[83] See Appendix 6

(Romer, 1986) involving the acquisition, processing, transformation and distribution of information (Nordhaus, 2002: p. 201). However, of the two firms that were investigated, it is only the software firm (Microsoft) that is performing differently to traditional firms. Intel is exhibiting the onset of decreasing returns like any large traditional firm. This is also relevant if new economy firms are defined through their products being weightless and virtual (Quah, 1999, 2001).

Decision Regarding the Validation of the Kauffman (1996) NK model to represent digital software.

The conclusion, drawn from the findings of the empirical analyses described above, is that over an eighteen year period the software firm of Microsoft Corporation exhibited increasing returns, which was a function of the length of the software code used in their products. This result is considered sufficient to validate the use of the Kauffman (1996) NK model to represent *virtual software products* in research simulations.

7.1.4 Finding # 4 Using Microsoft as a benchmark indicates that the global marketplace will provide payoffs of approximately $650USD per line of code for digital software firms.

Commentary

Although the empirical analyses were intended to validate one aspect of the modelling process, the data has potential benchmarking for other software companies.

During the period 1991 to 2002, Microsoft produced the highest revenues and highest levels of profitability of any software manufacturer in the world. In the year 2000, the average number of lines of code found in a Microsoft product was 35 million. The sales revenues in the year 2000 were $23B and net profit was $9.4B. This means that each line of code that programmers contributed to the Microsoft product returned $655 of revenue, of which $269 was net profit.

The year 2000 was exceptional due to the *millennium bug*[84] and so the most recent year of the dataset (2003) might be considered to be more representative. In 2003, Microsoft products had 50M lines of code. In the year 2003 the sales revenues were £32B and net profit was $7.5B. This means that each line of code that programmers contributed to the Microsoft product returned $643 of revenue, of which $150 was net profit.

7.2 Discussion and Findings from Simulation 1

A number of widely used theoretical models were looked at during this research. They were scrutinised to determine their suitability for describing economic processes within a simulation of the new economy. The following paragraphs discuss the various processes that were simulated and the findings that arose.

Polya Urn and Market Share

The basic Polya urn problem is an example of a stochastic self re-enforcing mechanism that has been mapped into a number of economic and social situations. It was originally a contender for the modelling element that would describe the way that market shares arise in an economic marketplace. However, the literature review revealed that it contained two embedded features that are rarely found in the real world that would reduce its applicability. The first, was that chronology (in terms of the ages of the balls in the urn) does not play any role in the systems outcomes. The second, was that all accumulated effects are indelible, so that system is anchored to the past in a manner that drives it towards a moribund state. By mapping a feature of real economic environment (product lifetime) into the Polya urn process an extended version of the process was created.

The extended Polya urn process limited the capacity of the urn so that when the urn was full new balls displaced old ones. The displaced balls were removed on a *first in first out* (FIFO) basis. This created a situation whereby balls remained in

[84] The millennium bug (Anderson, 1999) was a legacy problem relating to software memory limitations that resulted in an exceptionally high number of new computers and software packages being sold.

the urn for a finite number of cycles. The number of cycles that a ball resided in the urn was interpreted as product lifetime. This modification to the original Polya process provided a model that could represent several business and economic phenomenon. The extended Polya process was simulated as an individual modelling component and the outcomes were analysed in Appendix 9.

7.2.1 Finding # 5 A Polya urn system, with limited occupancy (size of urn/lifetime), tends towards a dominance/extinction situation, where the time before the onset of a monopoly is inversely proportional to the urn size

Commentary

The results, described in Appendix 9, show a family of Polya urn process outcomes, where occupancy of the urn has been limited to a finite number of balls. The empirical data that is presented shows that the system exhibits a tendency towards dominance/extinction. If mapped into an economic situation it can be used to illustrate the way that monopolies can develop in markets where products are frequently replaced. For example, were goods are perishable or rapid changes in technology drives customer behaviour. In the model the number of balls can be used as a proxy for product lifetime.

Logistic Growth applied to software products (simulation1)

This simulation involved a logistic growth equation with a finite lifetime component and an economic marketplace whose carrying capacity was subject to supply side, non-linear expansion .

The growth of software firms was modelled using logistic growth equations, derived from the study of population dynamics. The modelling approach used population numbers rather than ratios. The equations generated the numbers of products in the marketplace using concepts drawn from evolutionary biology. This is different to the traditional approach used by business managers, who focus on new sales into the marketplace, not the number of products that exist within the marketplace.

Two extensions were made to the standard logistic growth model. Firstly, the population of products that the equation was dealing with were considered to have a finite lifetime, so the equation was modified to keep track of losses and new additions. Secondly, the carrying capacity of the marketplace, which is usually a constant in the standard logistic equation, was replaced by a variable function that was linked to the desirability of the product being modelled. The simulation representing this extended logistic equation was called simulation 1 and families of outcomes from it are contained in Appendix 8.

The results in Appendix 8 have been analysed and are shown below:

In a flat marketplace, moderate levels of growth, of short lifetime products, results in a fairly constant demand from the marketplace. As the growth multiplier increases the demand characteristics of the system changes to one of periodic feast and famine. For products having a long lifetime, the demand characteristics are different. In a low to medium growth environment, demand for long lifetime products is cyclic. For medium growth conditions, acting upon long lifetime products, the demand function is generally that of high demand, but with occasional periods where demand is extremely weak. The demand trajectory in a high growth/long lifetime situation appears chaotic, sometimes resulting in the complete collapse of the model.

In a marketplace that is growing by 1% per orbit' products with a short lifetime fair very well. For all levels of growth , the demand for short lifetime products steadily increases after each cycle of the model, this is in contrast to the standard Verhulst model which exhibits substantial oscillations at high levels of growth. It is as if the combination of the growing market and product losses during each cycle quenches the destabilising effect of the high growth rate. As the lifetime of products increase, the patterns of demand change, whereby increasing growth rates promote the onset of periodicity followed by chaos.

In a marketplace that is declining by 1% per orbit products that have a short lifetime and which are associated with low, medium or high levels of growth, exhibit quasi-static, but slowly declining demand. For medium and long lifetime products, the effect of increasing the growth multiplier is to make demand function initially periodic, followed by chaotic.

In a marketplace that is shocked upwards by 10% half way through the simulation, there are no dramatic or unexpected effects to the system, where products have a finite lifetime. The relationships seen in a flat marketplace are evident and the shock causes only small amounts of turbulence. Once the effect of the shock is absorbed, after just a few cycles, the system experiences the positive effect of the increased market and settles down as if it were flat.

In a marketplace that is shocked downwards by 10%, half way through the simulation. As with the upward shock, there is surprisingly little impact to the demand function from the shock where products have a finite lifetime and the system settles down within a few cycles.

7.2.2 Finding # 6 Short product lifetime stimulates demand and reduces the onset of market instability.

Commentary

A general feature, that can be observed in all of the systems simulated in Appendix 8, is that specifying a finite product lifetime has a positive impact for the virtual firm producing the products, when compared to outputs from the original standard Verhulst logistic model. The first impact is to dramatically increase the cumulative demand for the products over the period of the simulation, which is a well known characteristic of real marketplaces (Packard, 1960). The second effect manifests itself as additional negative feedback to the system, which has a stabilising effect by providing a mechanism that reduces the population in the marketplace. At high growth rates this is rather like a safety valve. It is particularly noticeable when comparing high growth populations of the original Verhulst with the populations of the modified model, where the original is invariably more erratic.

The addition of an age structured matrix to the logistic equation, showed that increasing a products lifetime reduces the flux of future sales and makes the onset of chaos more likely for high growth rate situations. This model demonstrates the importance for firms to have regular planning sessions, since the period between such events represent the feedback delays in the systems and can influence the growth multiplier for the firm. A fast growing firm that fails to implement a *frequent feedback* planning system is on course for chaos. This observation offers a useful lesson to successful start up firms experiencing high growth.

7.2.3 Finding # 7 Modest (5%) upward or downward shocks to the marketplace generally have little effect on a marketplace

Commentary

Simulation 1 was especially useful in providing a vehicle that allowed the overall system to be manipulated. The environment (marketplace) could be expanded, reduced or shocked. Upwards or downward shock , of +/- 5% made little difference to the market dynamics, except where there was very high growth and long lifetimes.

7.3 Discussion and Findings from Simulation 2

The findings presented in this section relate to virtual firms. However, within the limitations outlined in 7.1 they should provide insights to real firms whose primary business dynamics involve the following:

- Digital software products
- Sales/product output growth.
- Competition with other software firms.
- Growing and maintaining market share
- Investment choices that involve tension between product development (R&D - Exploration) and servicing customer demand (Operations and Sales – Exploitation)

The Emergence of Attractors

In chapter 6 the features of simulation 2 were described together with the results from one hundred simulation runs. Whilst each of the simulation runs produced unique results, they fell into just five distinct patterns. Furthermore, for the firm that was programmed to *explore* the product fitness landscape, the numbers of patterns decreased to just two.

The observation that outcomes from the simulations formed patterns is being viewed as the emergence of attractors. These are not uncommon in complex situations, like those found in *NP complete* types of processes, but they are unpredictable and, in general, the only practical way that they can be identified is through simulation. This result justifies the chosen methodology as it has exposed knowledge and information about the strategic trajectories of a certain kind of firm that would otherwise have been inaccessible.

7.3.1 Finding # 8 There is no guaranteed strategy to achieve longevity for a software firm. Sticking with a niche product can produce longevity, but when this occurs it is associated with relatively small payoffs. Being a niche player can also result in failure. In contrast, software firms that search for 'killer' products invariably achieve high payoffs, but continuing with the strategy eventually leads to total failure.

Commentary

Within their virtual marketplace, firms that only *exploited* (Cyert and March, 1992) their products and stuck to a single product niche were influenced by one of five attractors. The performance associated with the attractors ranged from small steady revenue streams to sporadic, but high, payoffs. The average payoffs were poor and this is somewhat in contrast to the expectation of a niche/focus strategy, that is supposed to lead to high payoffs (Porter, 1980). This outcome reflects another limitation of the model, since staying in the same position on the landscape does not confer any explicit niche benefit. In a more sophisticated model, where the product fitness landscape has local fitness peaks, it would be possible to simulate niche firms that explore their *local* landscape for improvement opportunities and this could produce a different set of outcomes

In contrast, the firm that was allowed to *explore* (Cyert and March, 1992) the landscape always produced the higher, but sporadic, payoffs. These results have to be seen within the context of a simulation where exploration was a random jump to nearby options. The strategy of these virtual firms could be described as *prospectors* (Miles and Snow, 1978) or as adopting a *technology focus* (Porter, 1980). However they are described, they exhibited the highest average payoffs, but eventually they always failed. This too may reflect limitations of the model as the technological/product leaps were random, which may be unrealistic.

Finding #8 may be unduly pessimistic due to the limitations of the program. The replacement of random jumps with more sophisticated decision algorithms and search engines could produce virtual firms that manage to achieve sustainable high levels of payoffs.

General Observations regarding Simulation 2

The computer program described in this chapter has demonstrated that complex simulations can be built, by integrating a few fundamental algorithms, in ways that emulate real firms. In this case, the patterns of outcomes indicated that the highest returns were associated with exiting a market when profitability drops below a critical level and then searching for new products to exploit. Intuitively, this is unsurprising. However, this payoff maximising strategy, through random exploration, also always led to eventual failure with the total collapse of the firm. The random nature of the exploration algorithm might be considered as too risky and unrealistic. A more rational method of product development would be an interesting addition to the simulation. For example, the inclusion of a search procedure on the Product Fitness landscape rather than a simple random jump. Nevertheless, there are firms who's fortunes may be likened to the results seen here. GEC, of the UK, invested massive sums of money in obtaining 3G mobile phone licences from the government, only to write off its investment in a manner caused an almost total collapse of the firm.

In contrast, continuous exploitation of a single market sector, even when profitability becomes marginal, generates low returns over a potentially indefinite period. Although these simulations are targeted at new economy firms, it may be that they also give a more general an insight into traditional economy. For instance, the attractors seem to have a resonance when comparing small family firms with larger public companies. Family firms often appear content with longevity rather than growth, compared to limited companies where employees can find themselves under pressure for profit maximisation, even if it leads to eventual collapse.

In its present form, simulation 2 is still too basic to be truly useful in a practical sense, but it could be extended to represent a real market situation and then the outcomes would be worthy of serious consideration by business managers .

7.4 Application of the research

Using the Programs

There are no instructions within this document that explains how to operate simulation 1 or simulation 2, or any of the other stand alone components, but the controls are labelled on the screen view and operation is intuitive. If a user wishes to know more about how to operate them properly, then training could be given. This would be welcomed if the programs were intended to be used by a real software firm.

Achieving increasing returns

This research has provided a number of lessons that can be used by strategic managers of software firms. The most valuable of which is a generic outcome that applies to all digital software firms. It reflects the results from models where a product fitness landscape is linked to a logistic growth equation, as in simulation 1 and 2 .The practical advice that this aspect of the research provides is: ***Do not produce multiple stand-alone software products***. A single integrated product, comprising apparently the same functional attributes of three, equally valuable, stand alone products, will have nine times the potential value of a single product. This is a supply-side driven opportunity for wealth creation. It is consistent with the understanding that consumers value many facets of a product (Lancaster, 1966, 1971). It offers far greater potential than simply bundling the three products together, which will at best command a price of three times the individual items.

Managing growth and new product launches

The simulations offer the potential to manage growth; and to extract optimum payoffs from a marketplace through the timing of new product launches. However, neither simulation1 nor 2 has been used in this role. Before doing so, they would require extensive testing in a real situation, with a firm whose managers could be taught how to operate them. It is likely that the simulations need further development and refinement before having genuine commercial value, but the following paragraphs are an illustration of the claims that should be possible, for simulation 1, should such a process be undertaken.

The models can be used to provide strategic direction with regard to product development and product launches. Simulation 1 would provide the greatest value to high growth start-up firms. To use it, a firm would need to build a database that measures the ***population** of its products* in the marketplace and would then manipulate the parameters in simulation 1 to reflect patterns similar to the actual performance of the real firm. Business planning and simulation updates should be synchronised, and if population growth rates cause the model to predict chaos, then more frequent planning should be implemented to provide more timely feedback, which would bring the firm back under control. If population growth begins to flatten, then the launch of a new product revision could be scheduled to optimise payoffs. Comparing the length of code of original and revised products will give an indication of the new, higher demand for the revision, which will allow its payoff stream to be managed (using simulation 1) even more effectively than its predecessor. Using the Microsoft benchmark data will allow comparison of products against each other to determine their fitness, which can give indications of internal R&D performance and/or the fitness of competitors' products.

7.5 Contribution

In chapter 1, five gaps in the knowledge base, relating to the economic and business characteristics of firms producing digital software products, were identified. By drawing upon ideas from economics, complexity science and strategic management, a number of insights have been discovered, which are outlined in the points below.

1. The investigation, shown in appendix 6, provides evidence of increasing returns from an archetypal digital software company (Microsoft Corporation). The longitudinal analysis shows increasing profitability[85] as sales increase. More importantly, it identifies that as the lines of computer code within the product increase, then each additional line adds proportionally more value than its predecessor. This increase in returns as a function of length of code is supportive of the models and simulations that were created as part of this research. Furthermore, the analysis contrasts the Microsoft performance with that of the worlds top five hundred most successful firms[86] and shows that Microsoft's profitability is increasing with increasing turnover, which is which is odds with the general trend.
2. A model of has been developed that provides quantitive relationships between the number of lines of code in a software product and the distributions of product fitness[87]. The model indicates that potential payoffs are a quadratic function of program length, which has important implications for strategic decision makers, who are advised to develop ever longer versions of their original product by adding new features, rather than launching those features in new *stand-alone* programs.
3. Two complicated simulations have been created that show the influences of numerous control parameters upon software product revenue streams. These simulations can be used to inform strategic managers of the possible

[85] Profitability being defined as net profit as a percentage of sales revenue.
[86] Ranked by sales revenue.
[87] Product fitness is defined as the customers perspective of the desirability of one product compared to its competition

consequences of their own actions and the effects that might arise from changes in the size of marketplace.

4. Finally, a plausible business model that simulates software firms has been created, by using a correspondence mapping transposition from the Kauffman (1996) NK model of evolutionary biology. This model links the knowledge content of a software program to its potential to produce economic payoffs, as well as showing that it is the synergies between quanta of knowledge that is the source of increasing returns (a feature whose parallel in biology is the epistatic coupling of genes).

7.6 Limitations of this Research

The limitations of this research are many and varied and they permeate the work at all levels.

Epistemology and Ontology

At an epistemological level, the research has been performed on the basis of techniques and standards that are aligned with complexity science. It is a discipline that favours the use of computer simulations for experimentation and exploration, and it is still in the process of gaining acceptance within the academic community. Furthermore, it embraces a cross-disciplinary approach that is viewed as unsatisfactory by some sections of academia. Ontological concerns are centred on whether a virtual entity is an acceptable a proxy for the real thing, especially when performing experimentation.

These philosophical considerations limit the audience of the findings to those who consider that producing a weather report is a legitimate pastime that generates useful information. This is not a flippant comment. Weather reports are generated using the same approach as those used here and have equally nebular outputs, relying upon patterns and probability a rather than unambiguous certainty.

In addition, some of the assertions are audacious, such as the linkage between software string length and market growth, which leads to increasing returns. This aspect of the modelling is supported by an historical, empirical, analysis of just a single firm (Microsoft), which leaves the models open to criticism.

Generalisability

Beyond the underlying philosophy, the simulations have limited scope as they are highly focused on a sub-set of firms. Out of all possible firms, this research only applies to those producing digital software. As the research has illustrated, the new economy sector is a rapidly growing and dynamic marketplace and so it may be that the lessons from the past will not apply in general terms to the future.

In addition, the simulations and empirical data relate to a global data set and yet no externalities or government welfare policies have been taken into account (Stiglitz, 1988; Barr, 1998). In the real world, governments influence firms and the omission of government influences in the models should be considered as a flaw to their Generalisability.

Practicaility

The models are not optimised and have been synthesised from just five business/economic process concepts. This limits their use to firms who consider that the chosen concepts, and the way that they have been integrated, offers a reasonable approximation to their own company. There are also limits to the practical insights that the programs can provide, since they show trends and relationships rather than prescriptive rules. Uncertainty is an embedded feature.

7.7 Suggestions for Future Research

An important element of this work is the assertion that firms producing digital software can experience increasing returns through product development, which involves the addition of new features that lengthen the software code. It is an issue that is embedded within the core models and simulations and yet the supporting empirical evidence is based on a single example (i.e. Microsoft Corporation). This critical aspect of the research requires further investigation.

Assuming that the assertion of increasing returns is confirmed, in a manner that continues to verify the core model, then further work could be performed to develop the simulations through the addition of features and /or changes to the current algorithms. The aim of these changes would be make the simulations more accurate representations of the real economic landscape and thus make them more useful to business practitioners. Some examples that should be considered include:

- An increase in the number of virtual firms operating within the simulation.
- A change to the competition subroutine that provides alternative competition/cooperation interactions.
- The addition of rule sets to represent externalities, such as government policies.
- The addition of options that represent traditional economic phenomena, such as economies of scale/diseconomies of scale.
- The ability to partition the firm's resources, so that exploring and exploiting can be performed simultaneously.
- The addition of search algorithms to emulate R&D activities involved in exploration of the fitness landscape.

The above are just a few of the possible research activities that could be undertaken to build upon this work.

Appendix 1 Some Economic Growth Models

Classical growth theory

Towards the end of the eighteenth century " An Inquiry into the Nature and Causes of the Wealth of Nations" was published (Adam Smith 1776). In it Smith makes many points that are still relevant today, but two in particular add to the case being made here. The first is an observation that, historically, wealth generally increases over time. The second point, made by Smith, relates to the cause for wealth to increase, which he postulates is due to "productive labour". The essence of Smiths growth model was that output is a function of three variables: capital, land and labour. So output growth was also a function of these three variables. As a consequence , more investment meant more output, more available land meant more output, and in the case of labour, output would increase if there was more workers.

The issues raised by Adam Smith were of his time and were influenced by an economy that was still heavily based upon agriculture, but nevertheless they encapsulated some fundamental economic concepts which remain valid today. In particular, the recognition that productivity is a driving force for growth has been widely accepted in many later models, operating in quite different socio-economic environments.

Adam Smith's model is supply side driven and it encapsulated the key drivers of wealth creation in a period that was full of latent demand. Furthermore, Smith began to expose the role that specialisation could have in improving output, in the sense of increasing the average productivity per worker.

The success of mass production techniques, following the industrial revolution, can be seen to justify productivity as the source of wealth. It not only improved people's standard of living, by providing basic necessities of life at affordable prices, but in doing so it created fortunes for entrepreneurs and capitalists alike. By the twentieth century the success of productivity enhanced growth had changed the economic landscape. Farming had undergone two revolutions. The first had replaced farm labourers by industrial equipment, the second played god with nature by using chemicals to kill pests and enhance fertility. These changes have taken productivity and output levels, for some products, to levels where the possibility of market saturation is a reality and in saturated markets growth models can no longer rely just on supply side drivers.

Growth models based upon Keynesian economics

At the beginning of the twentieth century, macroeconomics, which looks at the economy as a whole, rather than the competitive process that set prices and output levels for different markets, was supported by three distinct theories. They were based upon the business cycle, growth theory and monetary theory. In the 1930's, John Maynard Keynes (Keynes 1936) sought to create an integrated theory, which embraced the economy as a whole, rather in the way that Newton had sought to describe the laws of physics. Keynes was not simply interested in what determined the levels of prices, but how other issues, like employment and output were interlinked. This approach was to supersede Adam Smith's views of how an economy functioned and instead of capital, land and labour, the new theory talked of employment, interest and money. The changes were not just in terminology, but included revolutionary concepts which broke conventional wisdom, like Say's law (total demand cannot exceed or fall below total supply), and reversed the savings investment causation. Keynes proposed a demand-determined equilibrium, which would determine aggregate output and as a consequence control employment. The theory laid out the features of a growth model, but they were not packaged as an explicit mathematical formulation. It was an omission that was rectified within a few years by others (Harrod 1939, Domar 1946) who extended Keynes work in this area.

The Harrod-Domar model linked: investment, savings, the rate of capital accumulation, aggregate demand and aggregate output to produce a 'warranted growth rate' (g) equal to the marginal propensity to save, divided by the 'capital to output' ratio. The model showed that economies operating under conditions where capital accumulation is equal to the rate of capacity growth, would grow at the 'warranted growth rate' and have full employment. This model offered governments the possibility of achieving full employment and a growing economy by applying controls over investment and savings. The problem was, that this happy equilibrium position occurred on a knife edge. If real growth exceeded 'g' then the model implied an excess capacity, which got progressively worse, with consequential increasing unemployment. Whilst if the real growth was less than 'g' shortages would exist, which would progressively get worse. So this model predicted that three types of economy were possible: (a) those with full employment and steady growth, (b) those in terminal decline with ever increasing unemployment and (c) those in continual growth with ever increasing shortages. Worse still, if a type 'a' real economy experiences some economic shock, which effected its real growth, it would be permanently displaced into category b or c. This difficulty with the model was overcome in the 1950's by the proposition of the propensity to save being a variable, (Kaldor, 1957) which would 'jump' to the necessary value to bring growth back to its warranted level.

The macroeconomic perspective of output growth looked fine from a government point of view of wealth creation, but in a capitalist society the question why owners of capital should invest was not explicitly aired. This was redressed, by proposing a stochastic link between output and profits (Robinson 1962), whereby investment decisions were a function of expected profit.

The neoclassical growth model

In the 1950's, the Kaldor solution, to the problem of a knife edge economy, which made the 'propensity to save' a variable was challenged (Solow 1956, 1957, Swan 1956) and an alternative solution was proposed. Both Solow and Swan claimed that it was the 'capital to output ratio' which should be variable. This was not the first time that this possibility was tabled, but the Solow –Swan proposal was notable in formulating a model in which, the pressures that exist in an out of equilibrium situation will have a tendency to move the system to the equilibrium state. The equilibrium state is associated with an investment rate, over time, (based on investment per unit of labour) which produces the 'warranted growth'.

Assuming that the marginal theory of distribution holds (so that capital and labour are in equilibrium and priced at their marginal products), the Solow-Swan model implies that a change in investment per unit of labour will put pressure on relative prices. This is because changes in investment per unit labour will alter the marginal products of capital and labour, and this is not allowed under steady state growth (Cassels 1918). To maintain the criteria of steady state growth the system must have a tendency to maintain investment per unit labour at a constant level.

The Solow –Swan model became known as the neo-classical model and held currency through out the latter half of the twentieth century. Put simply, the model has output growth dependant upon two factors: labour productivity growth and labour supply growth (Stiroh, 2002). Adam Smith had already revealed that growth could be achieved through an increased supply of labour; so the contribution of the Solow- Swan model, is its recognition that productivity is another major factor in achieving growth, which is the direct consequence of their initial assumption that the 'capital to output ratio' is a variable.

Appendix 2 Information Content in New Economy products: Digitalisation

The antecedents of the ideas in table 5 are not always made explicit, but a strong underlying theme concerns the nature of information and the way that it can be communicated. Information alone can be considered to be one of the most fundamental of 'virtual products'. Information as a product has existed for centuries (being traded by political spies and merchants for example), but a fundamental difference between the knowledge in the New Economy and older types of knowledge, is that New Economy knowledge is encoded and distributed as digital signals. Access to the benefits of the New Economy relies entirely upon the conversion of all information to and from digital formats, one of the most visible indicators of which is the now ubiquitous bar code. A further characteristic of the New Economy is the dominance of digital hardware in knowledge management, transmission and storage. Digital hardware is the enabling technology for information storage and transfer, and the relationship between: a virtual, information based, product and a tangible product, such as a computer or mobile phone, is highly symbiotic.

The symptoms of scientific and technological digitisation, within the New Economy, can be seen to have been widespread during the 1970's and 1980's, as demonstrated by products that used digital numbering as a basis for product identification. Memory products in particular were expressed as a decimal numbers, which were clearly derived from a digital (binary) root, see table 16.

Table 17 Binary and decimal equivalents

Powers of the Base Two	Binary Equivalents	Decimal Equivalents
2^0	1	1
2^1	10	2
2^2	100	4
2^3	1000	8
2^4	10000	16
2^5	100000	32
2^6	1000000	64
2^7	1000000	128
2^8	10000000	256
2^9	100000000	512
2^{10}	1000000000	1024

In the mid 1980's computer technology was making rapid advances in both processor power and data storage. In 1985 the Intel 386 processor was a 32 bit tasking machine, having taken over from earlier 8 and 16 bit systems. For the complimentary technology of data storage, the leading product was a memory device called the Seagate ST512 disc drive (512 indicated that it could store 512 kilobytes of binary information).

By 2001 Intel launched the Itanium, its first 64 bit processor, by which time there were a plethora of competing solid state memory products, with capacities measured in Megabytes or Gigabytes. Whilst the units of memory had increased by between one thousand and one million fold since the 1980's, the available products continued to follow a binary pattern; being available in quantities of : 4, 8,16,32,64, 128, 512…etc.. In the case of both data processors and data storage, the capacity to handle information had undergone some major technological advancements. Throughout the past fifty years, the trends in hardware technology have been towards: increased processing speed; smaller size, lower power consumption and larger memories, and they continue along these lines to this day.

It is clear that the digital computer and the terminology used to describe hardware technology and products, has contributed to the New Economy being viewed as "digital".

Digital computers

Without digital computers this research would not be a viable undertaking because, in a literal sense, the business modelling simulations take place within the computer. Furthermore, they occur in a way that exploits the special embedded properties which are characteristics of these machines. Digital computers are so dominant within the research, business and home environments that the fundamental mechanisms by which they operate are sometimes taken for granted, or even overlooked. These issues are so important to this work that they deserve to be articulated and explained.

To put the dominance of digital electronics and computing into context it is necessary to understand a little of the background. Today's market place for electronic products has it antecedents in the technology of vacuum tubes and electronic valves. These pioneering technologies were used to produce radios and televisions, for the general public, as well as more esoteric contraptions for academic and military purposes, such as computers. The first generation of computers that were built used valves as if they were electronically operated switches, which could be either switched on, or switched off, that is to say they had two states, which could be considered as either one's or zero's (i.e. the machines were digital and binary). However, this was not the normal mode in which these components were used, in fact valves were eminently suited for receiving inputs that varied in a continuous manner. Valves were capable of receiving inputs with a range of values and then simply amplifying them to create a larger output signals, so they were essentially analogue devices rather than digital. At that period of time, valves were not the only electrical components capable of amplification, transformers could also be used for this purpose, but they had some fundamentally different characteristics to valves (transformers could only amplify alternating current and they presented an inductive rather than resistive load).

When solid state technology, based upon semiconductor physics, was being developed, new electronic devices were conceived that would be able to provide both switching and amplification effects. They did so in a manner that was basically resistive, but had some characteristics similar to a transformer. The new component was thus named transistor as a hybrid of the words; *trans*former and res*istor*. At the very early stage of their development, two families of transistors emerged. One of them, the MOS FET (metal – oxide – semiconductor field effect transistor) was an almost perfect digital component. In effect it was like a perfect switch, in as far as it would either be in the on state, where a maximum current would flow, or it would be in the off state, where no current would flow. The second family of transistors was called bipolar transistors. When used in an operational circuit, bipolar transistors could never really be turned off, which made them unattractive for use as digital components; however, they were capable of being controlled so that variable amounts of current would flow (i.e. they could be held in any state, between being almost turned off, to being fully turned on). These two kinds of transistor were known as: *digital* (MOS-FET's) and *analogue* (bipolar).

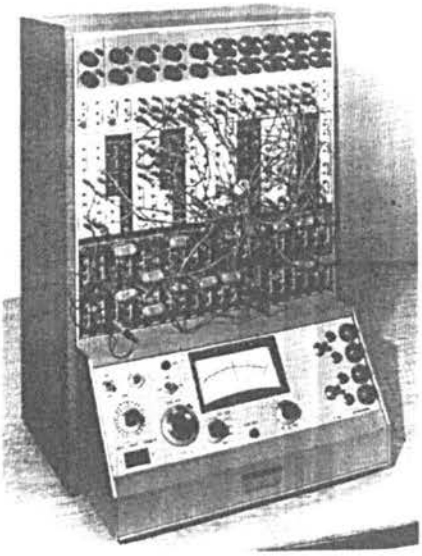
The new technology, represented by solid state, transistors, offered a way to create new kinds of computing machines, and in line with the digital and analogue components which had become available, the computing machines fell into families of analogue computers and digital computers. Some of the features that differentiated these families are shown in Table 17.

Table 17 Analogue versus digital computers

Characteristics of Analogue Computers	Characteristics of Digital Computers
• Inputs and outputs are typically variable voltages/currents, visualised on an oscilloscope. • Problems are solved holistically by building an electronic model that imitates the problems. • Setting up the problem can involve physically reconfiguring the machine and addition/removal of components , such as resistors, capacitors and operational amplifiers. • Very good at solving difficult problems which could be represented by differential equations • Not good at solving "simple" arithmetic problems involving addition, subtraction, multiplication and division, due to accuracy and reproducibility issues. • The computational method continuous changes to the state of the system which represent the problem.	• Inputs and outputs typically involve a keyboard and visual display monitor, which convert between digital strings and alpha numeric symbols. • Problems are converted into algorithms which are then solved sequentially. • Very good at adding, subtracting, multiplication and division (+-*/). • Can only solve complex problems (such as differential equations) when they have been dissociated into problems involving (+-*/). • The computational method involves algorithms, made up of many discrete stages, that solve the dissociated problem.

During the early exploitation of the two computing technologies, the analogue versions required direct electrical inputs and they produced graphical outputs on paper as well as cathode ray screens, but they did not produce text. In contrast, the preferred input devices for digital computers were based on keyboards, with output devices being tele-types (electronic type writers). For a number of reasons, the digital computer has shown itself to have been a fitter product that its analogue counterpart and today the digital computer is ubiquitous and all powerful. The consequence of this is that the blueprints for all products that are designed or stored on digital computers render down to a string of zeros and ones. In some cases (as with software) the product itself is the information represented by such a string of zero's and ones. The parallel, between the genetic code that instructs biological cells how to develop into a living entity and the binary code that represents a New Economy software product is evident.

Figure 22 Picture of an analogue computer



(Figure 22 is taken from: Welbourne, D. (1965) *Analogue Computing Methods*, Oxford, Pergamon Press, p. 21)

This research views the digital nature of the New Economy as being all embracing, it is not only embedded within the products, but governs the ways that firms behave. In a mathematical sense, one of the purest form of a digital representation is the binary code represented as zero's and one's (or black and white in the case of bar codes). The zero's may be used to represent the absence of some parameter and the one's its presence. When interpreted in this way, a digital environment becomes one where change occurs at discrete points in time as opposed to an analogue environment where continuous change is possible. The perspective taken here, is that all fundamental aspects of the New Economy are digital, in particular that the knowledge content of the economic environment is constant for a period of time and then increases instantaneously by a finite step. This approach has many consequences, three of which form elements of a proposed business model. Firstly, that the knowledge content of a product can always be expressed in terms of a binary (digital) code. This is directly analogous to the genetic code, found in living organisms. Secondly, that the knowledge content of a product determines both its complexity and fitness. Thirdly, that the most appropriate growth models for use in a digital environment are difference equations, rather than differential equations.

With the benefit of hindsight, it is clear that there was a transitionary phase to the New Economy that enabled digitalisation to take place. It was a period where technological innovation added new benefits to existing product lines, as well as offering completely new products, both of which provided an impetus for economic growth. During this transitionary period, neither the supply or demand side of the marketplace was motivated by a desire for digitalisation. It was a technological transition that led to products being made in a different way. The key change was the addition of solid-state electronics technology, to those of electro-mechanical and plasma based technologies. This change brought with it benefits of : increased reliability, miniaturisation, reduced power consumption and reduced costs through higher productivity. Some of the components, on offer from the new technology, happened to be digital.

To begin with, the choice of whether to make a product from analogue and digital technology was determined upon their suitability to replicate the original product. However, over a period of time the added benefits, which were unique to the digital paradigm, became a necessity for new products. This effect caused a further migration in product designs that increased the digital content of products enormously. Some examples of products which under went a transformation to digital technology are shown in table 18. It is important to recognise that the main benefits that arise when moving from an analogue semiconductor technology, to a digital one, are almost entirely due to the differences in the way that information is encoded.

Table 19 Product migration towards digital technology

Product	1st Generation Technology	Intermediate Technology	Current dominant (or leading edge) Technology
Camera (still)	Photo-chemical		Digital- semiconductor
Camera (movie)	Photo-chemical	Analogue-semiconductor	Digital- semiconductor
Telephone (static)	Electro-mechanical	Analogue-semiconductor	Digital- semiconductor
Telephone (mobile)	Plasma-mechanical	Analogue-semiconductor	Digital- semiconductor
Sound Recording Devices	Mechanical	Analogue-semiconductor	Digital- semiconductor
Radio	Plasma-mechanical	Analogue-semiconductor	Digital- semiconductor
Television	Plasma-mechanical	Analogue-semiconductor	Digital- semiconductor

Note: Plasma-mechanical refers to instruments using vacuum tubes and mechanical switching devices.

The picture that has been portrayed in this appendix is intended to emphasise a few basic features of the New Economy. Its products are knowledge rich; they can be described digitally, they operate digitally, and they evolve digitally (i.e. each new generation of a product type can be distinguished from each other, in an unambiguous way).

The benefits available to customers, from products that utilise digitally encoded information, has driven the growth of many products in recent years. So an associated issue, is whether the characteristics of the growth itself, are also best described digitally. If all aspects of the New Economy are taken as operating within a digital paradigm, then the approaches to modelling firms operating within it should also adopt this paradigm.

Appendix 3 Choice of Paradigm: Continuous or Discontinuous & Complexity Science

In chapter1, the choice of the paradigm underpinning the new models was stated to be of fundamental importance. The reason is that it determines which mathematics are most appropriate to use. It could be put simplistically as: to differentiate or not to differentiate, that is the question? The issue relates as to whether the system being modelled is considered to be one that changes slowly, in a continuous fashion, or whether it is capable of discontinuous change. The choice of mathematical framework to be used is made by the researcher, and it is very important. However, there is an underlying problem; it is that differential calculus has been so successful that its use has become almost ubiquitous, whether justified or not. It is not difficult to see why this is. From its conception in the 17th century calculus has been instrumental in uncovering many laws of nature. The orbits of the planets can be explained and described by using differential equations, as can the relationships between electricity and magnetism. As a mathematical tool, differential calculus has worked extremely well. For hundreds of years, calculus has uncovered solutions to problems in a positivist universe that was seen as operating unambiguously 'like clockwork'. Remarkably, differential calculus remained a powerful tool, even when the unambiguous scientific paradigm, of Newton, was replaced by the uncertainty and multiplicity of the relativistic nuclear age. Special and general relativity, quantum physics and wave mechanics all rely on, and can be expressed by, differential calculus. These very complicated aspects of nature have a high number of dimensions and it turns out that this allows calculus to produce solutions containing discontinuities, ambiguities and chaos.

The success of calculus, in finding solutions to difficult problems in physics, prompted its use in other positivist disciplines, like chemistry, engineering, biology, economics and others. Here too, calculus proved itself, by accurately describing chemical reactions, shearing forces in beams, cell propagation and macro-economic models, to name but a few. For three and a half centuries differential calculus has been the dominant tool in creating mathematical models of the world around us, yet when applied to explain the motion of pendulum made from two hinged sticks its solutions are to difficult to fathom. The reason is that calculus cannot offer chaotic solutions for systems with less than three dimensions. This limitation meant that "simple" and yet potentially chaotic phenomena remained unexplained, whilst "complicated" problems were being resolved. In some cases discontinuous systems were mathematically modelled in other ways, using Markov chains or difference equations. These models often produced solutions that, whilst mathematically valid, required massive amounts of computing power to produce specific explicit outcomes. So, during the three and a half centuries that differential calculus unravelled the mysteries of systems subject to continuous change there was no equivalent, universal, mathematical tool that could be applied to discontinuous systems. Instead, researchers took a piece meal approach. In some cases they relied upon descriptive models of their experiments and observations, as in the biological case of evolution being portrayed as survival of the fittest (Darwin, 1859). This tradition was modified a little when rules for genetics were being put forward (Mendel 1865 see Orel, 1996) where descriptions were combined with an early form of digital logic and statistics. More recently still, the genetic code was unravelled using physical representations of its chemical components in order to create a double helix structure (Watson & Crick, 1953).

Table 20 An illustration of a few discoveries made with differential calculus

Era	**Continuous Change**	**Discontinuous Change**
17^{th} century	**Laws of motion (Newton)**	
18^{th} century		
19^{th} century	**Laws of electricity and magnetism (Maxwell)**	
20^{th} century	**Macroeconomic models (Keynes, Solow-Swan)**	**Relativity (Einstein)** **Quantum physics (Bohr)**

Table 21 An illustration of a few important discoveries made without calculus

Era	Continuous Change	Discontinuous Change
17^{th} century		
18^{th} century	**Biological Evolution (Lamarck)**	**Biological Evolution (Darwin)**
19^{th} century		**Genetics (Mendel)**
20^{th} century		**DNA/genetic code (Crick & Watson)**

With the advent of cheap powerful computers, some of the non-differential techniques, which were previously tedious or impractical were resurrected. As a result, new insights have been obtained into previously unfathomable problems. Some of these problems involved situations that could lead to huge numbers of potential outcomes – as with NP complete problems – whilst others have non-linear terms that appear simple and yet confound simple analysis. Even difficult dissipative problems, that cannot be framed as being 'in equilibrium,' are beginning to yield to the might of these new calculating machines. It is proposed here that many of the characteristics of the New Economy place it within a low dimensional paradigm of discontinuous change and as such it should yield similar solutions to those mentioned here, a stance that is justified in the following section.

The next section , gives a brief introduction to complexity science and shows some of the reasons why it provides a suitable framework with which to study the New Economy.

Complexity science, a new paradigm for a new economy.

For over two millennia, ideas and information have been kneaded together, refined sorted and tested, until coherent strands of knowledge have developed. In some cases an underlying philosophical standpoint has linked some of the strands. Topics that have been grouped together as 'sciences' are one such example.

Sciences, as opposed to philosophy or mathematics, have experimentation at their core. A science is a synthesis of logical reasoning and practical experimentation. It is an endeavour aimed at describing what things are and then understanding how and why they do what they do. The general direction is towards uncovering fundamental issues, from which general laws can be created, which can give predictive insights into the future. The problem that presents itself when taking this approach to the biological world is its immense complexity; so much so, that most of the early effort went into codifying and describing flora and fauna rather than understanding how and why they did what they did. Arguably, more progress was made in the basic sciences of physics and chemistry, which deal with less complicated inanimate objects. Since the seventeenth century both physics and chemistry have made huge leaps forward in understanding the world around us. For physics in particular, the foundations were those laid down by Isaac Newton, which to this day dominate the way in which the physical aspects of nature are viewed. The Newtonian paradigm epitomises the deterministic viewpoint, whereby inanimate natural phenomenon could be understood as if they were parts of a great machine. Explanations of how things worked, came about through observation, analysis, experimentation and deductive reasoning. Laboratory experiments were developed, to demonstrate the laws of nature, in which observer and apparatus were, as far as possible, independent. These experiments were mostly set up with the goal of creating them as closed systems (i.e. ones that neither absorbed or released energy to the surrounding environment). For all of their limitations and simplifications, many of these stylised experiments were impressive in illustrating the laws of nature, and they essentially became perceived as the building blocks, from which inanimate reality was constructed. In spite of their success, the mathematical complexity of applying Newton's laws to many real world situations (like avalanches, or landslides or the weather) was so complicated as to defy analysis. These kinds of situations often appeared to exhibit a degree of unpredictability that made comparisons with clockwork machines incredulous. It seemed as if these inanimate situations resulted in apparently random or chaotic behaviour that was similar to that observed in bio-systems.

Newton's laws had immense success in being translated into practical, applied tools for many areas of life, including: astronomy, engineering, medicine, chemistry and many more. Their power was such that huge bodies of knowledge were built upon their foundations. However, the success of this deterministic approach in both analysing problems and creating new technologies for human advancement had another consequence; it attracted researchers away from investigating one class of real world, dissipative systems involving non-linear behaviours. It wasn't that people weren't interested in these phenomena; it was just that when real world problems were analysed, the solutions appeared too complicated and were often indeterminate. Some features of the classes of problems being referred to include:

- A large number of independent or interdependent entities.
- Interactions which have several possible outcomes, each of which may have specific probabilities attributed to them.
- Time delays between interactions.
- Feedback mechanisms , which can result in energy entering or being lost from the system, or changes of state (i.e. energy changing from potential to kinetic or visa versa)

These traits are rarely dealt with in traditional experimental systems, as is shown in Table 22.

Table 22 Some fundamental differences between ideal and real world (dissipative) systems

Idealised Experimental System	Real World Systems
1/ Closed (*conservative*) system, in which no energy or matter is absorbed or released. 2/ Descriptive, mathematical, equations that are independent of the direction of time. 3/ Equilibrium conditions can be achieved. 4/ Deterministic mechanisms prevail.	1/ Open (*dissipative*) system that can receive and emit energy and matter. 2/ Descriptive equations that are dependent on the direction of time (i.e. they do not give the same results if t is replaced by – t). 3/ Non-equilibrium conditions dominate. 4/ Stochastic mechanisms are routinely found. 5/ A large number of objects involved.

What is intriguing about many inanimate real world schemes is that they exhibit characteristics that are similar to those found in biological systems. Unfortunately, many of these problems appeared to be unfathomable, so they were often simply sidelined as being interesting, but too difficult to explore. The basic problem was that until the middle of the twentieth century, the tools to perform the vast amounts of arithmetic needed to expose the numerous solutions were unavailable. Even so, it would not be true to say that such problems were entirely ignored. Over the years there were many individual research efforts, in a variety of disciplines. These included: animal population dynamics (Verhulst, 1838) and convention currents in fluids (Gregorie and Prigogine, 1989). Individually, these pioneers made important contributions to understanding complex systems, but no critical mass of knowledge emerged to feed a broad based research community. This situation began to change, in the middle of the twentieth century, when modern computers arrived, which provided an enabling technology for solving these problems.

The advent of the modern computer was in some ways overdue, since it had been proposed in some detail by a number of theorists (Van Sindern 1980) ,but the technology to realise these ideas was unavailable when they were being originally aired. Arithmetic computing machines, on the other hand, have existed for a long time. They began as mechanical devices, which evolved into electromechanical ones and were primarily used to speed up laborious mathematical calculations that required a high degree of accuracy. However in the twentieth century, the way that computing machines were built was revolutionised with the use electronic components. The move, from being electro-mechanical machines to being electronic devices, allowed improvements in speed, reliability and memory. Whilst this change of technological hardware was important, the adoption of a binary algorithms methodology, to drive the computational logic, was possibly even more so. These new kinds of computers presented researchers with a new tool that was capable of exploring solutions to many of the difficult problems that had become marginalized. These included stochastic and 'NP complete' (Garey and Johnson, 1979) equations, as well as others that simply had a large number of variables. An important example of the way that an electronic, digital computer provided a new view of the world occurred in the 1960's, when the problem of weather forecasting was tackled using such a machine (Lorenz, 1963). Lorenz created a model that contained three coupled ordinary differential equations that represented a cell that is warmed from above and cooled from below. The model was translated into an algorithm which was run on the computer. The outputs from the program were unexpected. Lorenz's program produced complicated curves that formed patterns (like a bent figure eight), but they never repeated themselves; furthermore the patterns were extremely sensitive to their starting point (initial conditions).

During the era when Lorenz was investigating meteorology with an early modern computer, other new techniques began to be formulated that were to uncover the mysteries of formerly difficult 'complex' problems. Two pioneers of complexity science put it thus:

" Since the 1960's a revolution in both mathematical and physical sciences has imposed a new attitude in the description of nature. Parallel developments in the thermodynamic theory of irreversible phenomena, in the theory of dynamical systems, and in classical mechanics have converged to show in a compelling way,

that the gap between "simple" and "complex", between "disorder" and "order", is much narrower than previously thought" (Nicolis and Prigogene, 1989: p. 8).

The revolution that Nicolis and Prigogene (1989) alluded to, was enabled, to a large degree, by the increasingly available algorithmic computing power provided by digital computers. This was especially true for problems that contained probabilistic terms that could lead to huge numbers of potential solutions. Whilst many of the discoveries being made about complexity were based upon the natural sciences, the possibilities of using of this new knowledge was exciting people in a much wider range of disciplines, including economics and business management. The reason that economics and business were interested in the solutions to complex natural problems, was that when formulated mathematically they had a similar appearance to ones within their own discipline. Most modern economic theories are expressed in very sophisticated mathematics; differential calculus and complicated algebraic equations are commonplace. Also, economics deals with systems comprising of large numbers of free agents (people) interacting in ways that have a collective impact, which is difficult to predict. Sometimes historical analysis shows that major economic events have been triggered by the act of a single person, whilst at other times movements seem to emerge, on a broad front, as if out of nowhere. Economics had been treated as if it should be deterministic and yet the predictive ability of economists had been low when compared to scientists who study physics or chemistry. An increasingly popular view of economics is to see parallels between it and the natural world. From this perspective, it is not surprising that breakthroughs that have given insights into the complex processes of biology have stimulated the interest of economists. The cross pollination of ideas in this way has occurred in numerous locations. A leading centre of which is the Santa Fe Institute in New Mexico, where an eclectic group of intellectuals have been pushing at the boundaries of knowledge. Contributions from this group are extensive and many of their proposals draw upon the processes invoked by nature, which involve: feedback mechanisms, networks and stochastic trajectories.

Whilst economics was adopting some of the mathematical processes that complexity science was uncovering, a contemporaneous movement called systems theory was developing in the softer sciences of sociology (Buckley ,1967; Ackoff, 1974) and business management (Churchman, 1968; von Bertalanfy, 1968). Within these areas an holistic narrative was being presented to explain what, how and why things were the way they were. Although these approaches tended to offer words, rather than the formulae of hard mathematical logic, there were many underlying similarities to complexity science. A particular aspect of systems theory, which ties it to complexity science, is its rejection of understanding through decomposition; instead systems theory offers a way of perceiving problems by viewing them in the round, as gestalt images. One of the benefits of this technique is that it can provide a new understanding of complicated problems that were previously thought inaccessible.

Central features of both systems theory and complexity science are:

(a) The view of complexity as an emergent property, not something imposed upon a system (this is generally brought about through interactions, especially in the form of networks).

(b) Non-linearity: as a consequence of none equilibrium situations involving both positive and negative feedback.

(c) The relevance and importance, of the way that general principles cross man made boundaries.

At first sight the mathematical formulations of these complex problems seem to have an Achilles heel, in that specific solutions are often highly dependent on apparently minor details of the problem construction. In some cases the sensitivity is so great that an infinitesimal adjustment to the initial condition may give rise to dramatically different outcomes. This suggests that such formulations are only good for inductive rather than deductive research, but this does not have to be the case. In fact, whilst Lorenz's equation generated a trajectory that never reproduced itself, it did exhibit a property which offers the possibility of drawing deductive conclusions from these kinds of equations. What the Lorenz equation did, was to produce a trajectory that was predisposed to occupying one particular region of space. The exact pattern that it would map out was unclear, but whichever pattern was initiated seemed to be attracted around particular points in space. This phenomenon means that generalisation is possible, although precision may not be.

The Lorenz computer program is an early example of computer modelling. More specifically it is a simulation (which takes place in virtual reality) of phenomenon that are very difficult to model in any other way. The use of electronic computers to simulate complex situations has been as feature of many disciplines since the 1960's, when both analogue and digital computers were being used for this purpose.

Not all complex situations have been hijacked by the science of complexity, rather it has adopted a subset which conforms to a constructionist approach. The complexity referred to in the phrase 'the science of complexity' becomes evident when a system of many parts is governed by a few very simple rules (Kauffman, 1991) and/or where non-equilibrium situations exist (Kauffman, 1994). Good examples of where complexity is derived from simple rules can be found in the intricate patterns of fractals (Mandelbrot,1977, 1983). Fractals are patterns that arise, when simple mathematical equations embody the properties of self symmetry and scaling. In these patterns, new features are replicated in such a way that they are copies of the previous feature, and yet spatially relocated and rescaled. The result is that the patterns appear to look like objects found in nature. They may have dendritic features like trees or a crystalline aspect like a snowflake. Fractals appear to be immensely complicated and yet there are ways of describing them that are very simple.

The natural world appears to present examples of both continuous and discontinuous processes. A pendulum swinging, plants growing, day turning into night and night into day, rivers flowing to the sea, clouds moving across the sky, are examples of continuous changes. In contrast, a lightning strike or an avalanche in the Alps, reflect discontinuous change. Phenomenon exhibiting continuous change offers the possibility of being studied and analysed, to the point where either through inductive or deductive reasoning, future prediction is possible. Future predictions can be made about a swinging pendulum with such certainty that its exact position can be forecast for many seconds, minutes or hours ahead, depending upon the precise apparatus. Similarly, inductive reasoning tells us that the sun will rise tomorrow in the East. Not so however, for clouds travelling across the sky, or more generally the weather. Amazingly, it seems as if there are some situations where it is difficult to know what process applies. During the early part of the twentieth century physicists were struggling to grapple with this general issue. It manifested itself most clearly in the clash between classical theory, that allows for continuous change, and nuclear theory, that involves discrete packets or quanta. Put simply, a fundamental question can be stated thus: does a photon of light behave like a discrete particle or like an electromagnetic wave? The answer turned out to be both. One of the great intellects of the period, Neils Bohr (1949), brought a further insight into this apparent paradox, when thinking through the epistemological issues surrounding his subject of quantum mechanics.

Bohr realised that size matters, in both time and space, and that the analytical tools appropriate to one situation may become blunt instruments in another. An apparently straight edge, when magnified, becomes jagged and irregular; continuous change, when magnified, becomes periods of inactivity punctuated by step changes. The appropriate tools are subjective and depend upon the stimulus and the resulting effect. At some point one approach becomes inefficient and/or inappropriate when compared to an alternative. This issue is relevant when choosing the mathematical framework to be used when analysing problems. Almost by default, problems are expressed as differential equations because of the enormous success that they have had in the past. However, differential calculus is based upon infinitesimal changes in one parameter being associated with similar infinitesimal changes in another, and it works best when such changes are of a similar order of magnitude. Differential calculus just does not work well where systems change in a digital manner (i.e. very little happens, then a massive change occurs, then very little happens, then a massive change occurs, etc.). As with many topics the actual boundaries between one school of thought and another are often difficult area to investigate, but they do occur, as in the transition from classical to quantum physics (Stehle, 1994).

The issue of scaling remains topical to this day and is reflected in the units of measurement that are used in different topics. Quantum theory states that particles have characteristic wavelengths equal to Planck's constant (h) divided by its momentum (p); and where the particle is smaller than this wavelength it requires description using quantum physics. In superstring theory $h/2\pi$ gives rise to 'natural' units that are infinitesimally small and yet even here behaviours and description rely upon knowing whether objects are relatively small or relatively large.

Digital systems appear quite different to those which exhibit continual change. When moving through digital space, discontinuities are commonplace. When moving through digital time, the status quo is punctuated by instantaneous events, which precipitate a new status quo. The relevance of these comparisons is that many of the low dimensional real world phenomenon, which appear so difficult to analyse, are rich with discontinuities separated by stasis. The real world environment is further complicated, by the fact that the magnitude and direction of the discontinuous changes can be influenced by prior events. Whilst this picture appears complex, it has a structure, which can actually be modelled in a straightforward way when alternatives to differential calculus are considered. One method is to use a mathematical construction called a Markov chain (Howard, 1971)

A Markov chain is a series of outcomes from a repeated process (calculation), in which each outcome is stochastically influenced by its immediate predecessor.

Furthermore, each outcome contains sufficient information to describe the state of the system at the time of the calculation, but not enough , on its own, to describe previous situations. A simple example would be snapshots of a game of chess, taken immediately after each move. A chess game is a complicated example, since a high level process is enacted between each move, but there are many simpler processes, which could be the basis of fractal patterns, for example. A simple fractal could be based upon a repeated process such as: draw a cross and at each tip draw another similar cross, which is half the size of the previous one. The result is like a four pointed, 'square snowflake'. This example happens to have no unpredictable or surprising features, but, as with all fractals, it contains a non-linear instruction, which is to keep halving the previous term. The repeated operation of scaling in fractals has the effect of creating power relationships, which are non-linear.

Although the example of the square snowflake contains no surprises, the issue of non-linearity is a crucial one. When non-linear terms are incorporated into a process, which has both positive and negative feedback, they can provide a major source of uncertainty. The combination of non-linearity with both positive and negative feedback gives rise to the kinds of amplifying effects, that can translate the movement of one grain of sand into an avalanche (Kauffman, 1996), or the flap of a butterflies wings into a hurricane (Gleick ,1987). It is a combination which is relatively straightforward to model, but adds infinitely to the richness of outcomes which are possible from apparently simple processes. The difficulty with such models is that they are not as obliging as the square snowflake in converging to a stable solution. However, what has been discovered is that there are very many instances where problems that are unstable and which have many possible outcomes, nevertheless exhibit recognisable patterns. The remarkable thing is that even problems involving random or stochastic terms can produce solutions with attractors that cluster around a particular point, or number of points

The major breakthrough that complexity science has achieved is the ability to tackle problems that exhibit discontinuities and/or have multiple outcomes that are NP complete. In the same way that quantum theory gave scientists a new way of looking at problems that were previously unexplainable, complexity science has allowed researchers in a broad range of disciplines to view their difficult problems in a similar way. Within this paradigm, conditions of: continuous change, equilibrium, reversibility and certainty are not the norm; instead it is normal to find punctuated equilibrium, irreversibility, dissipative systems and stochastic processes. The new economy is routinely termed the digital economy and there is much evidence that this trait is systemic. The digital nature of the New Economy ranges from the virtual packages of knowledge that create software applications, through to hardware products such as computers and phones and into the behaviour of consumers and firms. With these issues in mind, the lessons learnt from complexity science seem very appropriate to use with the new economy.

Appendix 4

Microsoft Corporation

Yearly Income Statements

in millions USD, except EPS	FY85	FY86	FY87	FY88	FY89	FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	FY98	FY99	FY00	FY01	FY02	FY03
Revenue	140	198	346	591	805	1186	1847	2777	3786	4714	6075	9050	11936	15262	19747	22956	25296	28365	32187
Operating expenses:																			
Cost of revenue	30	41	78	158	220	273	410	581	785	1077	1346	2145	2170	2460	2814	3002	3455	5699	6059
Research and development	17	21	38	70	110	181	235	352	470	610	860	1326	1863	2601	2970	3772	4379	6299	6595
Acquired in-process tech'														296	0	0	0	0	0
Sales and marketing	43	57	81	152	205	300	490	758	1086	1135	1564	2185	2411	2887	3238	4126	4885	6252	7562
General and administrative	9	18	22	24	28	39	62	90	119	166	267	316	362	433	715	1050	857	1843	2426
Other expenses	0	0	14	14	10	14	16	11	7	16	16	19	259	0	0	0	0	0	0
Total operating expenses	99	137	233	418	573	807	1213	1792	2467	3004	4053	5991	7065	8677	9737	11950	13576	20093	22642
Operating income	41	61	113	173	232	379	634	985	1319	1710	2022	3059	4871	6585	10010	11006	11720	8272	9545
Losses on equity investees/other														-207	-70	-57	-159	-92	-68
Investment income	2	5	8	11	19	31	37	56	82	102	191	320	443	739	1951	3326	-36	-305	1577
Noncontinuing items	0	0	0	0	0	0	0	0	0	-90	-46	0	0	0	0	0	0	0	0
Income before income taxes	43	66	121	184	251	410	671	1041	1401	1722	2167	3379	5314	7117	11891	14275	11525	7875	11054
Provision for income taxes	19	27	49	60	80	131	208	333	448	576	714	1184	1860	2627	4106	4854	3804	2520	3523
Net income before acc' change	24	39	72	124	171	279	463	708	953	1146	1453	2195	3454	4490	7785	9421	7721	5355	7531
Cummulative effect of acc' change																	-375		
Net Income	24	39	72	124	171	279	463	708	953	1146	1453	2195	3454	4490	7785	9421	7346	5355	7531
Preferred stock dividends	0	0	0	0	0	0	0	0	0	0	0	0	-15	-28	-28	-13	0	0	0
Net income 4common shareholder	24	39	72	124	171	279	463	708	953	1146	1453	2195	3439	4462	7757	9408	7346	5355	7531
Basic EPS before acc' change		0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
Diluted EPS before acc' change	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1
Basic earnings per share		0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
Diluted earnings per share	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1

FY 85 through FY 01 Not restated for adoption of SFAS 123

ASCII-1963

	0	1	2	3	4	5	6	7	10	11	12	13	14	15	16	17
000	NUL	SOM	EOA	EOM	EOT	WRU	RU	BEL	FEO	HT	LF	VT	FF	CR	SO	SI
020	DC0	DC1	DC2	DC3	DC4	ERR	SYN	LEM	S0	S1	S2	S3	S4	S5	S6	S7
040		!	"	#	$	%	&	'	(	)	*	+	,	-	.	/
060	0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
100	@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
120	P	Q	R	S	T	U	V	W	X	Y	Z	[	\	]	↑	←
140																
160													ACK		ESC	DEL

The first standardized version of ASCII is shown here. It became a standard in 1963 by the ASA (American Standards Association) as it was called at that time. The last two rows were not yet decided on, but the last unfilled position (between **ACK** and **ESC**) was reserved for an additional control symbol.

The above was taken from:
http://homepages.cwi.nl/~dik/english/codes/stand.html

Appendix 6: An Empirical Analyses to Validate the Main Constructs of the Product Fitness and Market Value Landscapes

In chapter 3, a model of biological diversity and evolution through natural selection (the NK model), was mapped into the economic situation of software products in the New Economy. Some fundamental assertions are implied in the creation of this model that need to be validated, in order to legitimise their use as foundations of a practical, high level business simulation tool. The two main issues are considered to be the linkages between:

(a) Product complexity and product fitness
(b) Product fitness and market value.

Since the relationship between product fitness an market value is posited as one of linear scaling, the above two linkages boil down to that of product complexity and market value. This chapter describes an empirical investigation to look for evidence to support this relationship. Two firms have been looked at, both of which might be considered as exemplars of the New Economy, although one is a software company (Microsoft) and the other hardware (Intel).

Microsoft

The Microsoft Corporation supports a sophisticated web site (www.microsoft.com) that provides a great deal of information to the general public. The web site includes a significant amount of financial data as well as information on products and technology The ideal data base that was being sought, would show revenue by product, together with lines of code (LOC) by product. Unfortunately LOC data was not available on the web site as required and so information relating to sales income, products and lines of code were gathered separately.

Microsoft Revenue Streams

Within the Microsoft web site is a section entitled Corporate Information. This contains a large amount of information, including downloads of the last eight annual reports, as well as spread sheets of summarised information. A spreadsheet called "fiscal financial history 1985 – 2003" was downloaded as an Excel file and used as the source of financial data for the period 1985 to 2003. A copy of the spread sheet is shown in appendix 5. This spread sheet is the source of the sales revenue for Microsoft.

The time period over which the sales data spans is sufficiently large to be considered a longitudinal study which raises the issue of the changing value of money. The decision was made to present sales values in terms of value in the year 2003. This indexation exercise was performed by using the US government indexation figures. The US government indexation data was obtained from the official US government web site. The indexation figures are shown in table 23.

Table 23 Indexation figures for the USA

Year	Indexation multiplier, to achieve equivalent 2003 value
1985	1.7072
1986	1.6761
1987	1.6171
1988	1.5528
1989	1.4815
1990	1.4055
1991	1.3488
1992	1.3093
1993	1.2713
1994	1.2395
1995	1.2054
1996	1.1708
1997	1.1445
1998	1.127
1999	1.1026
2000	1.0668
2001	1.0373
2002	1.0211
2003	1.0000

Table 24 Microsoft revenues values (actual)

Year	Revenues $M (Actual)	Year	Revenues $M (Actual)
1985	140	1995	6075
1986	198	1996	9950
1987	346	1997	11936
1988	591	1998	15262
1989	805	1999	19747
1990	1186	2000	22956
1991	1847	2001	25296
1992	2777	2002	28365
1993	3786	2003	32187
1994	4714		

Complexity of Microsoft Products as Defined by the Number of Lines of Code (LOC)

In the context of the assertions being made in this thesis, obtaining the data that represents the number of lines of code making up a particular product has been difficult. Three problems were encountered: (a) there are multiple sources of the information, (b) consistent data is not readily accessible from the manufacturer and (c) the hypotheses in this thesis are based upon the lines of *unique code* in a product, whilst in reality, products contain redundancy through duplication (this issue is one reason for point (a)).

A decision was made to include all relevant product data relating to lines of code and to consider variations and anomalies as errors. The comment made in the first paragraph, (a), would suggest that the number of lines of code are likely to be overstated, but investigating this issue is a task that is outside the scope of this work.

Table 25 Lines of code in Microsoft products

Year	Lines of code 000's (min – max)	Year	Lines of code 000's (min – max)
1985	24	1995	11000-15000
1986	36	1996	8000-12000
1987	36	1997	8000
1988	36	1998	18000
1989	36	1999	18000
1990	36	2000	35000
1991	36	2001	40000
1992	36	2002	40000
1993	5000 -8000	2003	50000
1994	5000 -8000		

The data shown in Table 25, relating to lines of code, was obtained through a series of internet searches and derives from a several locations. This data has no academic accreditation but, prima facie, it appeared to be credible.

Analysis of Microsoft data

The sales revenue data shown in table 24 and the data relating to lines of code, in Table 25 are combined in Table 26 and presented as a scatter plot in Figures 25, 26 and 27. Results obtained from applying a statistical software package (SPSS) on the data are shown Figures 22,23 and 24.

Table 26 Combined Microsoft data table (revenues shown have been indexed to 2003 values)

Microsoft Data:
Lines of code &
Revenues
(Indexed to 2003)

Year	2003 Index	Technology/ Product	min code (k)	max code(k)	Total ($M)	Yr1 rev ($M)	Yr2 rev ($M)	Yr3 rev ($M)	Yr4 rev ($M)
1985	1.7072		24		239				239
1986	1.6761	Windows (MS DOS 3)	36		332	332	560	918	1193
1987	1.6171		36		560				
1988	1.5528		36		918				
1989	1.4815		36		1193				
1990	1.4055	Windows 3	36		1667	1667	2491	3636	
1991	1.3488		36		2491				
1992	1.3093		36		3636				
1993	1.2713	Windows NT	5000	8000	4813	4813	5843		
1994	1.2395		5000		5843				
1995	1.2054	Windows 95	11000	15000	7323	7323			
1996	1.1708	Windows NT	8000	12000	11649	11649	13661		
1997	1.1445		8000		13661				
1998	1.127	Windows 98	18000		17200	17200	21773		
1999	1.1026		18000		21773				
2000	1.0668	Windows Me/2000	35000		24489	24489			
2001	1.0373	Windows XP	40000		26240	26240			
2002	1.0211		40000		28964	28964			
2003	1.0000	windows 2003	50000		32187	32187			

Figure 19 Microsoft Corporation sales revenue (indexed to 2003 values) and Product Complexity by Year

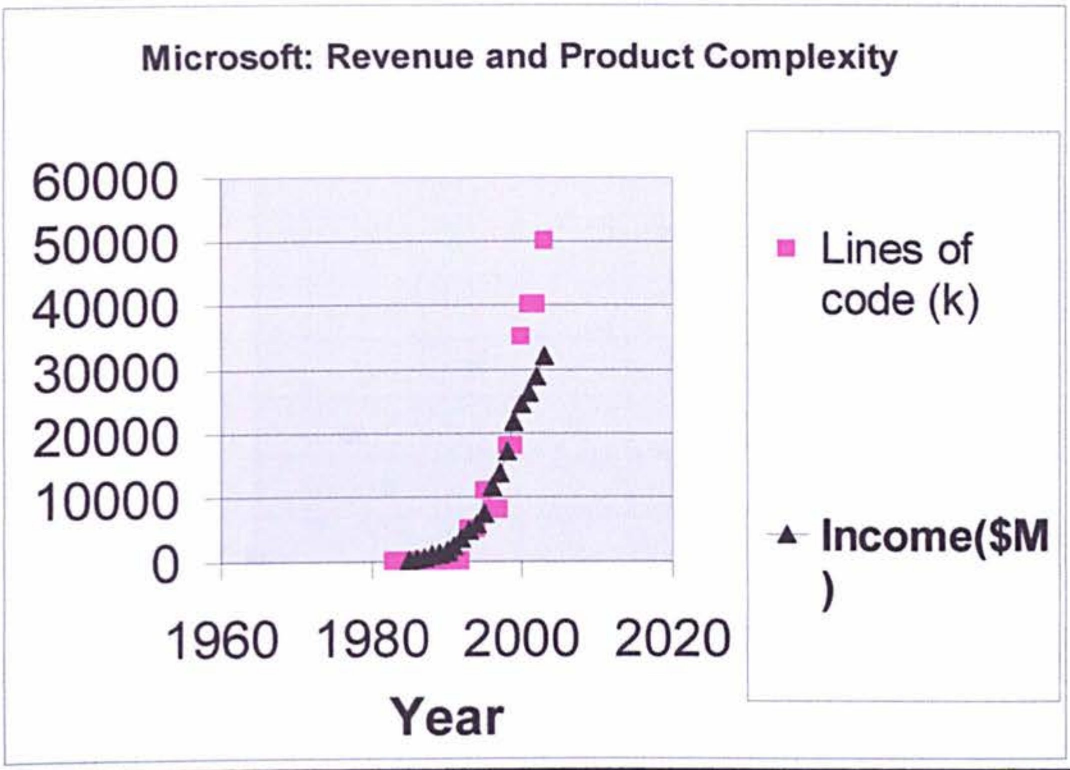


Figure 20 Microsoft sales revenue (indexed to 2003 values) versus Lines of Code

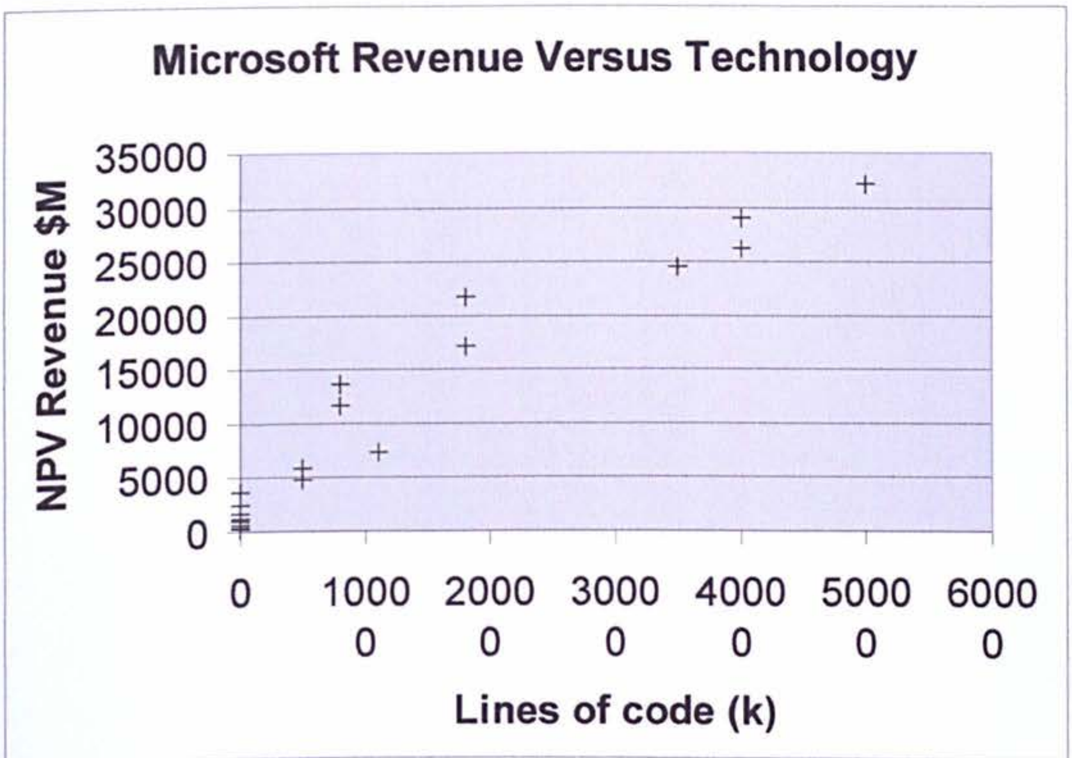


Figure 21 Microsoft Sales revenues during the first and second year after launch (indexed against 2003 values)

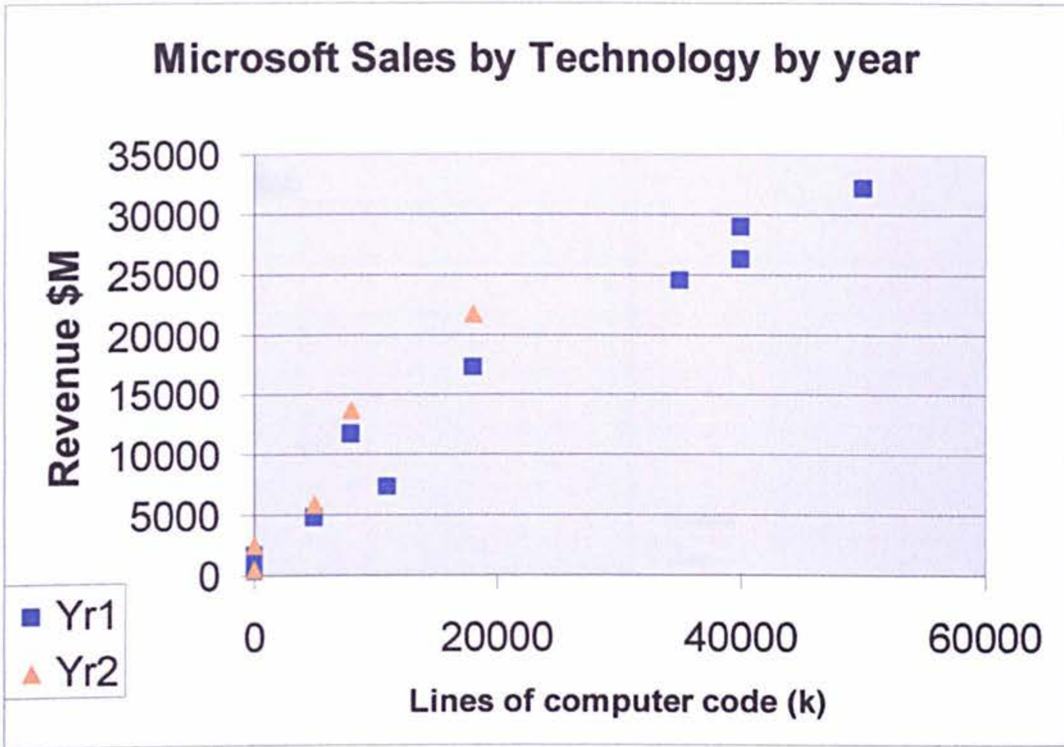
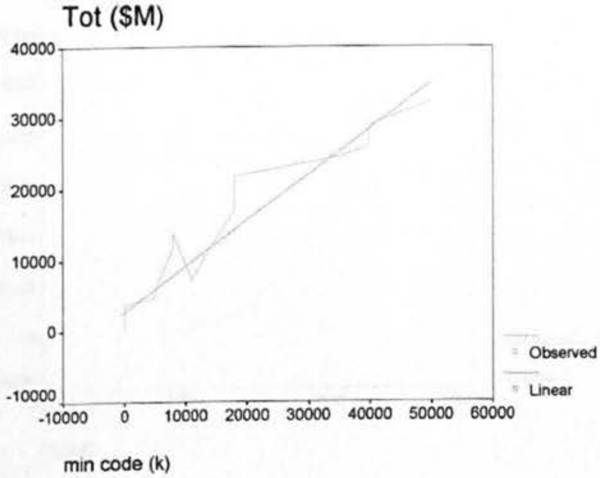


Figure 22

```
Independent:  MIN_CODE

Dependent Mth   Rsq  d.f.       F  Sigf      b0      b1

 V6       LIN  .928    17  218.42  .000 2736.46   .6429
```



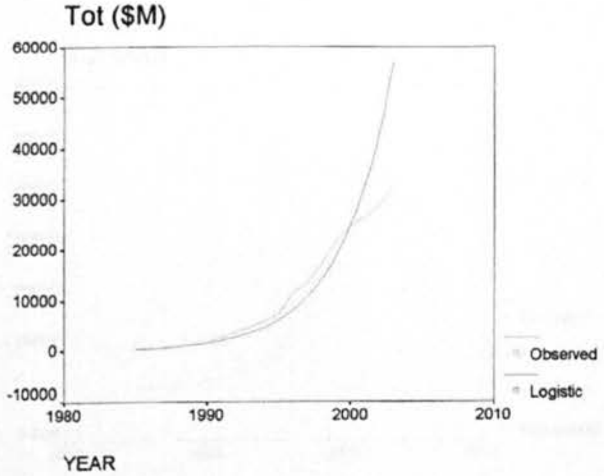
Microsoft SPS scatter plot
X axis – lines of code
Y axis - revenues

Figure 23

```
Independent:  YEAR

                                                  Upper
Dependent Mth    Rsq  d.f.        F  Sigf  bound        b0       b1

V6       LGS  .966    17  488.94  .000    .    5.3+236   .7576
```



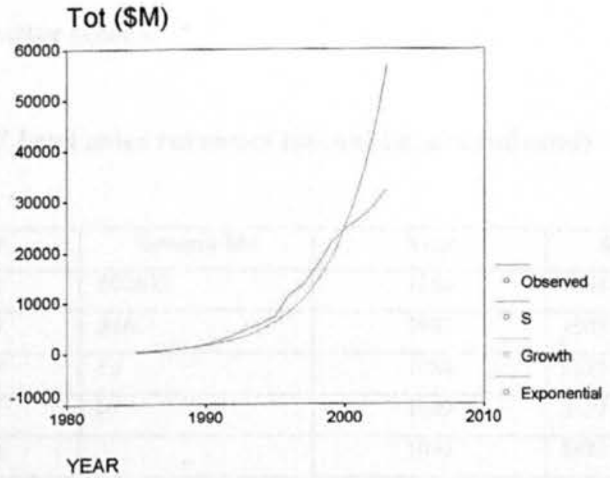
Page 2

Microsoft SPS analysis
X axis -year
Y axis - revenues

Figure 24

Independent: YEAR

Dependent	Mth	Rsq	d.f.	F	Sigf	b0	b1
V6	S	.967	17	502.13	.000	562.219	-1.E+06
V6	GRO	.966	17	488.94	.000	-545.08	.2776
V6	EXP	.966	17	488.94	.000	1.9-237	.2776



Microsoft SPS analysis
X axis – year
Y axis - revenue

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Intel

Intel Revenue Streams

As with Microsoft, the Intel Corporation supports an extensive and sophisticated web site. The Intel website [88] was the source of data relating to sales revenues and transistor counts.

Table 27 Intel sales revenues (actual i.e. not indexed)

Year	Revenue $M	Year	Revenue $M
1968	.002672	1986	1265
1969	.566	1987	1907
1970	4.5	1988	2875
1971	10	1989	3127
1972		1990	3921
1973		1991	4779
1974	135	1992	5844
1975	137	1993	8782
1976	226	1994	11521
1977	283	1995	16202
1978	399	1996	20847
1979	661	1997	25070
1980	855	1998	26273
1981	789	1999	29389
1982	900	2000	33726
1983	1122	2001	26539
1984	1629	2002	26800
1985	1365		

Complexity of Intel Products as Defined by the Number of Transistors

Table 27 is the consequence of huge amounts of investment, in R&D and manufacturing technology. Whilst the particular attribute being looked at is simply stated in terms of the number of transistors in a product, it does not reflect the huge technological improvements that were necessary to realise this result. To achieve this increase in transistors the technology has moved from

[88] Data Accessed on 15/07/05 [Available from www.intel.com]

printing lines that were a few microns across to ones that are less than 0.1 of a micron, at the same time productivity has improved by increasing silicon wafer sizes from 12mm in diameter to 300 mm in diameter. The increase in the numbers of transistors in an Intel product can be equated to a productivity improvement. At the same time, the product itself has improved in terms of its utility, in having lower power consumption, greater reliability, and faster processing speeds.

Table 28 The number of transistors in Intel products

Year	Number of transistors in the leading product (000's)	Year	Number of transistors in the leading product (000's)
1971	2.2	1987	275
1972	2.5	1988	275
1973	2.5	1989	1180
1974	5	1990	1180
1975	5	1991	1180
1976	5	1992	1180
1977	5	1993	3100
1978	29	1994	3100
1979	29	1995	3100
1980	29	1996	3100
1981	29	1997	7500
1982	120	1998	7500
1983	120	1999	24000
1984	120	2000	42000
1985	275	2001	42000
1986	275	2002	42000

Analysis of Intel data

Table 29 Combined Intel data with a year 1,2,3 analysis (revenues indexed to 2003 values)

Number of transistors in product	Sales $ M Indexed to 2003 values Total	Sales $ M Indexed to 2003 values yr1	Sales $ M Indexed to 2003 values yr2	Sales $ M Indexed to 2003 values yr3	Sales $ M Indexed to 2003 values yr4	Averages Indexed to 2003 values
1	24.1	24.15				
2.2	45.36					
2.5						
5	2558.35	503.037	467.7865	729.641	857.89	639.59
29	6297.34	1124.1825	1672.5283	1906.137	1594.49	1574.33
120	6662.73	1713.24	2069.4168	2880.072		2220.91
275	11998.7042	2330.328	2120.2665	3083.8097	4464.3	2999.68
1180	24241.0804	4632.6505	5510.9655	6445.9152	7651.55	6060.27
3100	69382.3945	11164.5566	14280.2795	19529.8908	24407.67	17345.60
7500	58302.286	28692.615	29609.671			29151.14
24000	32404.3114	32404.3114				32404.31
42000	63507.8015	35978.8968	27528.9047	27365		30290.93

Figure 25 Intel scatter plot

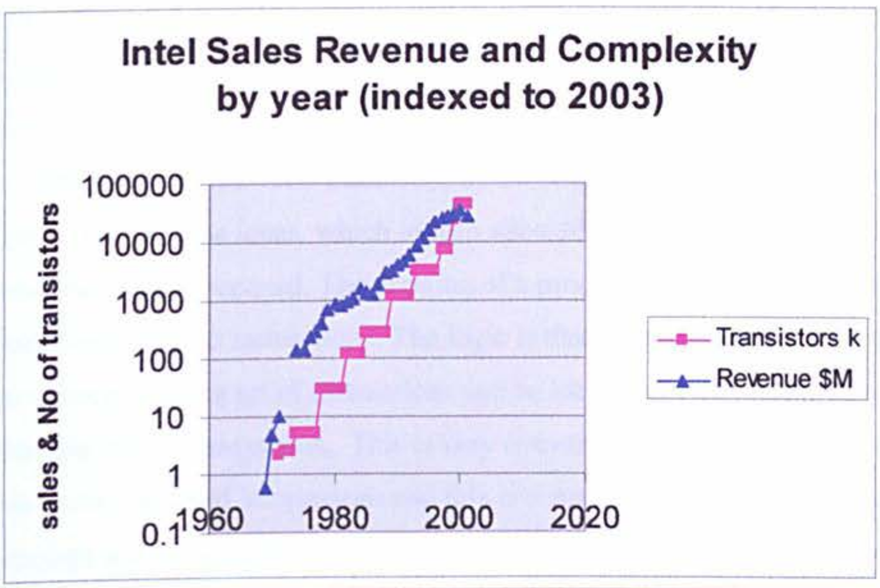
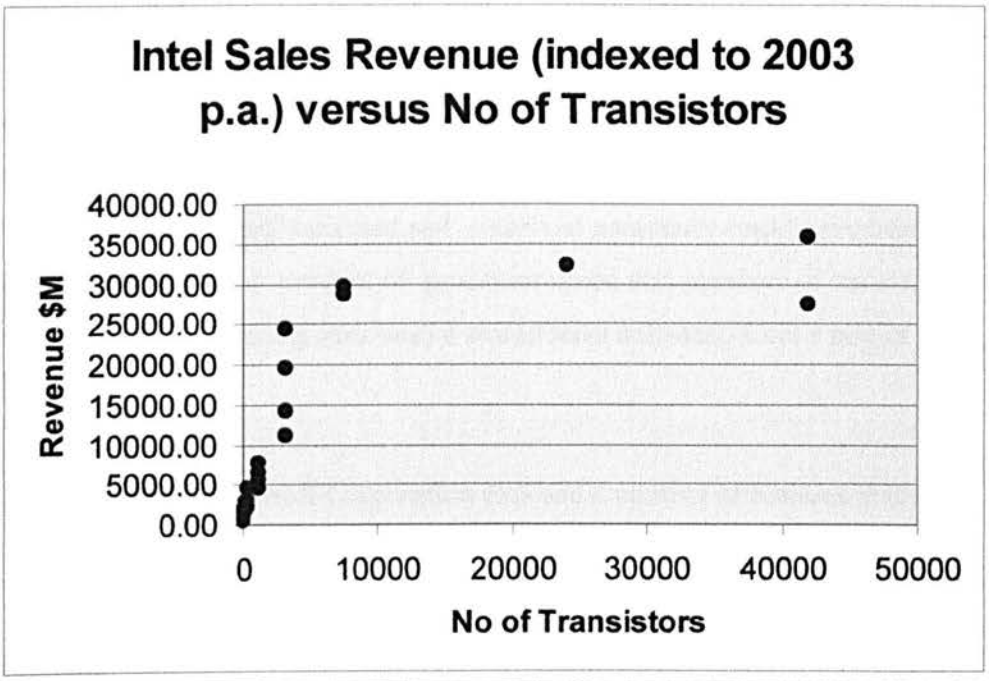


Figure 26 Intel scatter plot



Products and Complexity

One of the key concepts of the models being developed here is that of complexity. In this context complexity is seen as an emergent property that arises through simple interactions between discrete components. This idea was applied to products from the New Economy, by thinking of them as the realisation of a great many simple ideas, which in turn allowed a 'product fitness' landscape construct to be proposed. The creation of a product fitness landscape required a leap from ideas to instructions. The logic is that to realise an idea it is necessary to convert it into a set of instructions and so ideas and instructions may be thought of as synonymous. This is very convenient, since the essence of all software is a set of instructions and this is a strong link between the theoretical concept and its actuality. Instructions are written in code (computer code) and the number of lines of code is a rational measure of the number of instructions. Fortunately, the availability of data relating to the number of lines of code in Microsoft products is high.

For Intel, the complexity of its products has been defined in terms of the numbers of transistors contained within each microprocessor. This measure is relatively crude, as it does not take into account of other important functional parameters such as speed and power consumption. It has the advantage of being a basic digital parameter that is in some respects equivalent to the LOC measure used for Microsoft. A more sophisticated and contrived parameter could have been proposed; such as the product of processor speed and numbers of transistors and since both are improving over time it would have enhanced Intel's rate of performance.

The analysis of Microsoft Corporation exposed a number of features that are congruent with the theoretical concepts of a *product fitness* landscape and its extension, a *market value* landscape. The strongest support for both of these landscapes comes from the fact that the complexity and value of Microsoft products have tracked each other, as shown in Figures 22, 23 and 24.

The story for Intel is slightly different to Microsoft. Whilst Microsoft has seen revenues increase continually as its products become more complex, the revenue per transistor for Intel has begun to decrease in spite of the complexity of its products continuing to increase. The reasons behind this are not evident from the data here, but it can be speculated that the increasing investment in manufacturing equipment costs for Intel's tangible (as opposed to virtual) products may be outstripping their benefits .

Growth

The revenue growth of Microsoft Corporation has been impressive. For almost twenty years it has achieved year on year growth in sales that appears to be exponential in nature. If the theory proposed in this thesis is correct and the market expands in line with product complexity, then as long as Microsoft continue to increase the complexity of their products they will continue to enjoy exponentially increasing sales revenues. On the other hand if they stagnate or are constrained by other forces (such as anti-trust actions or politically imposed restraints) then they may hit a limit to their growth. Whatever the future holds, the statistical analysis shows that both exponential and logistic curves fit the data equally well, as shown in figures 23 and 24.

The statistical analysis that shows a logistic curve is a good fit to the Microsoft data is necessary, but not sufficient, evidence that Microsoft is following a logistic growth process. More data is required.

Profitability Decay: An analysis of some Empirical data

Theoretical aspects of economic and other kinds of growth have already been outlined, but they have not touched on the issue of what drives successful firms to produce new products, or to diversify into new markets. This section presents evidence of a phenomenon that can stimulate such actions; it is that of decaying profitability. The evidence presented here shows that as firms grow their profitability (profit as a percentage of sales) decays. The consequence of decaying profitability is that returns become more risky. At some point, a combination of high risk and low returns can provide the motivation for exploring new possibilities of making money. In simulation 2 (chapter 6), profitability is used as a parameter that determines whether a firm will continue to exploit a particular product, or move onto a new part of the product landscape and begin exploiting some new product.

This following analysis relates to an historic epidemiological study of data that is in the public domain, in order to investigate profitability on a microeconomic scale.

Population and Sample

Several million companies make up the UK economy (Curran, 1999) and there may be hundreds of millions of companies to choose from on a world wide basis. This global population of firms, range from those with just a few employees to ones with over a million employees. With such a large range, there was some unease about the practicalities of selecting a sample to study. The concerns were about two issues. First, if a random sample was proposed, how would it be possible to achieve it? Second, would accounting information be easily accessible from smaller foreign firms, which would inevitably make up a large portion of a random sample? On a practical basis, an alternative to random sampling was considered, based upon a rule that was easy to achieve. The rule was that if the firm was in the top 500 largest firms in the world, based upon revenues, then it would be included in the study, it was not in the top 500 then it would not be. This study has adopted this rule and the data is taken from the 500 largest (by sales revenue) firms in the world.

The data set, an analysis and the results

Initially, a longitudinal analysis of each firm in the specified sample was undertaken, for the years 1991, 1996 and 2001. The data was taken from that collated by Fortune magazine, a source that has provided information for business growth models in the past (Simon and Ijiri, 1967). The tabulated data for this study was published as the 'Global 500'. The profitability (profit as a percentage of sales) of these firms is shown graphically in Figures 27,28 and 29.

Figure 27

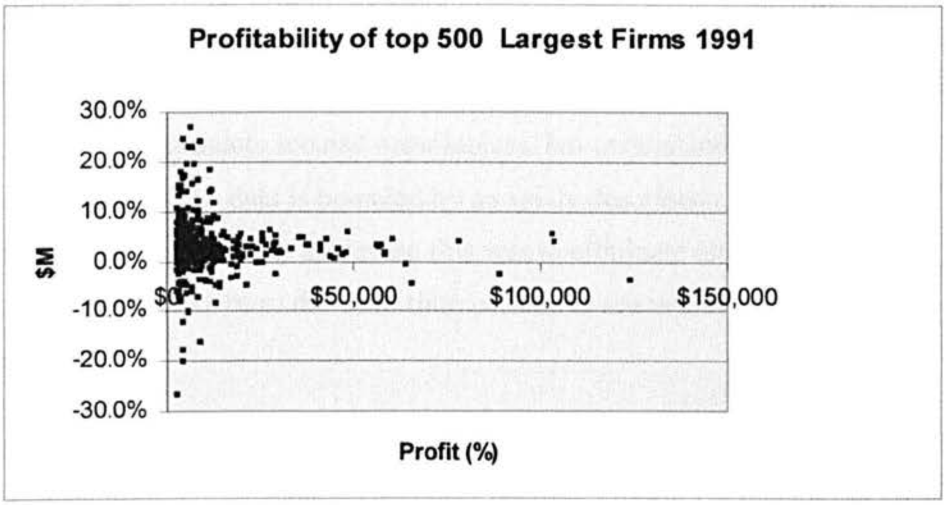


Figure 28

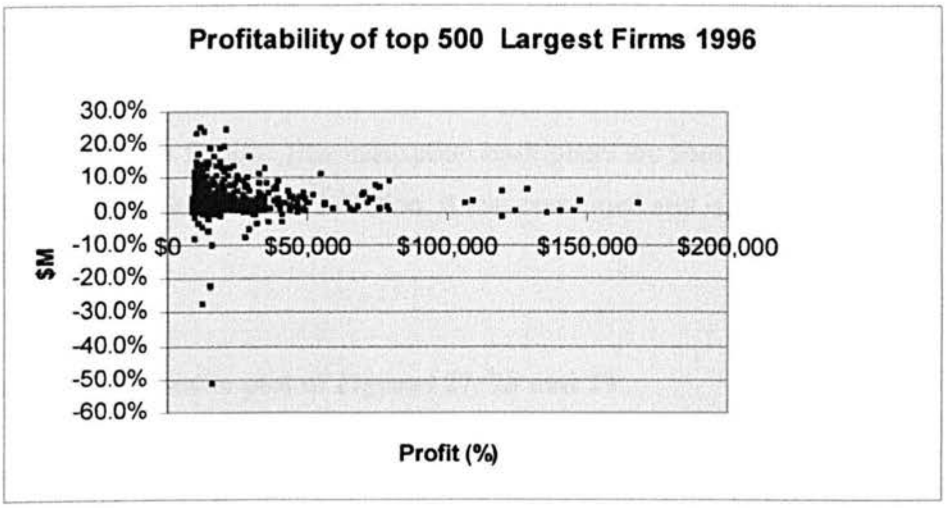
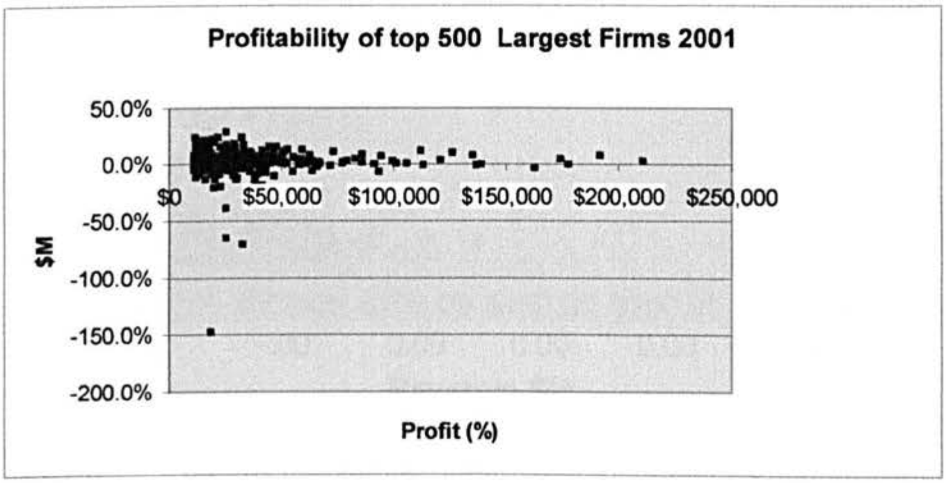


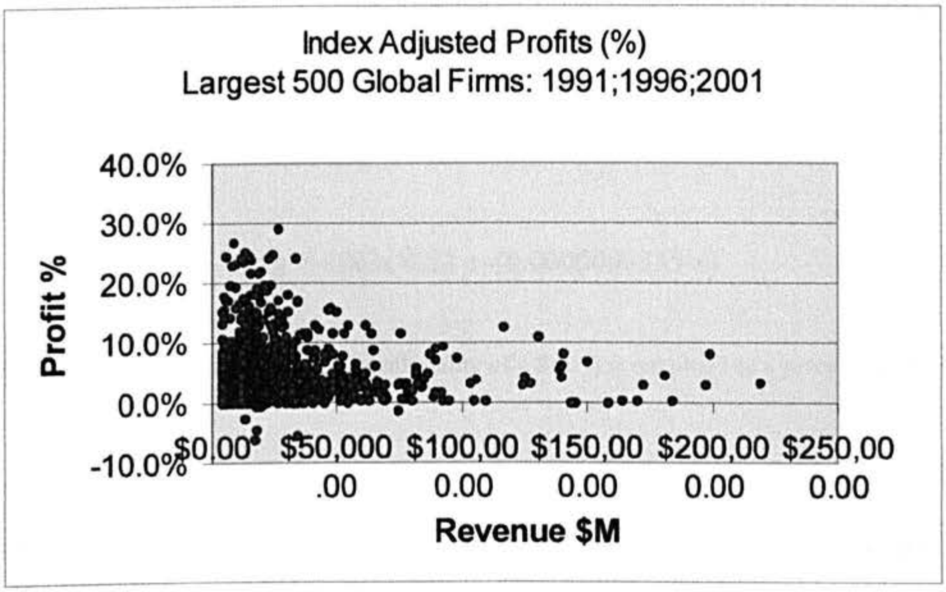
Figure 29



The patterns shown in Figures 27, 28 and 29 suggest that there is a tendency for profitability to decrease as revenue increases, but many firms exhibited losses and there is a bias towards the lower end of the revenue scale. Trying to fit a curve to these data points seemed meaningless, but understanding whether the upper envelope of the data is bounded by an easily described curve would be interesting. The first step in achieving this was to eliminate all negative values and combine the data from the three time periods to see whether an improved picture emerged.

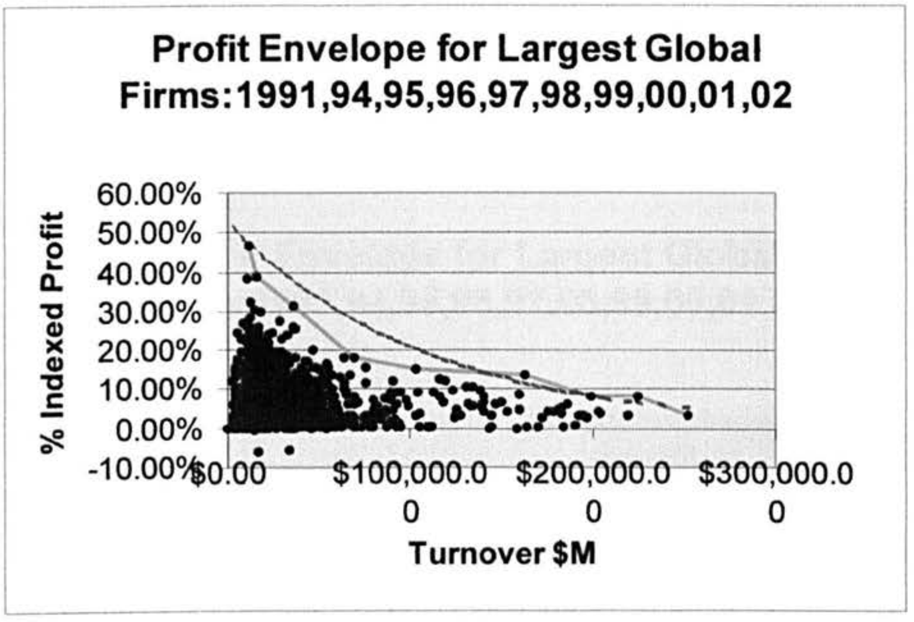
The dependent variable (% profit) is a ratio and so there is no need to modify these data. The independent variable (Revenue) is time dependent and expressed in US dollars, so, again for simplicity, all of the revenues were modified using an indexation table, derived from the US government department of National Statistics. The effect of this indexation is to present all revenues in terms of the value of the dollar in 2003 (the indexation multipliers are shown in Table 23). Having adjusted the data for inflation, it was combined and is shown in Figure 30.

Figure 30 Composite plot of Figures 27, 28 and 29



The pattern produced in Figure 30 is consistent, with the three previous figures, in showing that the upper performance envelope, of a firms profitability, decays as revenues increase. To refine this pattern even further, more data points were added from the years: 1993, 1994, 1995, 1997, 1998, 1999, 2000 and 2002. This resulted in the scatter plot shown in figure 31a.

Figure 31a



In Figure 31a, two lines have been added. The first (solid blue line) produces an upper profitability envelope, by joining up real data points (see Table 30 for details). The second (dotted red line) is a simple exponential decay curve described by the formula (12).

$$y = 100 \times 0.53 \text{ e } -(0.0000093355 \text{ x}) \qquad (12)$$

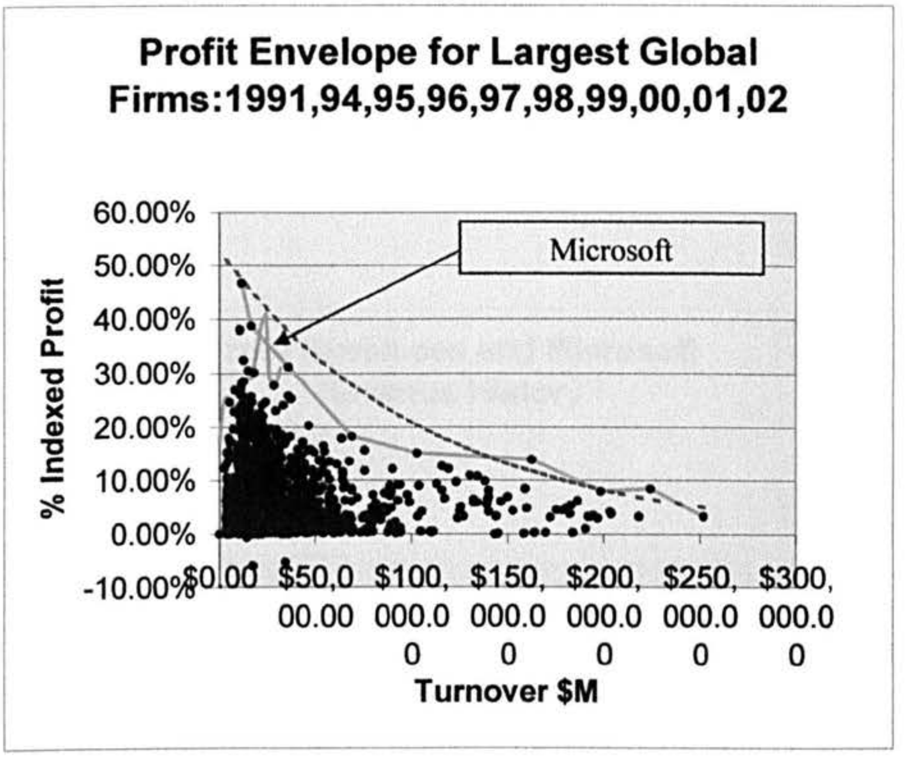
y = The percentage return on sales profitability of a firm (i.e. net profit as a percentage of net revenue)

x = Net revenue ($M).

The final part of the analysis was to plot the performance of a new economy firm onto figure 31a and review the result. Since this analysis has focused upon the largest firms in the world it was logical to select the largest, knowledge based, New Economy firm and here the clear choice was Microsoft Corporation. Microsoft is unambiguously a knowledge based company and has appeared in the Global 500 for several uninterrupted years, up to the present time.

The data for Microsoft was obtained from the Microsoft web site[89], which contains financial metrics going back to 1983. The Microsoft data was modified (indexed to 2003 values) using table 23 and plotted onto figure 31a to produce a new image (Figure 31b). This scatter plot was further refined in Figures 32a and and 32b.

Figure 31b Profit envelope with Microsoft performance added



[89] Data Accessed on 15/07/04 [Available at www.microsoft.com]

Figure 32a

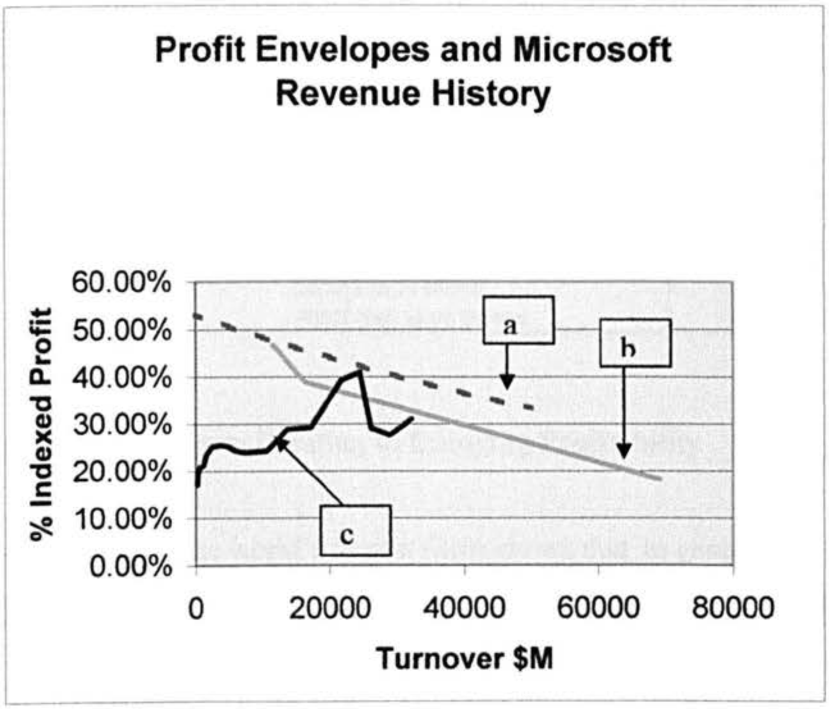
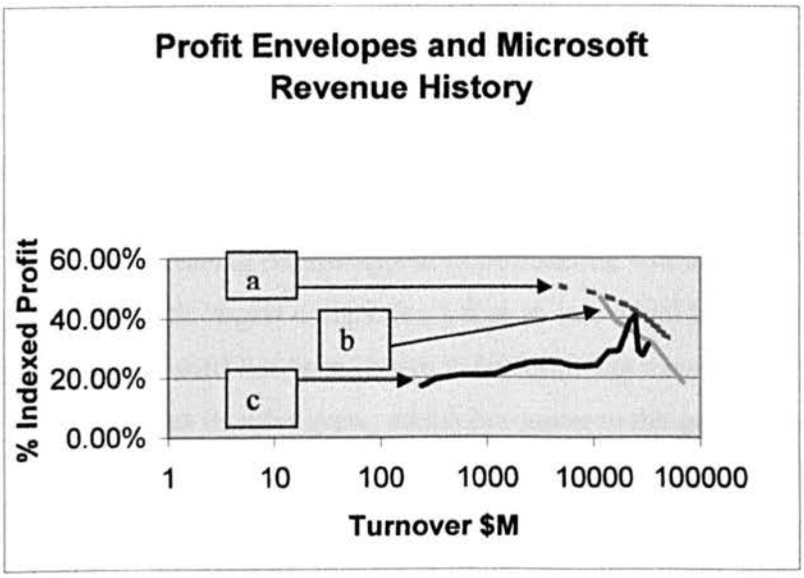


Figure 32b



Key to Figures 32a and 32 b
(a) The curve to formula 12
(b) The empirical envelope
(c) The revenue history of Microsoft Corporation

Table 30 Profitability decay envelope empirical definition

Rank during year	Year	Firm	Revenue ($M) Indexed	% Profit
413	1994	Standard Life Assurance	11537	46.70%
315	1999	Cable & Wireless	16346	38.84%
110	2000	Intel	35978	31.24%
32	2000	Verizon Communications	69029	18.23%
13	2002	Citigroup	102915	15.16%
3	1998	Ford	162756	13.90%
2	2001	Exxon Mobil	198726	8.00%
1	2000	Exxon Mobil	224446	8.42%
1	2002	Wall Mart Stores	251726	3.26%

Conclusions and Comments Relating to Decaying Profitability

The normalised data for the world's largest firms shows that, in general, profitability decreases as revenues increase. This is consistent with decreasing returns dominating increases in productivity. The upper envelope of this data can be considered as an empirical, aspirational, benchmark, i.e. a performance level that has actually been achieved, by some of the world's largest and most profitable companies. For a large company choosing to perform a gap analysis against this benchmark, the equation shown in (12) is a practical tool for this purpose.

The results of this study show evidence of both diminishing returns and increasing returns. Decreasing returns appear to be endemic within the set comprising of the worlds largest companies, yet at an individual level one of these companies (Microsoft) has been shown to be following a course of increasing profitability as its sales grow, which is counter to the general trend.

The evidence from Microsoft is that profitability increases with increasing sales revenues and this phenomenon is worthy of research since, within the context of this work, it suggests that Microsoft has a strategy for moving upwards on the product fitness landscape that works. If this strategy were known then it could be built into a practical model, but it isn't. As an alternative, the general observation of decreasing profitability was incorporated into the simulation 2, and a strategy of randomly moving to a new point on the product fitness when profitability fell below a trigger point was adopted for two out of the three firms. The third firm was immobile on the profit fitness landscape.

APPENDIX 7 LIST OF ORIGINAL PUBLICATIONS

During the production of this thesis, some of the findings were released at academic conferences as detailed below:

1/ Matthews, R. and M.Hodgetts (2000) "Complexity Polya Processses and Industrial Change: Theory Application and Simulation", in the proceedings of the conference of "Complexity and Complex Systems" Eds. I. P. McCarthy & T. Rakotobe-Joel. Warwick University UK, pp 455 – 465

2/ M. Hodgetts and R. Matthews (2004) "Empirical Evidence that Traditional firms are Pre-disposed to Falling Profitability as they Grow; whilst the New Economy provides an Example of the Opposite" presented at the conference of "Competitive Advantage in Large and Small Businesses: Comparative Analysis" 20th March 2004 at the Academy of National Economy under the Government of the Russian Federation, Moscow.

3/ Matthews, R., Hodgetts, M. Augousti, A. and I . Shagaev (2004) "The Polya Urn Problem and Organisational Memory" in the proceedings of the IPSI Conference, Prague.

Copies of the above papers follow, in accordance with Kingston University DBA rules (see Kingston University Research Students Handbook, September 2003, section 1. subsection 8.6) although in so doing they constitute duplication of work contained with in the body of the thesis.

COMPLEXITY POLYA PROCESSES AND INDUSTRIAL CHANGE: THEORY APPLICATION AND SIMULATION

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ABSTRACT

The paper presents some results of the research programme on complexity developed in the Centre for International Business at Kingston Business School. The research is interdisciplinary, linking complexity and co-operative games. The basic theory is summarized for convenience. The focus of the presentation will be on applications and simulation results. Two applications are described: to the nascent natural gas vehicle industry and to the evolution of OPEC. Industrial applications are described and discussed. Strategic trajectories are described using simulations of the Lotka Volterra model incorporating Polya processes and together with a simulated industrial coalition process.

INTRODUCTION

Usually theories begin as metaphors. Only later are they transformed into formal structures. The metaphor underlying this paper runs as follows. Consider the business environment as a landscape, containing firms, industries, and organizations,. The landscape is an uneven one, of peaks and troughs, mountain ranges and valleys; all subject to change, perhaps continuous, perhaps consisting of periods of stability punctuated by violent transformations. The contours of the landscape are payoffs. Payoffs take the form of perceived costs and benefits: perceptions and valuations of payoffs differ. Perspectives are conditioned by anticipations and expectations that affect behaviour profoundly. Alternatively the landscape can be viewed as a random matrix with diagonal elements corresponding to stand alone values of activities (processes, businesses, organizations, depending on the degree of generality) and off diagonal elements are complementarities or synergies between activities: ever higher contours are reached by the formation of coalitions. The task of decision-makers is to reach the highest level of payoffs, but they attempt do so with bounded rationality and encounter information entropy as they attempt to plan their journey further ahead in time or space. Whether they have reached a local peak, or a summit, or indeed whether they are in the right mountain range or not, is clouded in uncertainty. Viewing dual of the problem, it is akin to rolling a ball on a surface in order to reach the lowest point, and using simulated annealing techniques, in particular the metropolis condition, to shift the ball (a strategic move) to a lower level, if it gets stuck in a minor valley.

The complexity inherent in the landscape image is clear, non-linearity, learning, evolution, the importance of expectations, large numbers of interacting variables and NP completeness. The link with game theory is also implicit the picture of coalition formation on a random matrix, and the definition of payoffs as cost and benefits. Different patterns of payoffs alter the game of coalition formation. Parallels with business decision making are also clear. Organizations are coalition of activities, that are subject to transformation by technology, competitive dynamics, the business environment, and so on. Managerial decisions are made with limited information; satisficing rather than optimising. Corresponding to annealing and the metropolis condition, strategic moves by organizations are governed by expectations about payoffs. Strategic moves are trajectories from one state (payoffs, positions on the landscape) to another. Many kinds of feedback processes are possible.

THEORY

The spin glass

The model we adopt is based on a simple relationship between payoffs and co-operation. Activities are the building blocks of the model. Potential payoffs result from interactions between activities j and k, as stand alone activities (j=k) or as synergies or complementarities (j > k). Realisation of payoffs depends on the joint decisions by agents or stakeholders of j and k. We use the following terminology; Bkj, are potential payoff and the joint actions of decision-makers are SkSj (k>j). We constrain decisions about cooperation or non co-operation to all or nothing, or *zero- one* choices, (Sk, Sj $\in$ 0,1). Payoffs are mapped into the real number system (R^N) as transferable utilities, (Bkj $\in$ R^N). The dependence between realising payoffs and cooperation can be summarised as

(Bkj) ~ (SkSj). (1)

Expression (1) corresponds to the spin glass formulation, which is the origin of recent applications of statistical mechanics. Spin glasses display sharp phase transitions without developing a spatial magnetic ordering pattern. The individual spins (atoms that act like microscopic bar magnets) settle down in directions that are more or less fixed individually but are not part of an overall spatial pattern. Two essential ingredients are frustration and randomness. Randomness arises because the magnetic atoms (spins) are distributed randomly in material among a large number of other spinless atoms. Frustration refers to the conflict or competition among the interactions between pairs of spins. Although the interaction between a pair tends to give a very definite alignment, with tree or more spins interacting the individual pairwise alignments cannot be achieved simultaneously. This not only leads to a lack of spatial order but also to many, many frozen states. Frustration and randomness prevent there being a single optimum state. Instead there are many possible optima unrelated by symmetry.

Organization matrices and fitness landscapes

Organisations can be thought of as coalitions of activities, whose boundaries shift as they grow, decline, or restructure.[1] Evolution of organizations takes the form of recognizing and actualizing payoffs through coalition formation in a cooperative game. Coalition formation takes place at many overlapping levels, within organisations, and between them; alliances, and mergers between firms, coalitions between divisions, functional areas, businesses, and projects and teams. Activities are the building blocks of coalitions: their definition depends on the problem at hand. At one level they correspond to value chains, or a process (Porter, 1991; Hammer and Champy, 1993). In mergers they correspond to entire organizations. In alliances relevant activities may refer to components of organizations. For convenience in the paper, alliances are assumed to be the simple entities out of which more complex organizational forms emerge.

Coalitions

Consider organisation as a coalition of N activities. Payoffs are created; (i) individually, as single - member coalitions), a_{ik} $(i = k)$, and (ii) interdependently as two or more member coalitions that generate synergies, a_{ik} $(i \neq k)$. Interdependence is simplified by viewing agents as producing joint outputs, those that have value in themselves, and those which create value in others. One activity potentially creates value in others: similarly, it permits other businesses to create value - the yin and yang of business synergy; neither would be possible if coalitions were *unbundled*. The value of interdependence or synergy is given by the difference between the sum of the values of assets in isolation and the value of assets as part of the organizational network. The total value created by a coalition is $Z(C)$

$$Z(C) \leq \sum_{i,k \in C} a_{ik} \,. \tag{2}$$

where C is a subset of a grand coalition of all activities in the organization matrix. Define the organisation matrix as:

$$\mathbf{a} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1N} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2N} \\ a_{31} & a_{32} & a_{33} & \cdots & a_{3N} \\ \vdots & & & & \vdots \\ a_{N1} & a_{N2} & a_{N3} & \cdots & a_{NN} \end{bmatrix} . \tag{3}$$

In the matrix, $\mathbf{a}$, synergies are off-diagonal elements (a_{ik} and a_{ki}, $i \neq k$): outward synergies, a_{ik}, are the contributions to value added in activity k by activity i in coalition C, and inward synergies, a_{ki}, the contribution of k to businesses i. Total synergy in the coalition C is the sum of both types of synergies: $\sum_{i,k \in C} a_{ik}$.

Payoffs illustrated in expressions (1) and (2) are potential rather than actual. The given conditions illustrated in the payoff function, that underlie the organisation matrix discussed below, form a landscape which recalls the Kauffman's evolutionary metaphor (Kauffman, 1993; Kauffman, 1996) resembling his exposition of Boolean networks but differing substantially in potential for chaos, order or evolution. Radical improvements are easier, at first, but later, longer jumps are necessary across the matrix if improvements are to happen. Major advances become more difficult, and waiting times increase, as bigger efforts are required to reach more distant optima. The landscape itself is rarely static since perception of elements in the payoff function are ever changing. So the game is seldom repeated exactly – an issue that is examined in the two following sections.

In the simplistic case illustrated by the hypothetical numbers in (5), payoffs to the grand coalition are potentially, $Z(a_{11} + a_{12} + a_{21} + a_{22}) = 10$. Payoffs to single member coalitions ($Z(a_{12}) = 2$, $Z(a_{21}) = 2$) are *security levels*, assumed to be the lowest that can be forced on individual agents: $Z(\emptyset) = 0$.

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} = \begin{bmatrix} 3 & 2 \\ 2 & 3 \end{bmatrix} \tag{4}$$

The marginal value of an activity, that is the value as a stand alone unit, a_{ii}, plus the value of inward and outward synergies within a coalition, is its contribution to economic rent of a particular coalition; the difference to the rental of a coalition if it withdrew:[12]

$$m(a') \le \sum_{i\in C, i\ne s} a_{is} + \sum_{k\in C, k\ne s} a_{sk} + a_{ss} \,. \tag{5}$$

Convexity

Organisation matrices that satisfy the condition that the bigger the coalition joined by an activity, the bigger the contribution, are described as convex: there are increasing returns to co-operation. The structure of the firm, considered as a co-operative game, is convex if the larger the coalition that agent s joins, the larger his or her marginal contribution. For any two coalitions, C and T, such that $C \subset T$ in an organisation with N agents, convexity implies that for all $C, T \subset N \setminus \{s\}$,

$$C \subset T \Rightarrow Z(C \cup \{s\}) - Z(C) \le Z(T \cup \{s\}) - Z(T) \,. \tag{6}$$

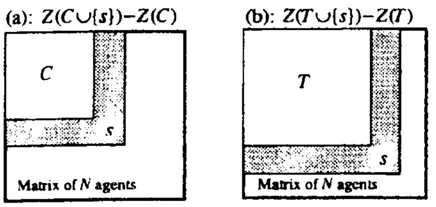

Figure 3: The shaded areas in (a) and (b) graphically represent $Z(C \cup \{s\}) - Z(C)$ and $Z(T \cup \{s\}) - Z(T)$ correspondingly.

A sufficient but not necessary condition for convexity is that all elements in the matrix be non-negative. To simplify the exposition, unless otherwise stated we make two assumptions in the paper. The first is that relevant coalitions in the organisation matrix are convex. The second is that the number of activities and the number of agents or decision -makers are equal.[iii]

Convexity is an important property of many modern network organizations.

i. The increasing returns it implies may not be dependent on the success of any one company, but on the network - which may be, as in Silicon Valley for example, an architecture of inter-related firms and customers.

ii. The size of a network increases by the square of the number of activities, and in the case of convexity payoffs potentially increase exponentially.

iii. So the marginal costs associated with increasing coalitional size falls relatively, and we reach a position where it pays firms (in telecommunications, media, and computing) to give products away, gain market share, and having captured consumers, charge for upgrades.

Transforming the organisation matrix into a game

Figure 4 illustrates the transformation of the arbitrary data in (5) into a co-operative game: players have the alternative of forming single member or two member coalitions. Joint co-operation (*C*, *C*) leads to payoffs (5, 5); co-operation by just one player (*C*, *D*), or (*D*, *C*), leads to payoffs (3, 5), and (5, 3), respectively; joint failure to do so (*D*, *D*), to (3, 3). If the distribution of payoffs to each player is x_1 and x_2 respectively, then payoffs to single member coalitions are $x_1 = 3$ and $x_2 = 3$, and total payoffs are 6. It is assumed in making the transformation from the activity matrix to a co-operative game that neither player can be forced below his or her stand-alone value (the minimum-security level), if they fail to co-operate. The shaded area in Figure 4 describes the set of feasible solutions, given this assumption. The line OV illustrates equal distribution of payoffs: an increase or decrease in the slope of this line symbolises a distribution of payoffs in favour of one player or the other. If they are fully realised, payoffs lie on the line segment *XY*, which is the core of the game. The shaded area below *XY* illustrates only its partial realisation. The extent to which payoffs are realised depends on decisions about co-operation, the values of θ_t and θ_k.

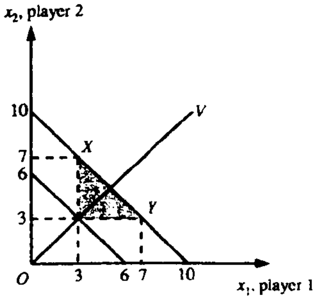

Figure 4: Illustration of viability and the core under convexity.

Two notions of efficiency are defined at this point: viability meaning that some synergy gains are realised and the core of the game under which gains are fully realised. Viability requires two conditions: that a coalition adds value (if rents were negative, the organisation would be driven out of business) and that some synergy gains are realised so that the whole is greater then the sum of the parts.

Definition (viability):

$$Z(S \cup T) \geq Z(S) + Z(T), \text{ with } Z(S \cup T) \geq 0. \qquad (7)$$

The core is the set of feasible payoffs that no coalition can improve upon, in a sense that it is impossible to make one player better off without making another worse off.[iv]

Definition (The core):

$$\sum_{s \in N} x_s = Z(N) \text{ and } Z(N) \geq Z(C) \text{ for all } C \subseteq N, \qquad (8)$$

where x_s is an allocation of payoffs to any player S. Core allocations are, of course, Pareto efficient and in the hypothetical case they lie on the line segment XY in Figure 4. Viable allocations include the core, but are satisfied anywhere in the shaded area below XY.

The benefit-cost structure of the organisation matrix

Consider an organisation of 2 activities as in (4) above, with a_{12} and a_{21} being the contribution of the first to the second, and the second to the first respectively, as shown in Figure 5.

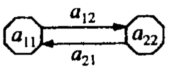

Figure 5: Pair interaction of units in a coalition

Complex decision equations

For simplicity the agents (or players) are given the alternative of taking only one of two decisions: co-operate (C) or not (D), denoted 1 and 0, respectively. Then the decision variable of player 1 towards player 2, θ_{12}, can take values of 1 or 0, similarly the decision variable of player 2 towards player 1, $\theta_{21} \in \{1, 0\}$.

Suppose synergies are divided into two parts: (i) those created by solo actions, $\{r_{12}, r_{21}, c_{12}, c_{21}\}$, and (ii) those created by joint action, $\{b_{12}, b_{21}\}$. In (i), player 1 creates synergy benefits r_{12} $(r_{12} > 0)$ for player 2 and incurs costs c_{12} $(c_{12} > 0)$ by making a decision $\theta_{12} = 1$ to co-operate with player 2: both can be avoided if the decision is not to co-operate, $\theta_{12} = 0$. Suppose the position is the same for player 2. In (ii), joint action synergies b_{12} and b_{21} are created only if both players co-operate $(\theta_{12} = \theta_{21} = 1)$. Potential payoffs of the organisation $Z(\theta_{12}, \theta_{21})$ can be written

$$Z(\theta_{12},\theta_{21}) \le (r_{12}-c_{12})\theta_{12} + (r_{21}-c_{21})\theta_{21} + (b_{21}+b_{12})\theta_{12}\theta_{21} + a_{11} + a_{22} \qquad (9)$$

This expression is the equivalent of the spin glass formulation in (1) which we repeat for convenience

(Bkj) ~ (SkSj). (1)

The two expressions are termed complex decision equations henceforth.

It can be seen that potential payoffs are fully realised (the core of the game) only if both players co-operate. If only one player co-operates, we have a viable solution and co-operation by neither merely amounts to attaining the security levels of the two players.

The payoff table of player 1 can be written as

	$\theta_{21} = 1$	$\theta_{21} = 0$
$\theta_{12} = 1$	$b_{12} + r_{21} - c_{12} + a_{11}$	$a_{11} - c_{12}$
$\theta_{12} = 0$	$r_{21} + a_{11}$	a_{11}

and the payoff table of player 2 is

	$\theta_{21}=1$	$\theta_{21}=0$
$\theta_{12}=1$	$b_{21}+r_{12}-c_{21}+a_{22}$	$r_{12}+a_{22}$
$\theta_{12}=0$	$a_{22}-c_{12}$	a_{22}

At this point we merely note that, if $c_{12}>b_{12}$ an $c_{21}>b_{21}$, the game takes a Prisoner's Dilemma form. If the inequalities are reversed, we have a co-ordination game.

APPLICATIONS

Results of two applications of the complex decision equations are reported.

i. The nascent NGV industry

The beauty of expressions (1) and (9) lies in their generality. They draw attention to the factors essential to the emergence of the NGV industry: the existence of potential payoffs and the necessity of co-operation if it is to evolve. We report interactions between three stakeholder groups: industry, government and the consumer sectors. Each in itself is a coalition capable of blocking or frustrating the emergence of the NGV industry, but incapable of ensuring the creation of the industry on its own. The industry will not arise unless there is co-operation both within and between them.

ii. OPEC

An application to the evolution of OPEC is reported. OPEC is analysed in terms of two games. G1 a repeated prisoners dilemma between the host nations and the oil majors and G2 an evolutionary game between OPEC members.

SIMULATIONS

This section of the paper represents a relatively new stage of the research programme. Preliminary results of three simulations are reported.

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[i] The paper develops ideas presented in Matthews, 1994, 1996a, 1996b, and Matthews and Korolov, 1997.

[ii] In (4) the marginal value of activity 1 to a two (one) agent coalition is the difference it makes to a one (empty) coalition: $m(a^{1}) = z\{1,2\} - z\{1\} = 10 - 7 = 3$, and $m(a^{1}) = z(1) - z(\emptyset) = 3$.

[iii] The assumption of convexity is used to simplify the analysis. Unless it is relaxed it is difficult to define the boundary of the firm. This issue is discussed in Matthews, 1996. The assumption also means that the core potentially exists.

[iv] Our assumption of convexity ensures that the core potentially exists. For discussion of the core in the organisation matrix see Matthews, 1996.

Empirical Evidence that Traditional firms are Pre-disposed to Falling Profitability as they Grow; whilst the New Economy provides an Example of the Opposite

Mark Hodgetts and Robin Matthews

Abstract: *Historically, firms have followed a path, whereby supply side growth through productivity and economies of scale have stimulated demand, through lower prices and improved products. This kind of growth pattern has led to diminishing returns. Recent evidence, from the largest companies in the World, is presented, which shows that profitability decays as revenue grows. Decaying profitability is generally consistent with diminishing return. However, the new economy presents a new productivity paradigm and there is also data to support the notion that the new economy can provide a route to increasing profitability as revenues increase.*

Background

For almost three hundred years, there has been an understanding that the process of wealth creation is influenced by both positive and negative forces, which together shape the way that investments produce payoffs. The phenomenon of decreasing returns was articulated in the seventeenth century (West1688), by economists studying agricultural yields from the land. Decreasing returns mean that although output continues to increase with additional investment, the returns per unit investment are progressively lower. In the eighteenth century, an opposite effect was identified, within manufacturing firms, that of increasing productivity. The technique that enabled productivity to increase was identified as specialisation (Smith 1776), which could be amplified through investment in order to realise economies of scale. Today, both of these forces are accepted as relevant to modern businesses.

When looked at from the perspective of a firm, the logical consequence of decreasing returns is to squeeze the profit margin, whilst the consequence of increasing productivity is to increase the profit margin. Consider two scenarios for a firm that has steadily increasing sales: in the first, productivity is growing very slowly, in the second it is growing very rapidly. When productivity grows slowly, the firm will see its revenue grow and so will its profits, but the profits will grow more slowly than the revenue, meaning that its profitability will fall. In contrast, if productivity is growing very rapidly, then each new quantity of sales will be from a period which is more profitable than its predecessor and so profits will grow as revenues grow, meaning that the firm will experience increasing profitability. Until recently most economists have considered the first scenario to be the most realistic. However, as the knowledge economy/new economy was emerging, the possibility of increasing returns was again being aired again by some economic researchers(Arthur 1994).

In the last quarter of the twentieth century there has been an ongoing debate as to whether, what has become known as the 'new economy' really exists, or whether it is just an extension of the traditional economy. Those in favour of a new economy claim to be able to discern a step function increase in productivity, whilst sceptics claim it is a natural variation that will settle down in the long run. As an alternative to analysing productivity, this study has looked at the profitability of firms, to see whether there is any evidence for increasing returns or not.

The Population and Sample

Several million companies make up the UK economy (Curran 1999) and there may be hundreds of millions of companies to choose from on a global basis. This population of firms, range from those with just a few employees to ones with over a million employees. With such a large range, there was some unease about the practicalities of selecting a sample to study. The concerns were about two issues. Firstly, if a random sample was proposed, how would it be possible to achieve it? Secondly, would accounting information be easily accessible from smaller foreign firms, which would inevitably make up a large portion of a random sample? On a practical basis, an alternative to random sampling was considered, based upon a rule , which was easy to achieve. The rule was that if the firm was in the top 500 largest firms in the world, based upon revenues, then it would be included in the study, it was not in the top 500 then it would not be.

The Analysis and Results

Initially, a longitudinal analysis of each firm in the specified sample was undertaken, for the years 1991, 1996 and 2001. The data was taken from that collated by Fortune magazine, which is published as the 'Global 500'. The profitability of these firms is shown graphically in Figs 1,2 & 3.

The patterns shown in Figs 1,2 & 3 suggest that there is a tendency for profitability to decrease as revenue increases, but many firms exhibited losses and there is a bias towards the lower end of the revenue scale. Trying to fit a curve to these data points seemed meaningless, but understanding whether the upper envelope of the data is bounded by an easily described curve would be interesting. The first step in achieving this was to eliminate all negative values and combine the data from the three time periods to see whether an improved picture emerged.

The dependent variable (% profit) is a ratio and so there is no need to modify these data. The independent variable (Revenue) is time dependent and expressed in US dollars, so, again for simplicity, all of the revenues were modified using an indexation table, derived from the US government department of National Statistics. The effect of this indexation is to present all revenues in terms of the value of the dollar in 2003 (the indexation multipliers are shown in Table 1). Having normalised the data, it was combined and is shown in Fig 4.

The pattern produced in Fig4 is consistent, with the three previous figures, in showing that the upper performance envelope, of a firms profitability, decays as revenues increase. To refine this pattern even further, more data points were added from the years: 1993,1994,1995, 1997,1998, 1999,2000 and 2002, which resulted in the scatter plot shown in Fig 5. In this figure two lines have been added. The first produces an upper profitability envelope, by joining up real data points (see table 2 for details). The second is a simple exponential decay curve described by the formula (1).

$$y = 100 \times 0.53\ e^{-(0.0000093355\ x)} \qquad (1)$$

y = The percentage return on sales profitability of a firm (i.e. net profit as a percentage of net revenue)
x = Net revenue ($M).

The final part of the analysis was to plot the performance of a new economy firm onto figure 5 and review the result. Since this analysis has focused upon the largest firms in the world it was logical to select the largest, knowledge based, new economy firm and here the clear choice was Microsoft Corporation. Microsoft is unambiguously a knowledge based company and has appeared in the Global 500 for several uninterrupted years, up to the present time.

The data for Microsoft was obtained from the Microsoft web site (www.microsoft.com), which contains financial metrics going back to 1983. The Microsoft data was modified (normalized) using Table 1 and plotted onto figure 5 to produce a new image (Fig 6).

Conclusions & Comments

The normalised data for the worlds largest firms shows that, in general, profitability decreases as revenues increase. This is consistent with decreasing returns dominating any increases in productivity. The upper envelope of this data can be considered as an empirical, aspirational, benchmark, i.e. a performance level that has actually been achieved, by some of the worlds largest and most profitable companies. For a large company choosing to perform a gap analysis against this benchmark, the equation (1) is presented as a practical tool for this purpose.

The profitability trajectory of Microsoft Corporation clearly indicates a positive correlation with revenue, which is counter to the characteristics of its peer group, within the 'traditional economy'. This data is supportive of two assertions: (a) the knowledge economy is different to the traditional economy by virtue of having higher productivity and (b) new economy firms offer the possibility of increasing returns.

Future work

Further comparisons of historic revenue data need to be performed, for representative firms of both old and new economies. Also the apparent symmetry between profit and loss would merit analysis.

Figures

Fig 1

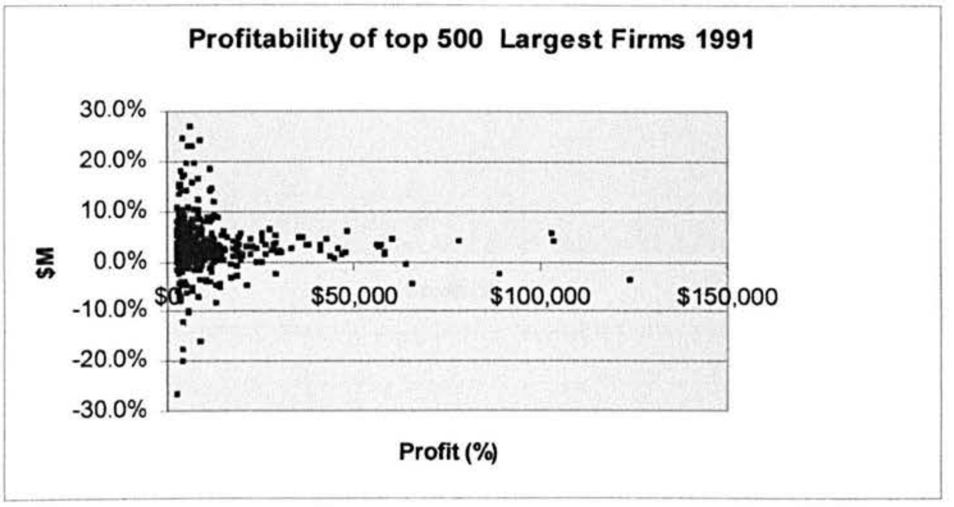


Fig 2

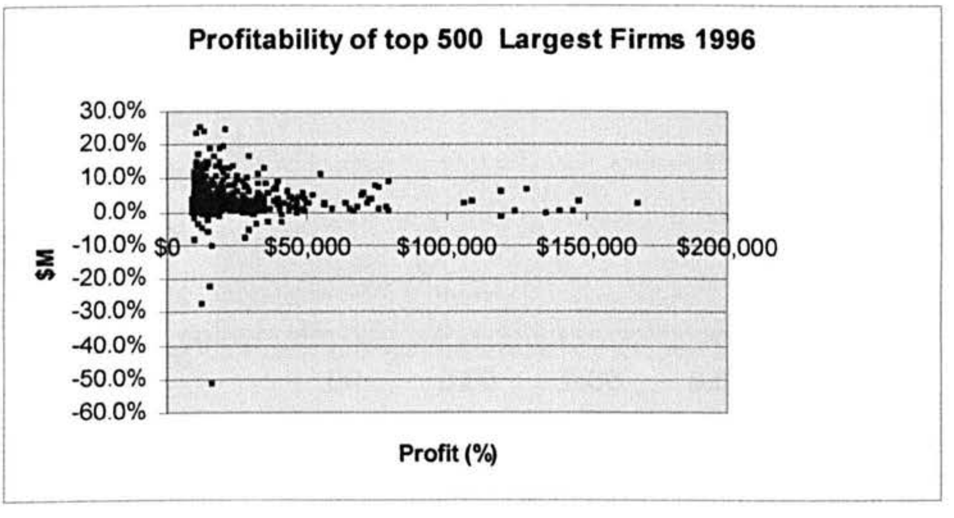


Fig 3

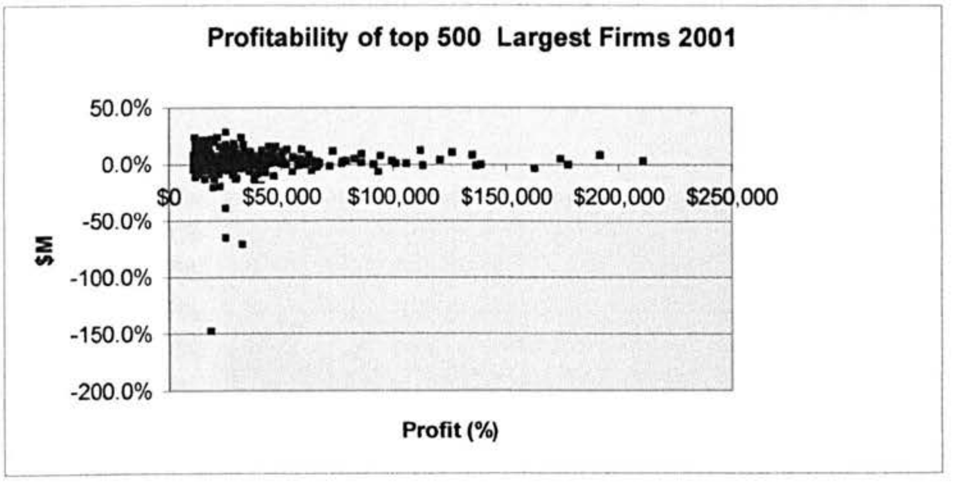

Profitability of top 500 Largest Firms 2001
50.0%
0.0%
-50.0%
-100.0%
-150.0%
-200.0%
$M
$0
$50,000
$100,000
$150,000
$200,000
$250,000
Profit (%)

Fig 4

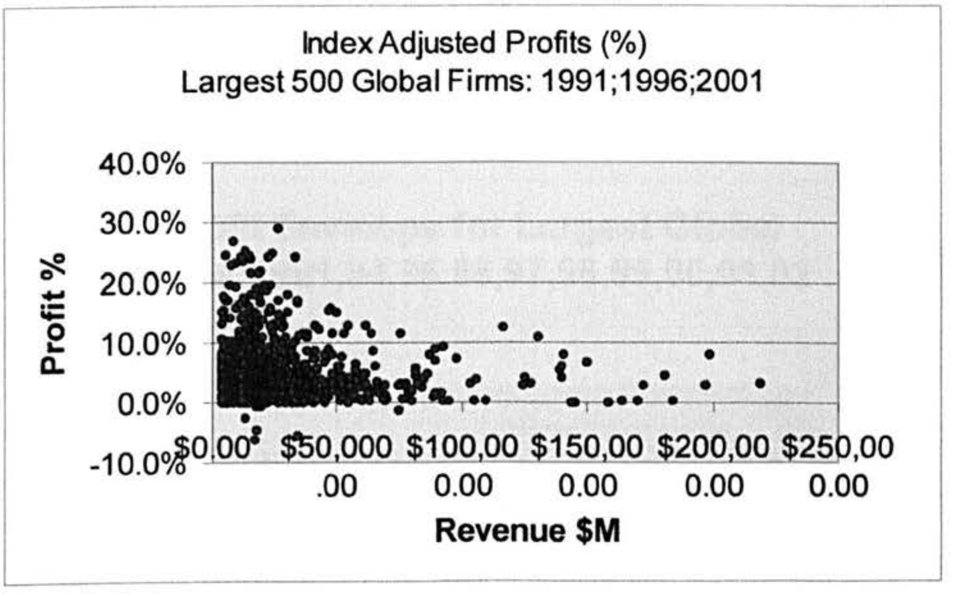

Index Adjusted Profits (%)
Largest 500 Global Firms: 1991;1996;2001
40.0%
30.0%
20.0%
10.0%
0.0%
-10.0%
Profit %
$0.00
$50,000.00
$100,000.00
$150,000.00
$200,000.00
$250,000.00
Revenue $M

Fig 5

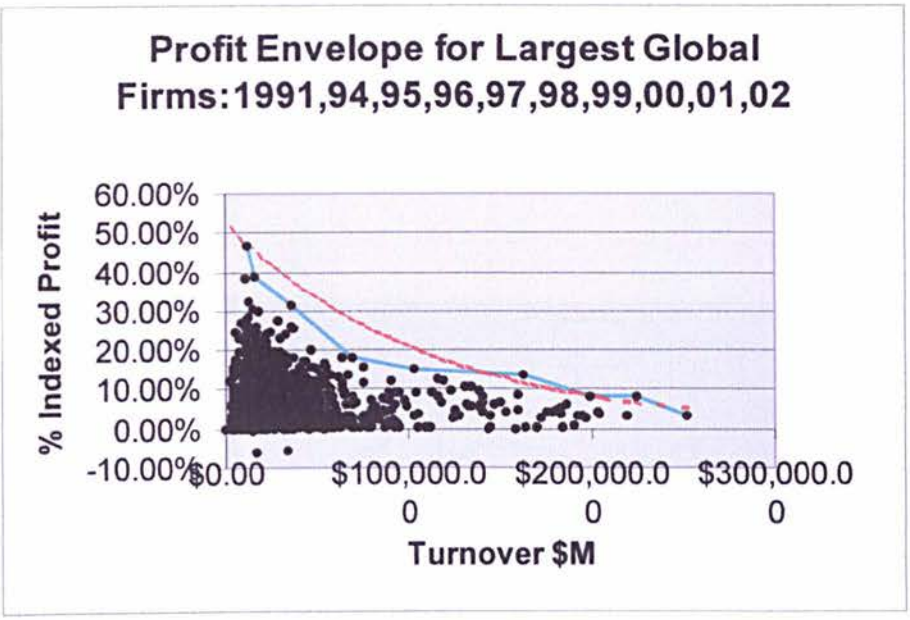

Profit Envelope for Largest Global Firms:1991,94,95,96,97,98,99,00,01,02
% Indexed Profit
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
-10.00%
$0.00
$100,000.0
0
$200,000.0
0
$300,000.0
0
Turnover $M

Fig 6

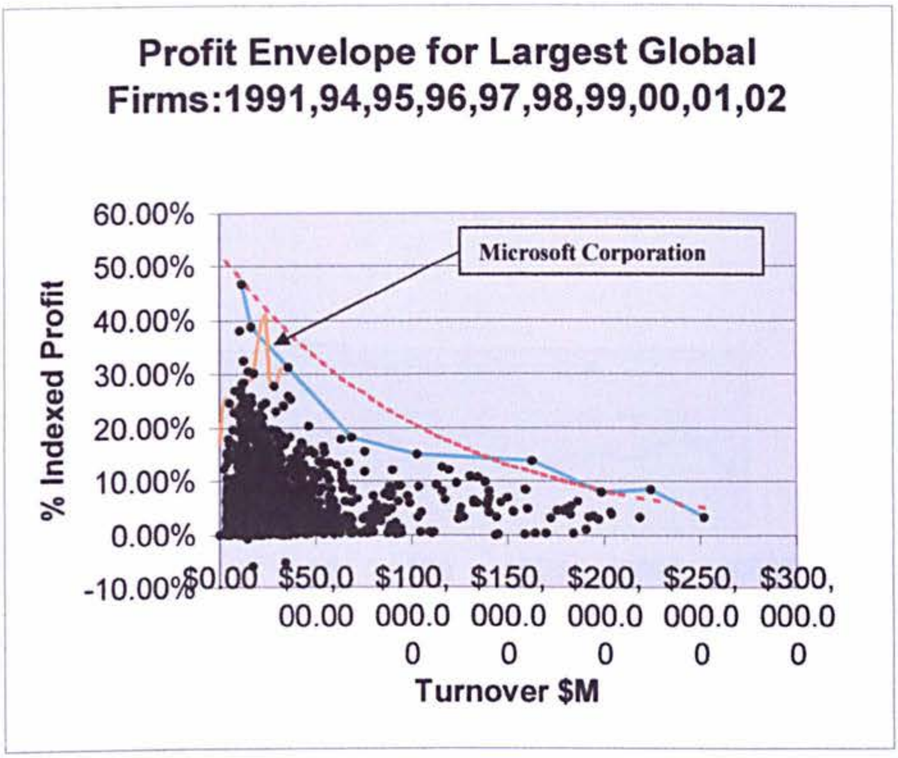

Profit Envelope for Largest Global Firms:1991,94,95,96,97,98,99,00,01,02
Microsoft Corporation
% Indexed Profit
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
-10.00%
$0.00
$50,0
00.00
$100,
000.0
0
$150,
000.0
0
$200,
000.0
0
$250,
000.0
0
$300,
000.0
0
Turnover $M

Fig 6a

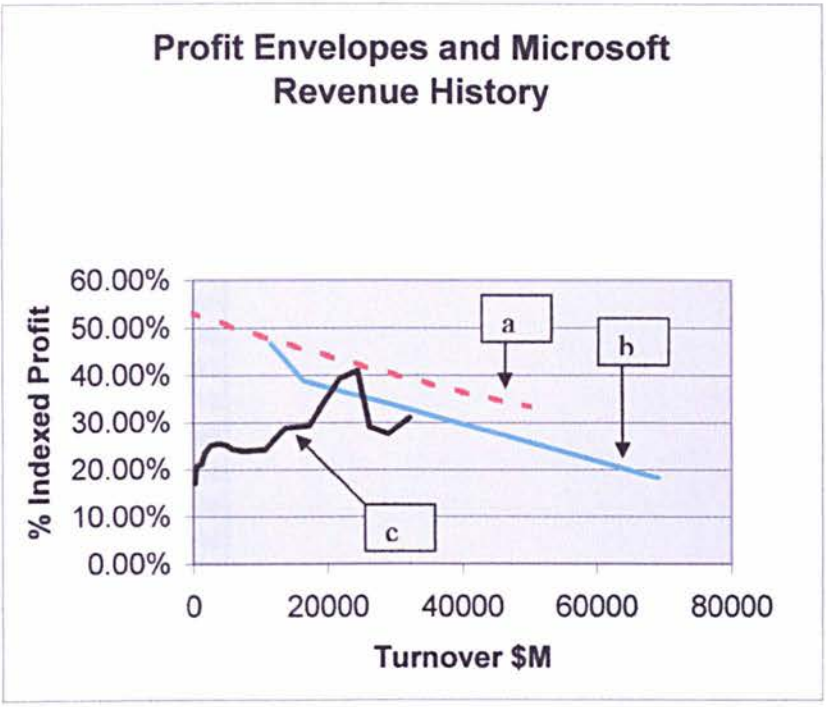
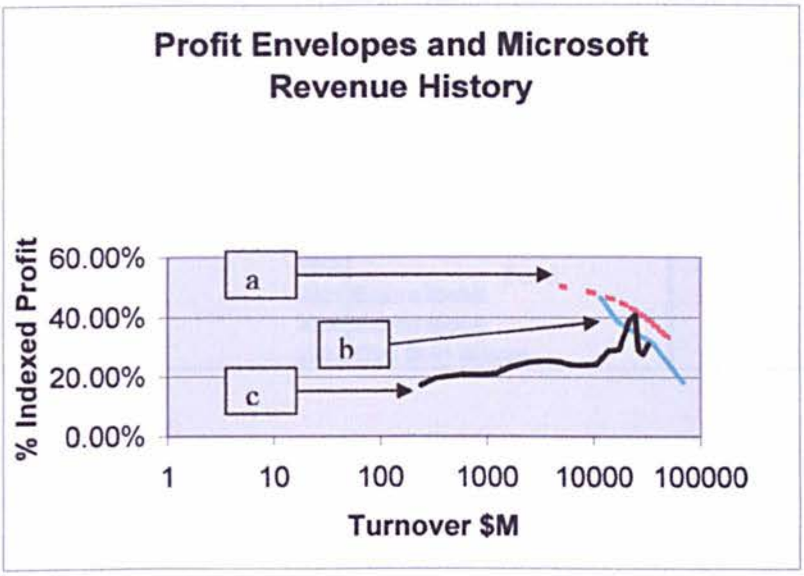


Fig 6b



Key to Figs 6a & 6b: (a) The curve to formula 1

(b) The empirical envelope

(c) The revenue history of Microsoft Corporation

Tables

Table 1

Date	Indexation Multiplier
1985	1.7072
1986	1.6761
1987	1.6171
1988	1.5528
1989	1.4815
1990	1.4055
1991	1.3488
1992	1.3093
1993	1.2713
1994	1.2395
1995	1.2054
1996	1.1708
1997	1.1445
1998	1.127
1999	1.1026
2000	1.0668
2001	1.0373
2002	1.0211
2003	1

Table 2

Rank during year	Year	Firm	Revenue ($M) Indexed	% Profit
413	1994	Standard Life Assurance	11537	46.70%
315	1999	Cable & Wireless	16346	38.84%
110	2000	Intel	35978	31.24%
32	2000	Verizon Communications	69029	18.23%
13	2002	Citigroup	102915	15.16%
3	1998	Ford	162756	13.90%
2	2001	Exxon Mobil	198726	8.00%
1	2000	Exxon Mobil	224446	8.42%
1	2002	Wall Mart Stores	251726	3.26%

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The Polya Urn Problem and Organisational Memory[1]

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Abstract

The Polya urn problem demonstrates an elegant process that illustrates the phenomena of path dependence and lock in. We are concerned with its status as as a model of memory. We discuss simulation experiments of different memories embedded in the urn problem. We generalise our findings to business and social life. Different attractors are discussed especially stochastic self reinforcing situations, where early lock in transforms competition into limited choice monopoly and dominance conditions.

Introduction

Early in the twentieth century George Polya investigated numerous problems associated with combinatorial sets. Since then, researchers in many other disciplines, including chemistry (Polya and Read 1987) and economics (Arthur 1987; 1999) have used his results with respect to the *urn problem*. Arthur (1989,1990) used Polya's results on the urn problem to illustrate path dependence, the non-linear impact of early choices on outcomes. The basic idea of the *urn problem* can be described by a game conducted as a thought experiment as explained by Arthur following Polya & Eggenberger (1923):

[1] http://business.kingston.ac.uk/CIBP

"Think of an urn of infinite capacity, to which are added balls of two possible colors - red and white, say. Starting with one red and one white in the urn, add a ball, each time, indefinitely, according to a rule. Choose a ball in the urn at random and replace it: if it is a red, add a red, if it is a white, add a white."

The characteristic result of this game, is that for low numbers of balls in the urn the ratio can vary significantly as balls are added. As the number of balls in the urn becomes large, the ratio of the colours converges rapidly towards some value between zero and one. It is impossible to predict the exact proportion, but the closed interval zero one is an attractor to which the proportion (of coloured balls) converges.

The Polya urn problem as outlined above can be described as being a difference equation of a particular specification operating as a Markov chain process. Usually difference (or differential) equation specifications raise the issue of time dependency. In Koyk distributions for example each new result is (statistically) dependant on previous results, with recent results weighing more heavily than more distant results. In a Markov chain, the problem of time dependence is straightforward: we have a random walk, the path of the variable(s) concerned following random trajectories from the latest point.

Polya showed that the Urn process was ergodic, but only within the (closed) zero one interval. The interval itself constituted an attractor, but the urn problem was ergodic in the sense that if the process was repeated an infinite number of times, all possible ratios of balls in the urn would be encountered and they would be encountered with equal probability. He proved that whilst convergence occurs for a particular trial, on average, the final ratio of the coloured balls in the urn is random.

In this paper we focus on three aspects of the urn problem:

i. The influence of history or path dependence

ii. Sensitive dependence on initial conditions.

iii. The role of memory embedded in the nature of the thought experiment, the urn problem itself.

It is the latter problem that we give most attention.

Phases in the urn problem

Consider the stages of the urn process as described by Polya. The first is the setup phase, the conditions of the experiment itself. This involves a notion of memory in the sense that the urn is assumed to remember its own contents exactly. Given this assumption, in the second stage, the plastic phase, choosing a ball, the probabilities of drawing a colour are uniquely determined by the contents of the urn (its memory). Hence we get, in the third stage, a *quasi* stable phase, convergence, within the attractor, the closed interval, zero one.

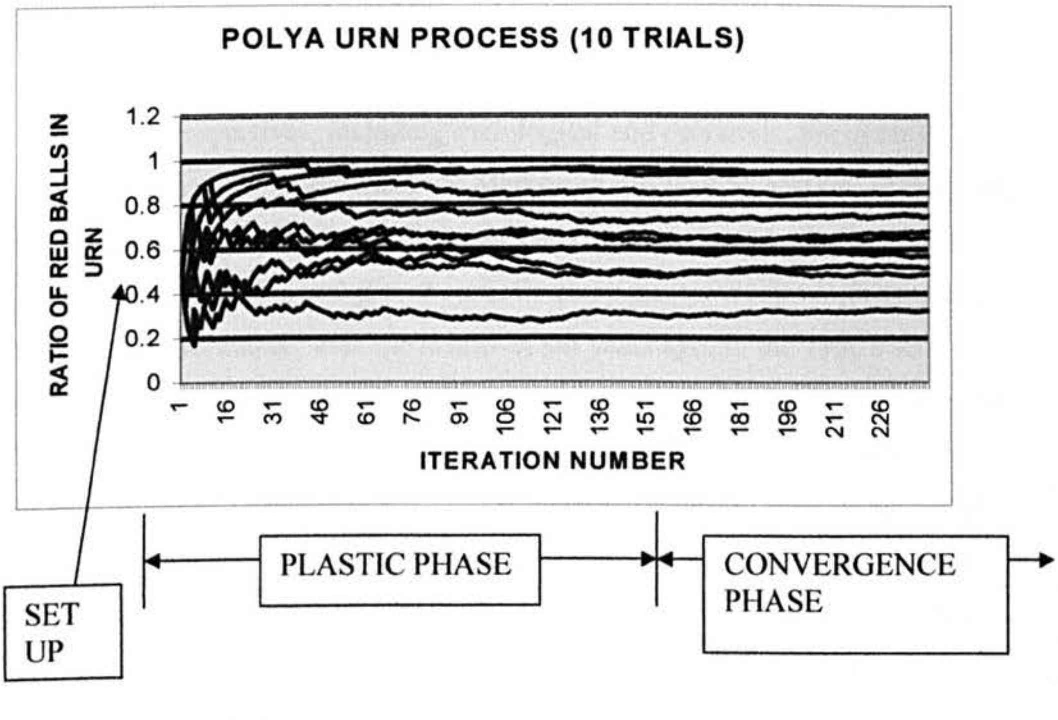
The urn experiment is more than a metaphor for memory, it reproduces the memory process. The setup phase reproduces history. Suppose, we ask, that we change the assumption about memory. Suppose we allow for different memory lengths, short memory, long memory, limited memory. Quite different results naturally emerge, depending on how we specify the experiment. We simulate a few of these results. In the film medium, the films *Memento* and *Ground Hog Day* experiment with a different notions of memory that produce an endless cycle of repeated behaviours. In his psychological reflections Oliver Sacks records the nightmare experiences of memory that spans only a few seconds, or memory that stops somewhere in a man's the distant past. LP Hartley notes that the *past is a different country* – in the sense that people in the past remember clearly what we have long forgotten: hence their culture and behaviour is at least to some extent inexplicable because the memes of former generations are so different. Hence each present has a different version of the past. We produce more mundane results from a number of memory experiments based around variations of the urn problem. We also present an application, to marketing and advertising.

The plastic phase is one where the addition of a single ball makes a significant change to the ratio of the colours and where the ratio can swing to and fro, in favour of either colour. In the plastic phase (the initial stages), the vagaries of the random selection from the urn, dominate over the stochastic influence of the current ratio of colours in the urn, when another ball is added.

The final phase is one where there are so many balls in the urn that the effect of the random selection is ironed out, by the stochastic inertia of the contents of the urn. The consequence of this is that the process, in practice becomes increasingly convergent. Change in the ratio is difficult to achieve because of the accumulated weight of history in the memory (as the urn gets to contain more and more balls). We call this a situation of *quasi* stability in the sense that in all our trials, we arrived at convergence. However, even if there are a billion white balls in our thought experiment urn and only one red, there is nothing, in principle, that entirely eliminates the possibility that the next billion selections will all be red.

Figure 1 shows some outcomes of the Polya process with these stages identified.

Figure 1



Polya chaos and clocks

We note the chaotic status of the urn. The key aspect of chaos is sensitive dependence on initial conditions (SDIC). In effect this means a positive Liapunov exponent. Strange attractors are chaotic in the attractor itself. Even within the attractor there is unstable motion. Here we do not examine whether the attractor in the conventional urn problem is strange or not. What we highlight is the fact that initial choices in the experiment are extraordinarily important in determining eventual outcomes. An attractor is represented by a set of points P (here the closed zero one interval) towards which the system of interest moves over large times, after so-called transients have died out.

In applying the Polya urn case to *a real life situation*, the Markov condition implies
that the influence of the items, within the group, is constant over time. Arthur gives an example of how clock hands rotated in an arbitrary fashion until one "clockwise" style began to dominate in the fourteenth century. This early dominance prevailed for over five hundred years. However, this dominance was broken at the end of the twentieth century and it is now possible to own a talking clock or digital watch, neither of which are anchored by an event in the distant past.

From many perspectives, including sociological and economic, the order of historical events is important and yet Markov chains take no account of this. The relevance of a recent event, is often considered greater than one in the distant past. Last year's profits and growth, usually carry greater weight in forecasting next years performance, than the results of ten years ago. In the 1950's semi-Markov processes were proposed (Levy 1954, Smith 1955), but it was more than twenty years later before the concept of time homogeneity was criticized (De Dominicis 1979).The importance of semi-Markov processes when dealing with the real world has been stated thus: "*Henceforth, it is clear that if we look for stochastic processes useful for applications in the real world, the evolution we have known is such that almost all phenomena we may study are not time homogeneous*" (Janssen & De Dominicis 1984).

It is being suggested here, that the Markov chain nature of the Polya urn process puts limits on its use in describing real world conditions. The next section illustrates situations that do, and those that do not map into the process. An extension of the process is then outlined that improves its accuracy when dealing with the real world.

Memory and the urn problem

In this section we outline a number of simulation experiments reproducing results that occur when we alter the conditions of the urn experiment. We focus in this version of the paper on a particular counter intuitive result that follows when we shorten memory span, a situation akin to *dementia*, which results in convergence on a single point in the closed interval zero one: either one or zero. We conducted a number of simulations. This paper refers to only two experiments (in our presentation we will refer to others we carried out). The first experiment relates to the original urn problem, the second is a constructed 'limited memory' experiment.

A computer simulation was created, with a graphical output, to explore this model, which is being called the 'Polya urn process with limited memory'. The simulation included three variables. They were: (a) the number of different coloured balls at stage one, (b) the memory capacity of the urn, (c) the number of iterations allowed to 'complete' the process.

The assumption is that memory and storage are synonymous. An urn with infinite capacity has infinite memory. The limitations of performing the process are demonstrative of this assumption. If it is enacted as an experiment with real balls and a real urn then the process is limited by the size of the urn. If performed as a mind game, then the limit is determined by the memory of the individual playing the game. The parallel between the size of urn and size of memory is clear.

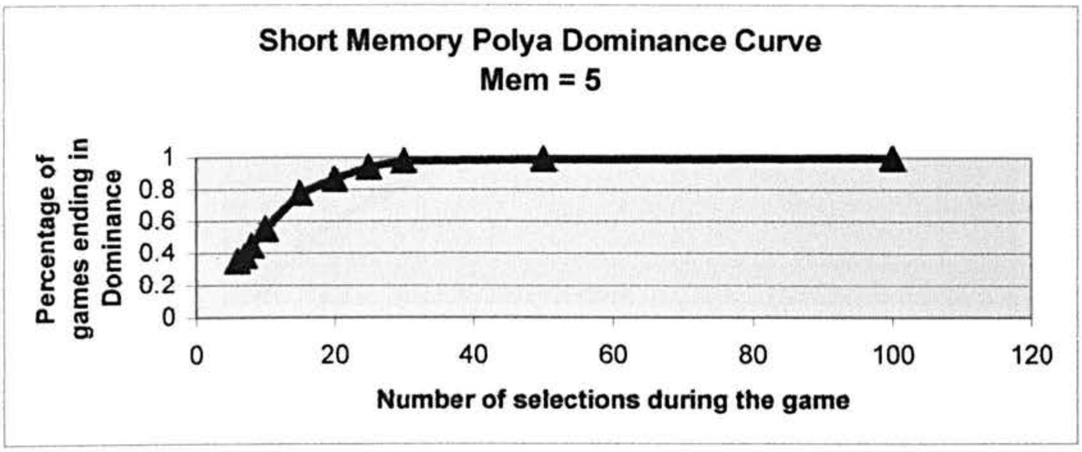
The original Polya process is designed to have an urn with infinite capacity that accumulates balls forever. It represents a perfect system where no information is lost and there are no limits to the amount that can be stored. This situation is atypical, memories fade, systems are corrupted through amnesia or dementia or simply there is insufficient capacity to begin with. The simulations performed during this study mimic circumstances where memory capacity is limited to just a few items. The sizes of memory that were investigated could store 5,10,20 or 50 pieces of information (balls).

The various simulations were run a number of times and in contrast to the original Polya process, two strong attractors emerged, of zero (0%) and one (100%). If more than two colours were placed into the urn at the starting point then the process proceeded until one after another the colours became extinct, until only a single colour remained. There were ways to slow down or stop the onset of this monopoly. The first was to reduce the number of allowable iterations, which in effect froze the system at some point prior to monopolisation. The second was to increase the size of the urn memory.

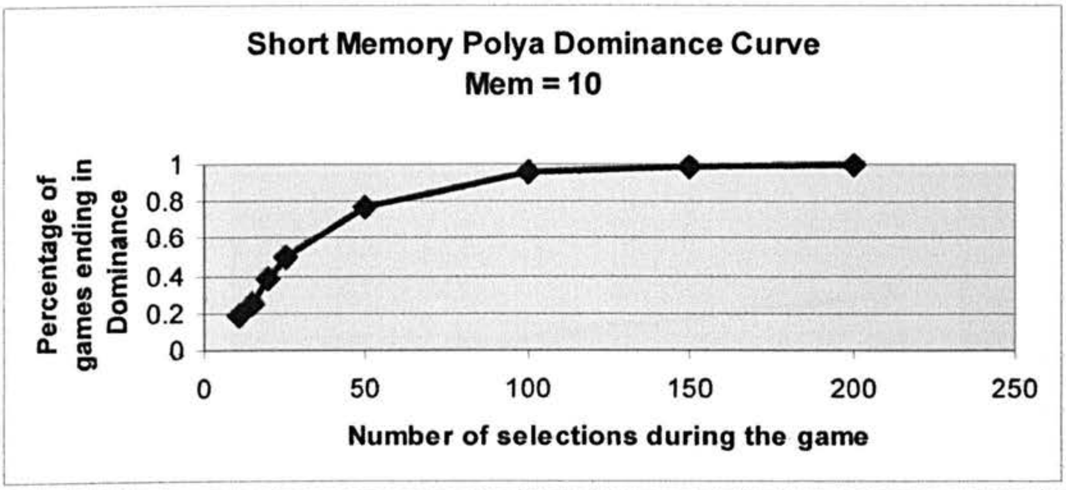
To obtain quantitative data relating to the new process, another program was written. The second program ran the new process many times and created histograms of final ratio values. The interval between zero and one was divided into ten equal parts, but in the first and last interval the data was divided again, in order to extract the frequencies of the values of zero and one. This produced histograms with twelve potential columns. A number of trials were performed and many histograms were produced. The frequency of zero's and ones in the histograms showed how the strength of the attractors varied with urn memory size; these results are shown in figure 2 a –d

Figure 2

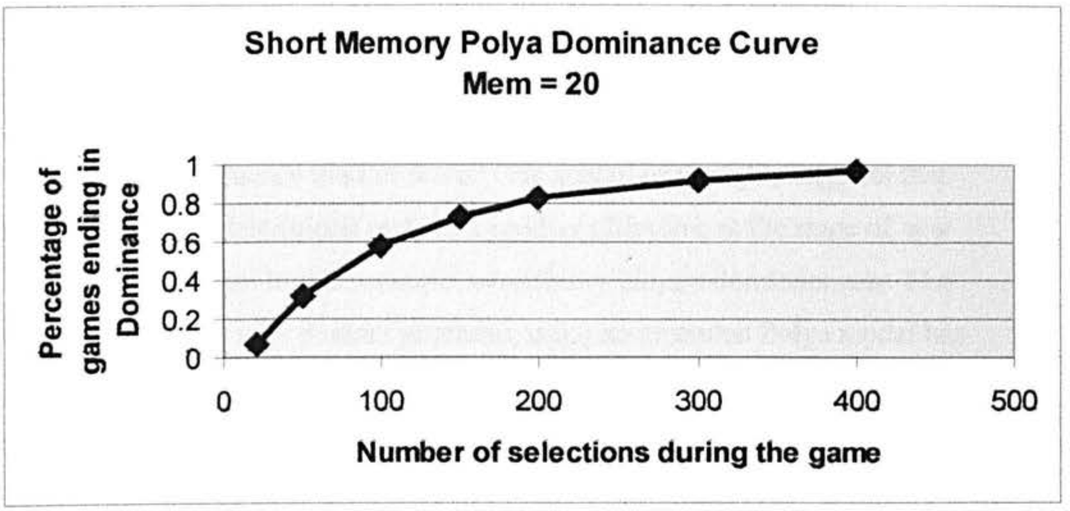
a)


Short Memory Polya Dominance Curve
Mem = 5
Percentage of games ending in Dominance
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
120
Number of selections during the game

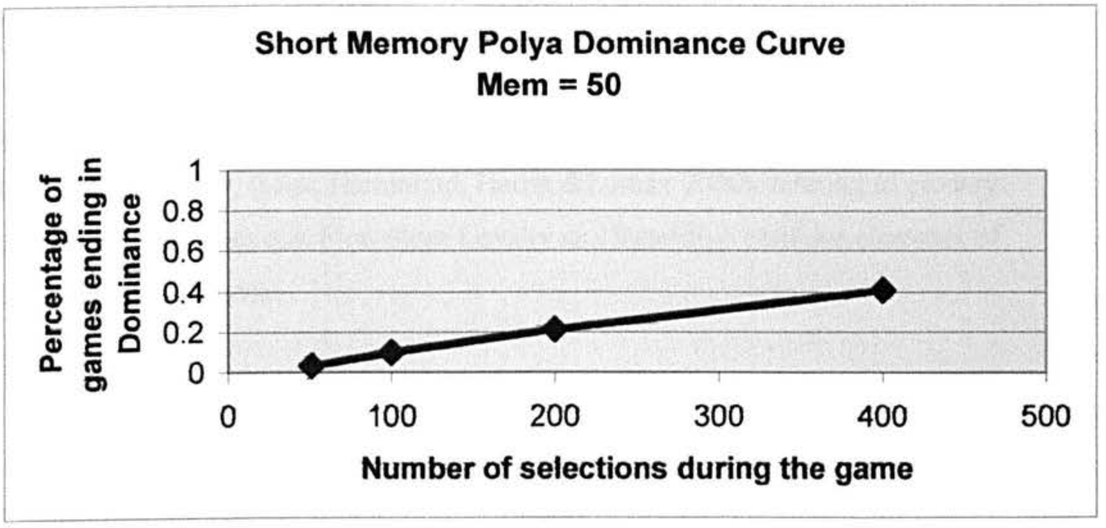
b)


Short Memory Polya Dominance Curve
Mem = 10
Percentage of games ending in Dominance
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
Number of selections during the game

c)



d)



Marketing loyalty and retention

The experiment throws some light upon a recurrent problem in marketing. The purpose and efficacy of advertising has long been a source of debate. The issues are well delineated in the area of tobacco advertising. Anti smoking groups claim that advertising encourages people to smoke, who otherwise would not do so. The Tobacco Industry points to countries like Finland, where all tobacco advertising is banned and yet smoking has not declined (Metra Consulting Group Report 1980). The remarkable increase in smoking that followed the American

Congress' ban on media advertising in 1970 is even more confounding (Hamilton 1972, Doron 1979).

If advertising is ineffective in determining whether products are bought or not, then what does influence market share? One school of thought, suggests that market shares are determined early in a products lifetime, at the stage of new product introduction. In this scenario, availability plays a dominant role. The micro-dynamics of new product purchase, using an extended Polya model has been studied (Wagner & Taudes 1991) as well as purchase timing (Wagner & Taudes 1986) and order of entry (Bowman & Gatignon 1996). One example of this effect within the New Economy is Daishin Securities whose early entry into cyber trading was cited, by Business Korea in December 1999, as its reason for having the largest Market share. These views are congruent with some, within the Marketing discipline, who argue that advertising in established markets serves mainly to keep existing buyers (Ehrenberg 1974).

A marketing study, (East, Hammond, Harris &Lomax 2000), relating to grocery purchasing, indicates that First Store Loyalty and Retention contains elements of serendipity and inertia:

"*About half of the reasons for switching were related to store accessibility*". And , "*The evidence that brand loyalty is associated with First Store Retention, suggests that a proneness for routine may also be a basis for this form of loyalty*".

Two situations were discussed, relating to customer loyalty, in terms of the percentage of expenditure at the 'First Store'. The first situation considered those shoppers who bought all of their groceries from one store. It was noted that this situation restricts trial and therefore makes any substitution of the First Store less likely. The second situation considered shoppers who purchased from three stores. It was pointed out that relatively small changes in share can displace the current dominant store. Both of these scenarios can be modelled using the Polya urn where the number of different coloured balls would relate to the number of stores.

There are many examples in the business world where the Polya urn process appears to mimic the dynamics of a system. Market shares, of competing products, come to mind, although in reality the three stages are blurred and the process may be interfered with in order to try and change outcomes. The almost saturated availability of Pepsi and Coca cola suggest a situation redolent of stage three, where changing the market share requires significant intervention by either company. In the electronics industry a similar comparison can be made between Intel and AMD, the producers of microprocessors.

If the Polya urn process determines the market share of competing firms then it makes fools of those who spend money on advertising and perhaps, more fundamentally, it offers no explanation of how monopolies can develop. This second point, relating to monopolies, is interesting since a perfect monopoly is excluded in the Polya urn process (a perfect monopoly would be all red or all blue, but there is *always* the one ball of the opposite colour that was there at the initial condition). If the Polya urn process did apply to all market share situations then Betamax videos would still be viable, in spite of having a small market share. This would be similar to the way that Apple computers have a small, but stable, portion of the personal computer market. In reality, many products become extinct through domination of the market by a competitor and the Polya urn does not cater this for. However, a simple modification to the process can make it capable of producing monopolies as well as offering an explanation of why advertising makes sense.

An embedded feature of the Polya process is that all balls in the urn have an equal influence upon future outcomes. This does not map well into reality. Consider the situation where the item being equated to a coloured ball is a product, and the urn is seen as the marketplace. In such a system the products can be consumable, perishable or even virtual; and the model of the marketplace filling up forever with these products, like balls in an infinite urn breaks down. The products themselves are dynamic, they have a lifetime and their influence is temporal rather than absolute.

Taking these issues into account leads to the proposal of giving the balls a limited lifetime. This amendment reflects the variability in the way that past events influence future choices. An alternative, but complimentary way of looking at it, is to limit the size of the urn.

Limiting the size of the urn implies that an economic marketplace has a finite memory. There are many ways to modify the Polya process to achieve this result, but a very simple one has been investigated here, whereby balls are added to and removed from, the urn on a first in first out basis (FIFO). If the capacity of the urn is set at twenty, then the first ball must be removed in order to make a place for the twenty-first addition and so on. Generalized urn schemes that have rules governing the way that balls are selected, removed and added are not new (Gouet 1997) but are mostly confined to the domains of mathematical and statistical research.

Conclusions

In this version of the paper, because of space and time constraints, we provide just one variation upon the theme of memory. We chose this variation precisely because on the face of it, changing the duration of memory produces a counter intuitive result, fixation on a single point, or in multidimensional space, fixation on a set of points. The emphasis is upon fixation upon a particular set of experiences: dominance in the marketing example, dementia if we chose to extend our parallel to that of *felt* experiences.

We conclude by referring to some of the work of the Centre for International Business (CIBP) at Kingston University. One of the key issues addressed is that of complexity, and complex adaptive systems. Chaos, randomness and path dependence form a subset of the study of complexity, which in the biological sciences has high practical applicability: certainly it rises above the status of mere metaphor that it is currently accorded in the business sciences. We hope this contribution will be considered a contribution to a view of complexity studies as a practical business tool.

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Appendix 8 The full results from computer simulation number 2:Verhulst logistic growth with lifetime component, interacting with a market value landscape, an intermediary simulation.

Figures 14a to 14r relate to a Marketplace that has a constant, fixed level, of demand Fig 14a LT1_G1.5

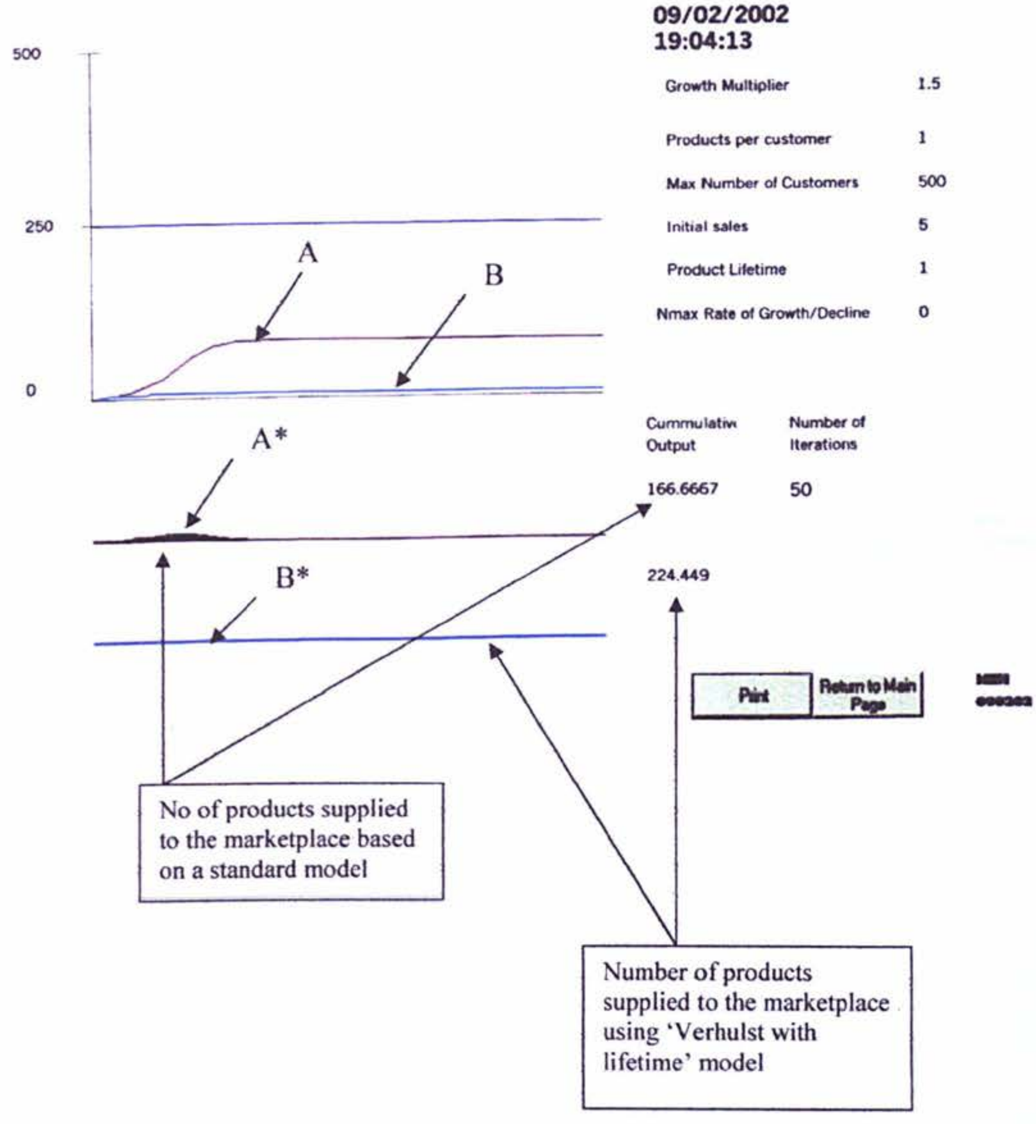
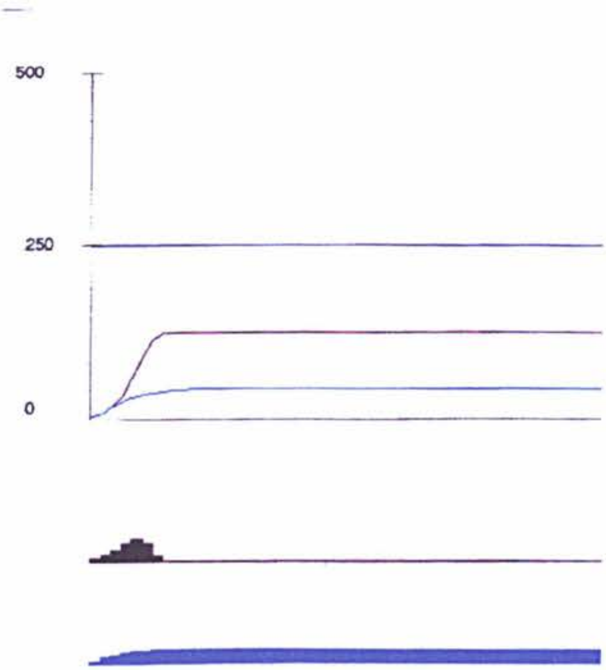


Fig 14b LT1_G2.0



09/02/2002
19:06:29

Growth Multiplier	2
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	1
Nmax Rate of Growth/Decline	0

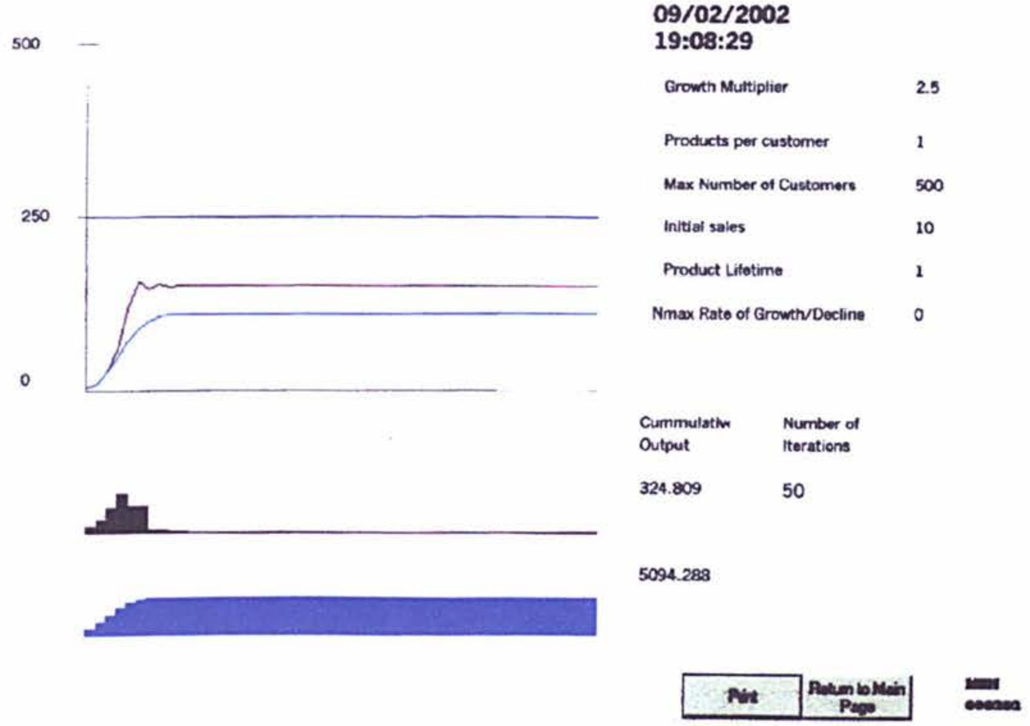
Cummulative Output	Number of Iterations
250	50

1916.017

Print | Return to Main Page

LT = Lifetime of the Product G = Growth multiplier

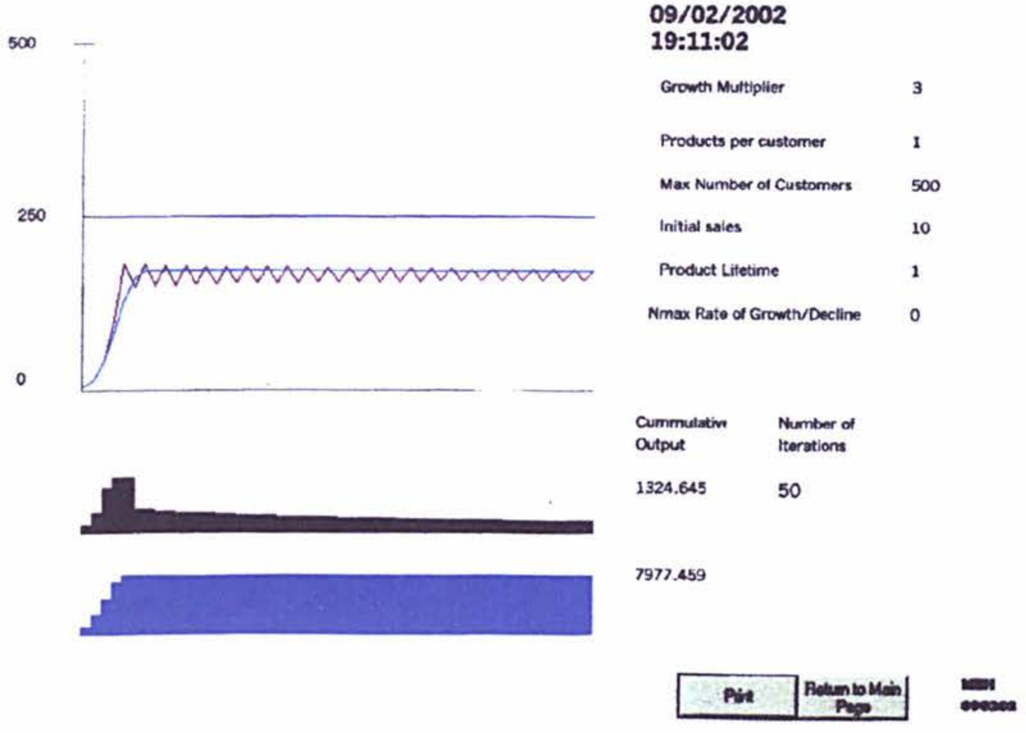
Fig 14c LT1_G2.5



LT = Lifetime of the Product G = Growth multiplier

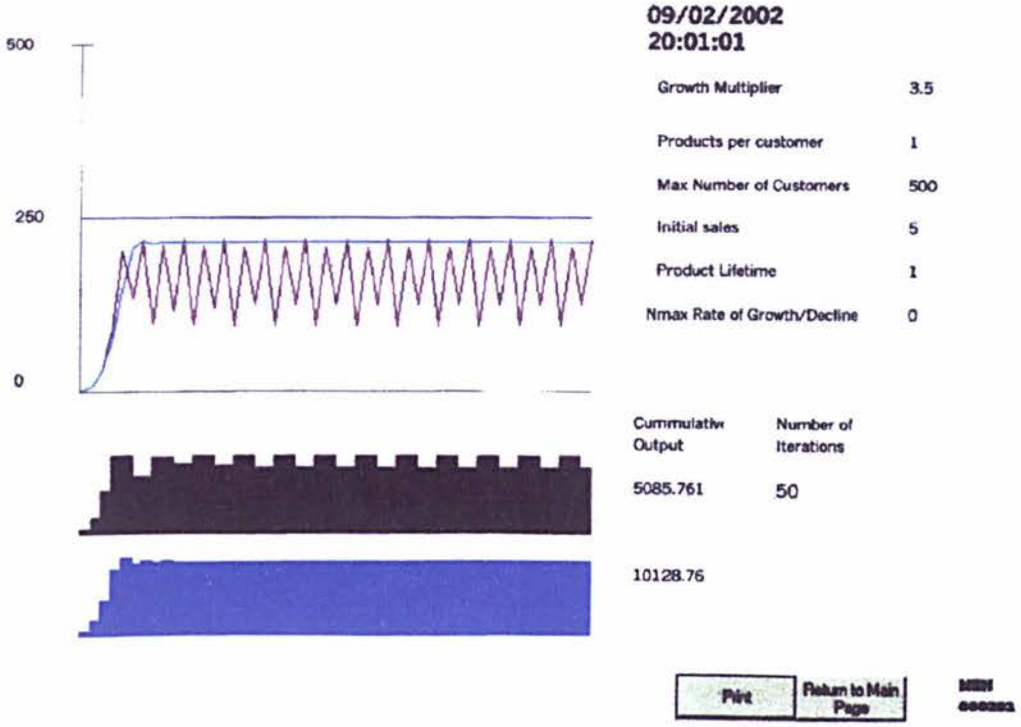
Fig 14d

LT1_G3.0



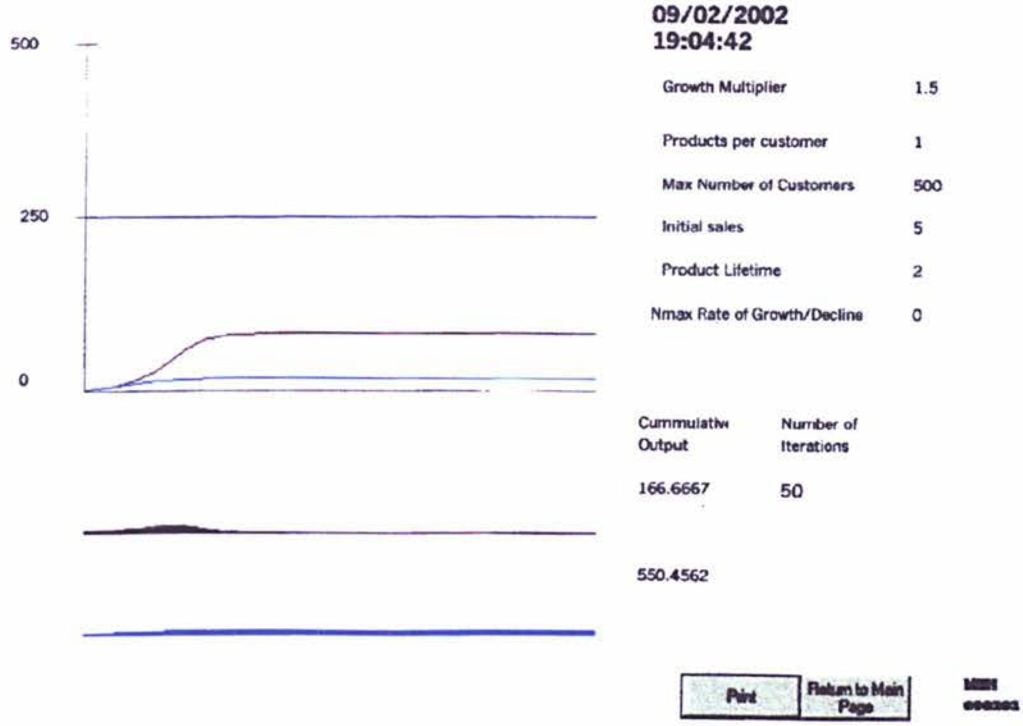
LT = Lifetime of the Product   G = Growth multiplier

Fig 14e LT1_G3.5



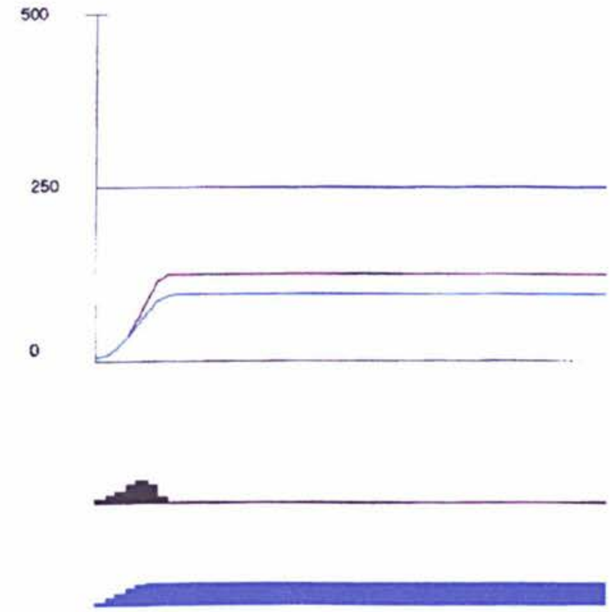
LT = Lifetime of the Product G = Growth multiplier

Fig 14f LT2_G1.5



LT = Lifetime of the Product G = Growth multiplier

Fig 14g LT2_G2.0



09/02/2002
19:07:00

Growth Multiplier	2
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	2
Nmax Rate of Growth/Decline	0

Cummulative Output	Number of Iterations
250	50

2969.094

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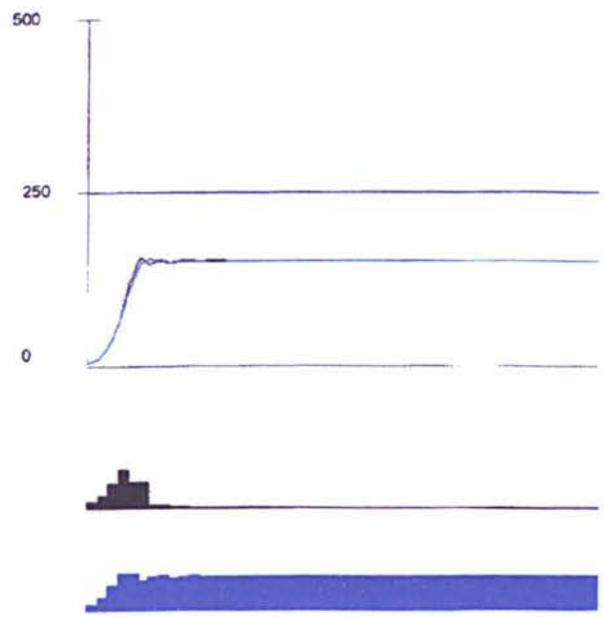
LT = Lifetime of the Product G = Growth multiplier

Fig 14h LT2_G2.5



09/02/2002
19:08:52

Growth Multiplier	2.5
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	2
Nmax Rate of Growth/Decline	0

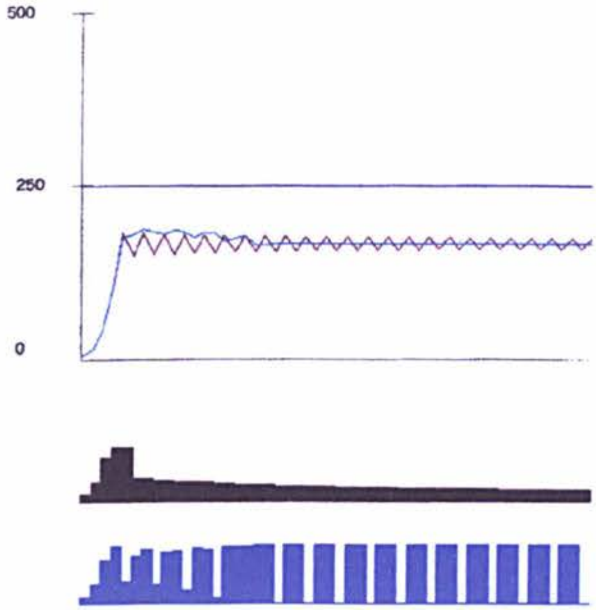
Cummulative Output	Number of Iterations
324.809	50

4717.668

Print | Return to Main Page

LT = Lifetime of the Product G = Growth multiplier

Fig 14i LT2_G3.0



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19:11:36

Growth Multiplier	3
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	2
Nmax Rate of Growth/Decline	0

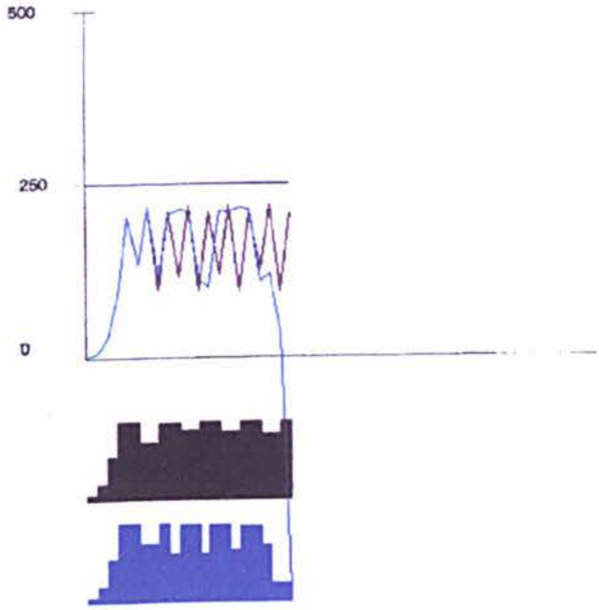
Cummulative Output	Number of Iterations
1324.645	50

5454.905

Print | Return to Main Page

LT = Lifetime of the Product G = Growth multiplier

Fig 14j LT2_G3.5



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20:02:29

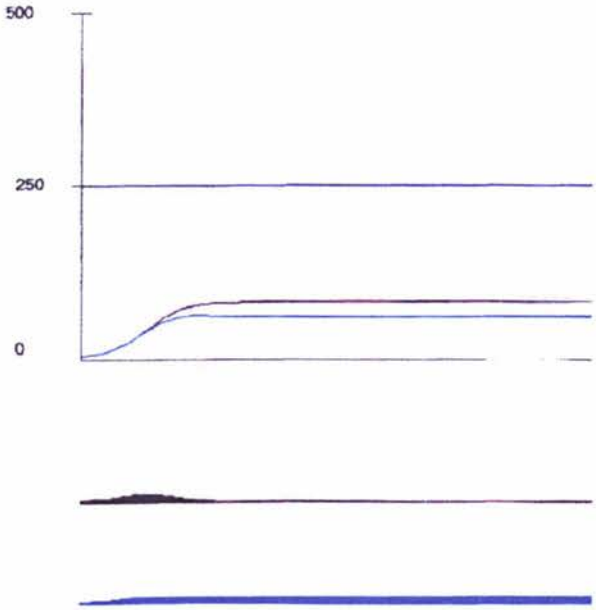
Growth Multiplier	3.5
Products per customer	1
Max Number of Customers	500
Initial sales	5
Product Lifetime	5
Nmax Rate of Growth/Decline	0

Cummulative Output	Number of Iterations
2034.86	20
2294.29	

Print | Return to Main Page

LT = Lifetime of the Product G = Growth multiplier

Fig 14k LT5_G1.5



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19:05:46

Growth Multiplier	1.5
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	5
Nmax Rate of Growth/Decline	0

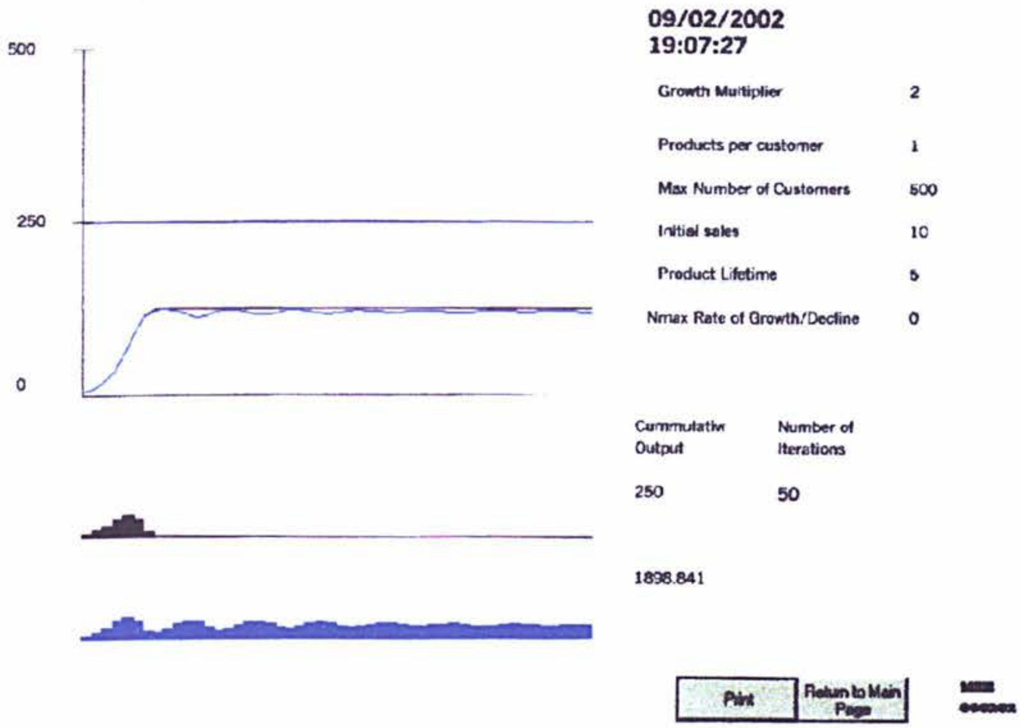
Cummulativ Output	Number of Iterations
166.6667	50

928.3288

Print | Return to Main Page

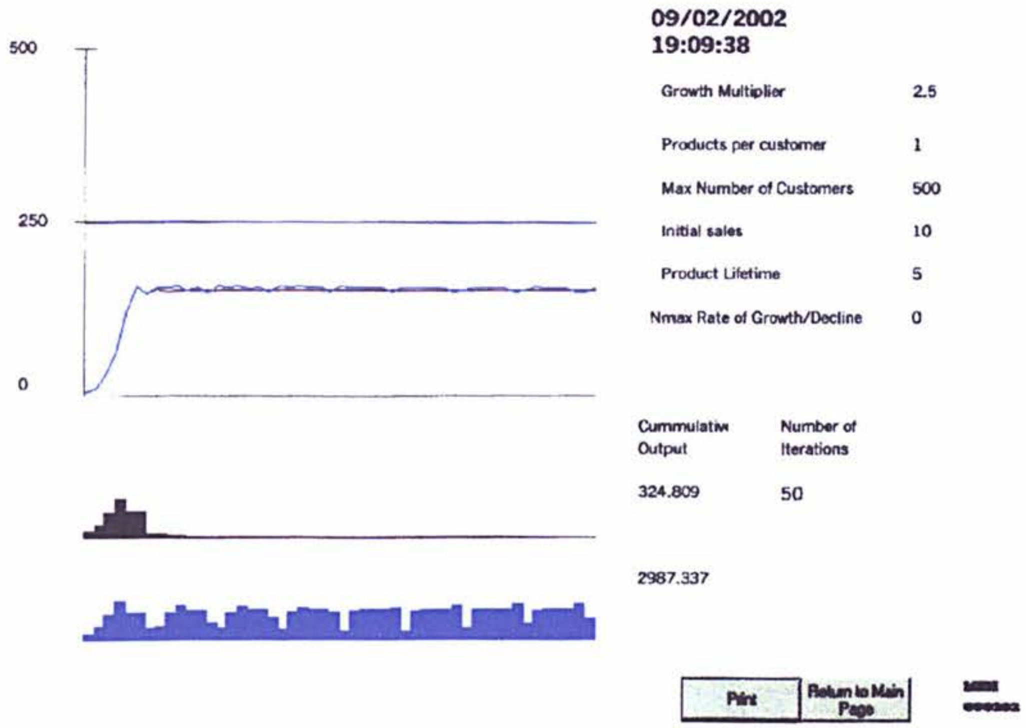
LT = Lifetime of the Product G = Growth multiplier

Fig 14l LT5_G2.0



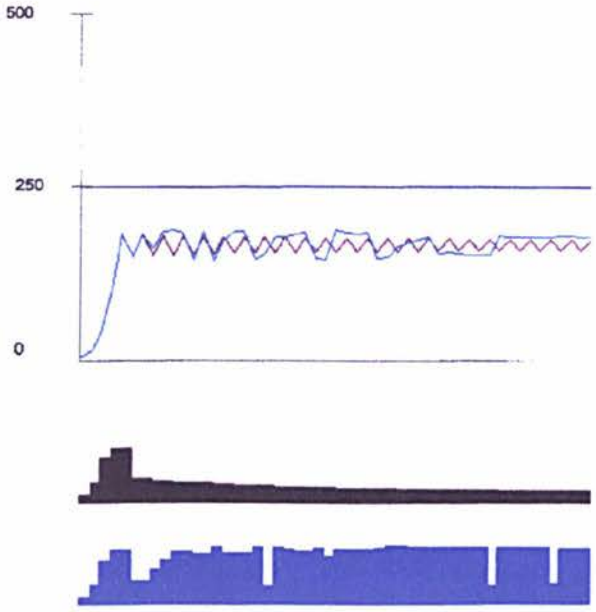
LT = Lifetime of the Product G = Growth multiplier

Fig 14m LT5_G2.5



LT = Lifetime of the Product G = Growth multiplier

Fig 14n LT5_G3.0



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19:13:00

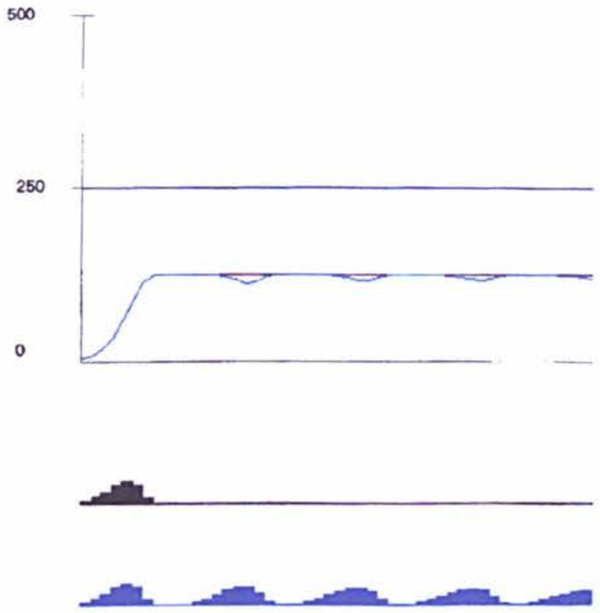
Growth Multiplier	3
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	5
Nmax Rate of Growth/Decline	0

Cummulative Output	Number of Iterations
1324.645	50

5917.033

Print | Return to Main Page

Fig 14o LT10_G2.0



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Growth Multiplier	2
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	10
Nmax Rate of Growth/Decline	0

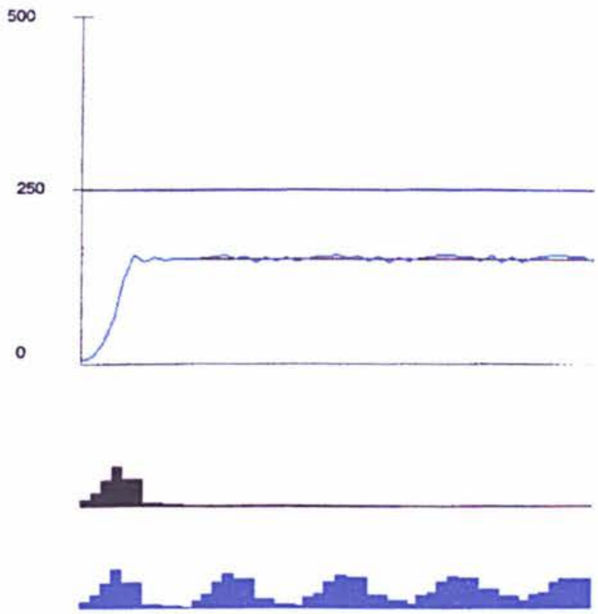
Cummulative Output	Number of Iterations
250	50

1127.899

Print | Return to Main Page

LT = Lifetime of the Product G = Growth multiplier

Fig 14p LT10_G2.5



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Growth Multiplier	2.5
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	10
Nmax Rate of Growth/Decline	0

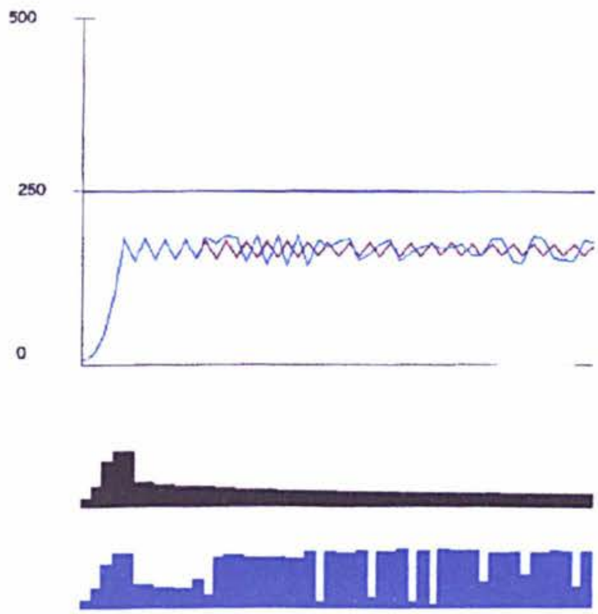
Cummulative Output	Number of Iterations
324.809	50

1818.239

Print | Return to Main Page

LT = Lifetime of the Product G = Growth multiplier

Fig 14q LT10_G3.0



09/02/2002
19:13:51

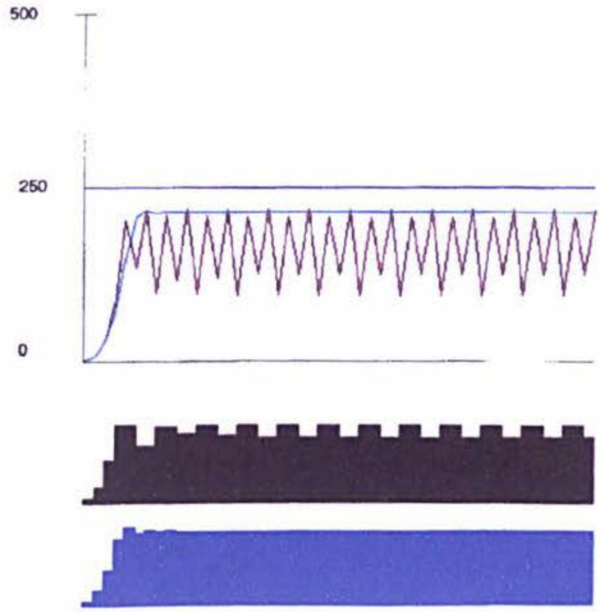
Growth Multiplier	3
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	10
Nmax Rate of Growth/Decline	0

Cummulative Output	Number of Iterations
1324.645	50
4281.981	

Print | Return to Main Page

LT = Lifetime of the Product G = Growth multiplier

Fig 14r LT10_G3.5



09/02/2002
20:01:01

Growth Multiplier	3.5
Products per customer	1
Max Number of Customers	500
Initial sales	5
Product Lifetime	1
Nmax Rate of Growth/Decline	0

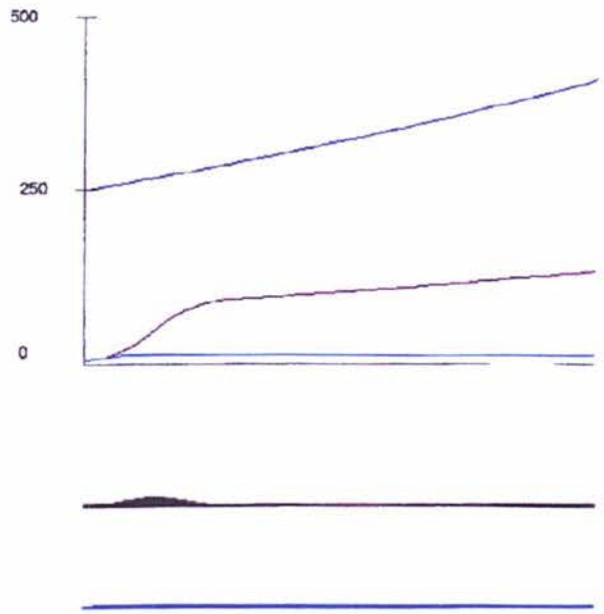
Cummulativ Output	Number of Iterations
5085.761	50
10128.76	

Print | Return to Main Page

LT = Lifetime of the Product G = Growth multiplier

Figures 20s to 20af relate to a Marketplace that has a steadily increasing level of demand of +1% per growth cycle

Fig 14s GM LT1_G.15



09/02/2002
19:26:57

Growth Multiplier	1.5
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	1
Nmax Rate of Growth/Decline	0.01

Cummulative Output	Number of Iterations
268.6233	50

423.8029

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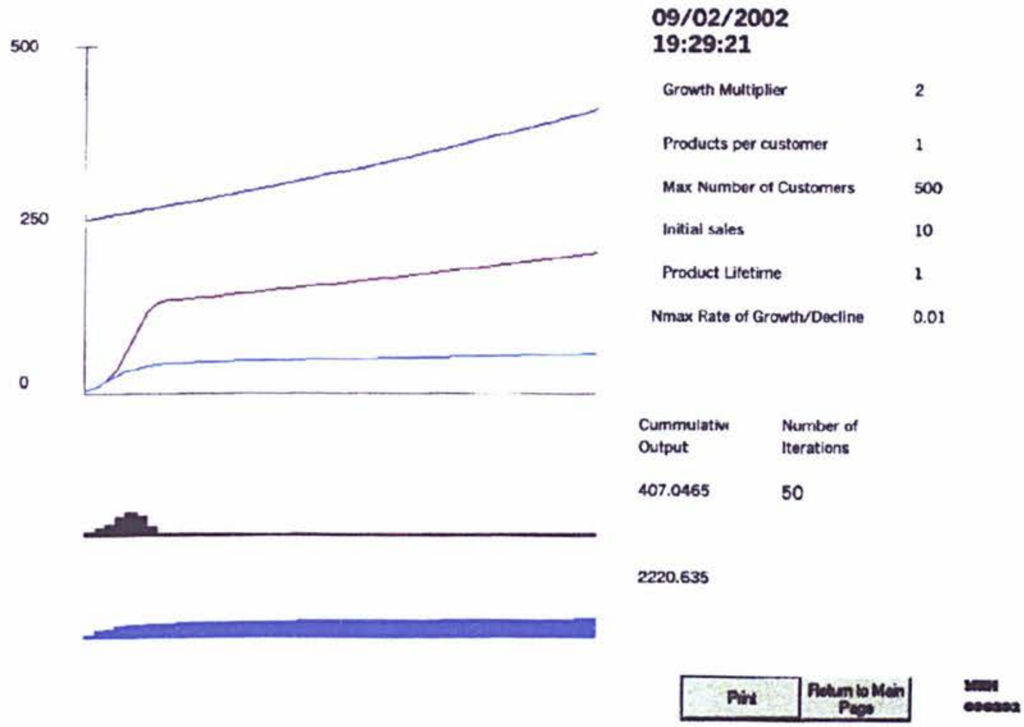
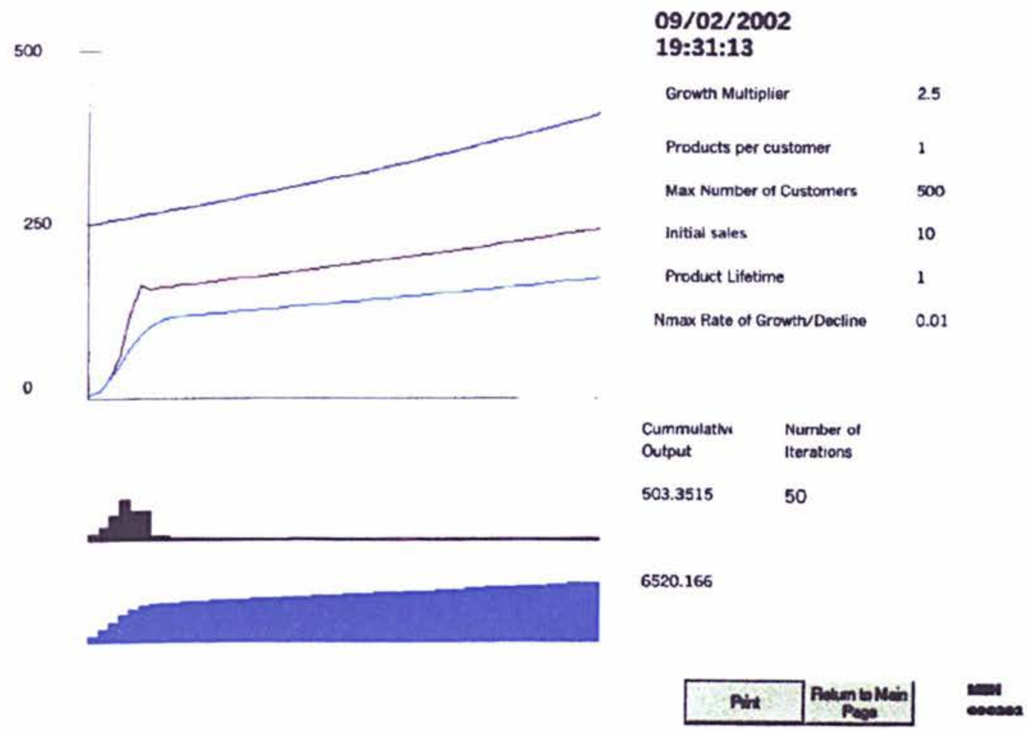
Fig 14t GM LT1_G2.0



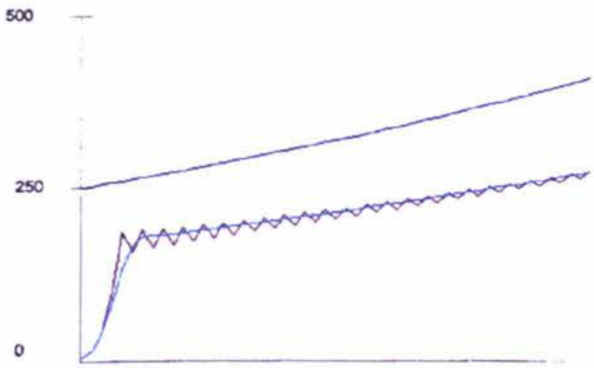
LT = Lifetime of the Product G = Growth multiplier

Fig 14u GM LT1_G2.5



LT = Lifetime of the Product G = Growth multiplier

Fig 14v GM LT1_G3.0



09/02/2002
19:32:51

Growth Multiplier	3
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	1
Nmax Rate of Growth/Decline	0.01

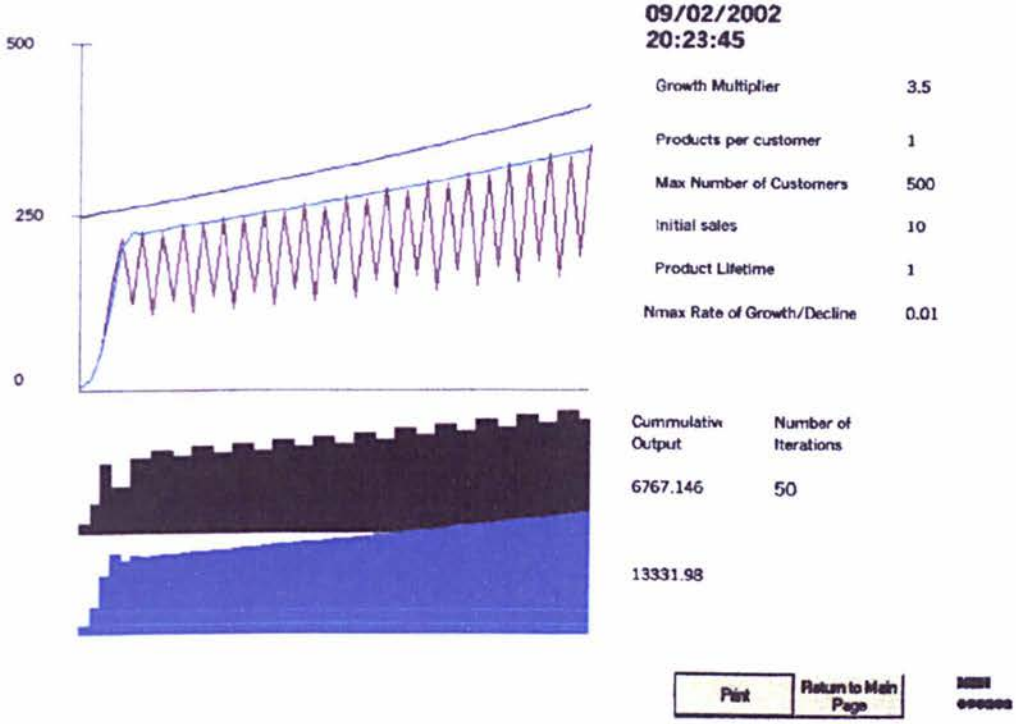
Cummulative Output	Number of Iterations
1168.818	50

10392.96

Print | Return to Main Page

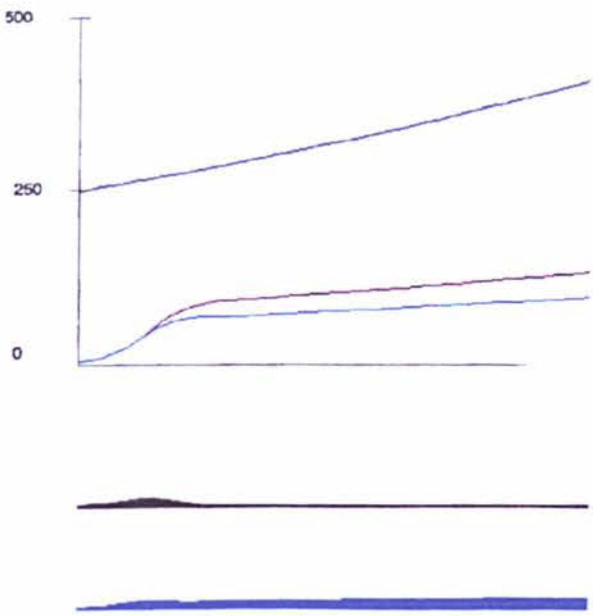
LT = Lifetime of the Product G = Growth multiplier

Fig 14w GM LT1_G3.5



LT = Lifetime of the Product G = Growth multiplier

Fig 14x GM LT5_G1.5



09/02/2002
19:27:57

Growth Multiplier	1.5
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	5
Nmax Rate of Growth/Decline	0.01

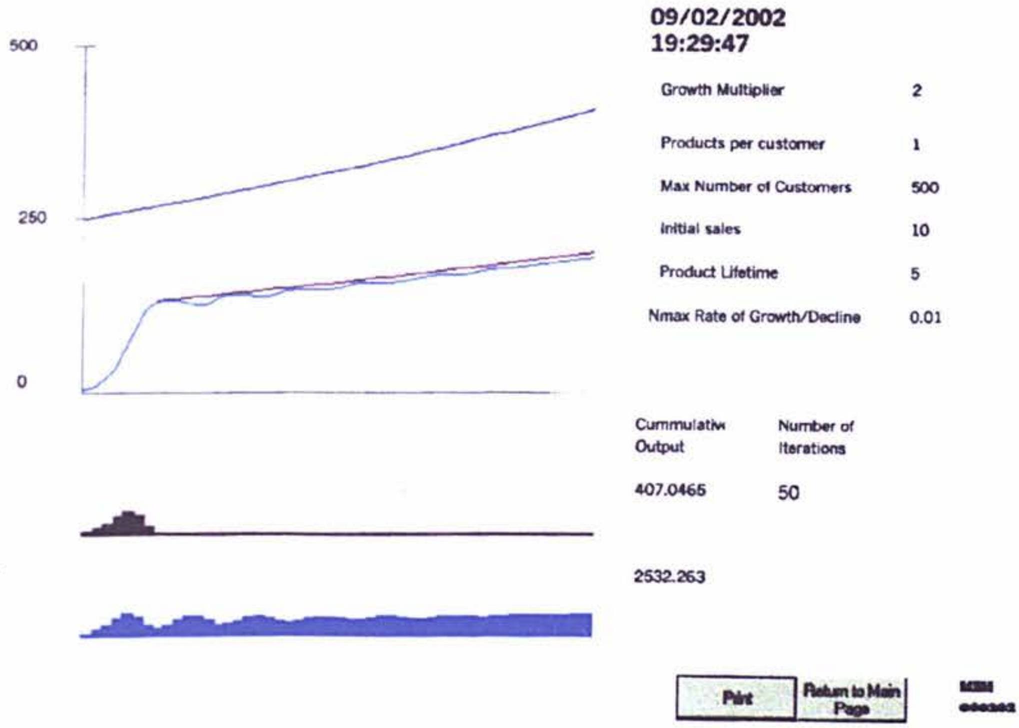
Cummulative Output	Number of Iterations
268.6233	50

1229.293

Print | Return to Main Page

LT = Lifetime of the Product G = Growth multiplier

Fig 14y GM LT5_G2.0



LT = Lifetime of the Product G = Growth multiplier

Fig 14z GM LT5_G2.5

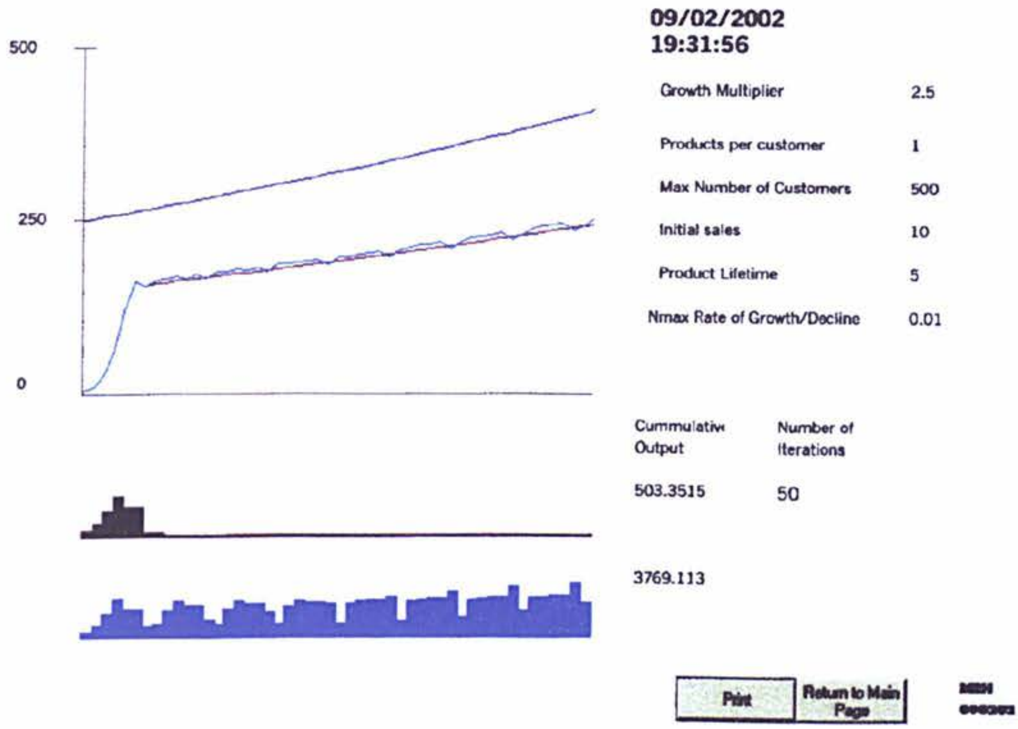
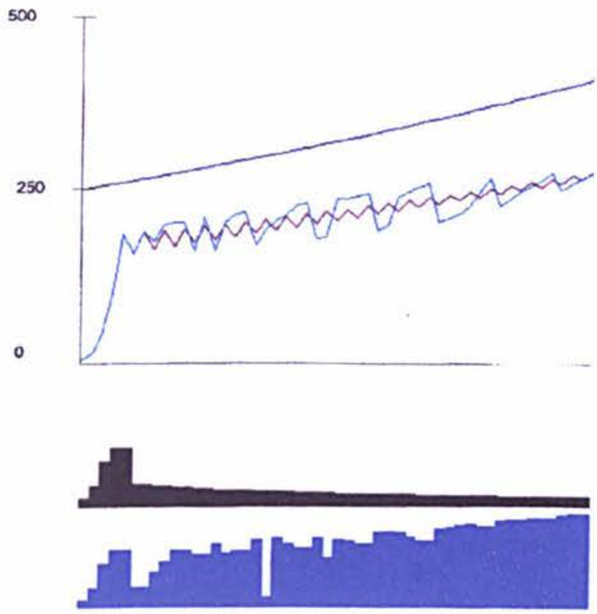


Fig 14a GM LT5_G3.0



09/02/2002
19:33:20

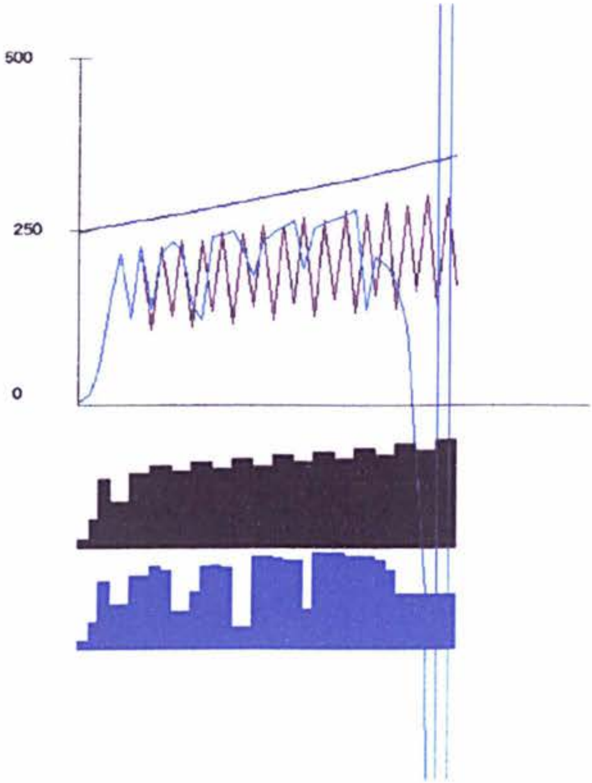
Growth Multiplier	3
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	5
Nmax Rate of Growth/Decline	0.01

Cummulative Output	Number of Iterations
1168.818	50
7464.162	

Print | Return to Main Page

LT = Lifetime of the Product   G = Growth multiplier

Fig 14ab GM LT5_G3.5



09/02/2002
20:27:06

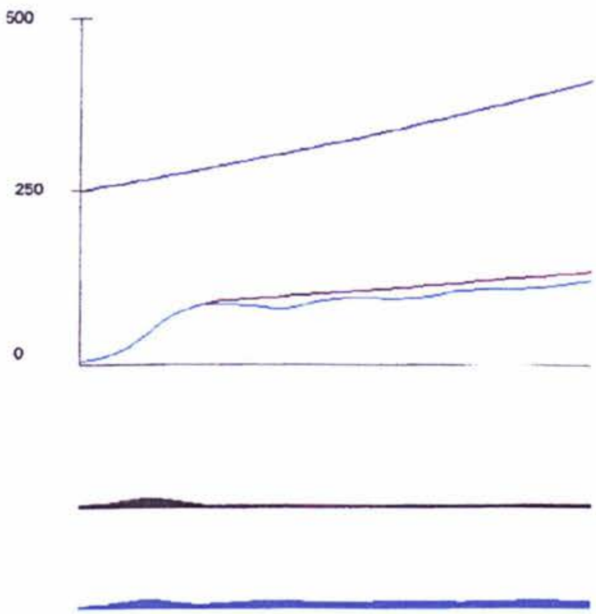
Growth Multiplier	3.5
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	5
Nmax Rate of Growth/Decline	0.01

Cummulative Output	Number of Iterations
4535.118	37

5323.172

Print | Return to Main Page

Fig 14ac GM LT10_G1.5



09/02/2002
19:28:52

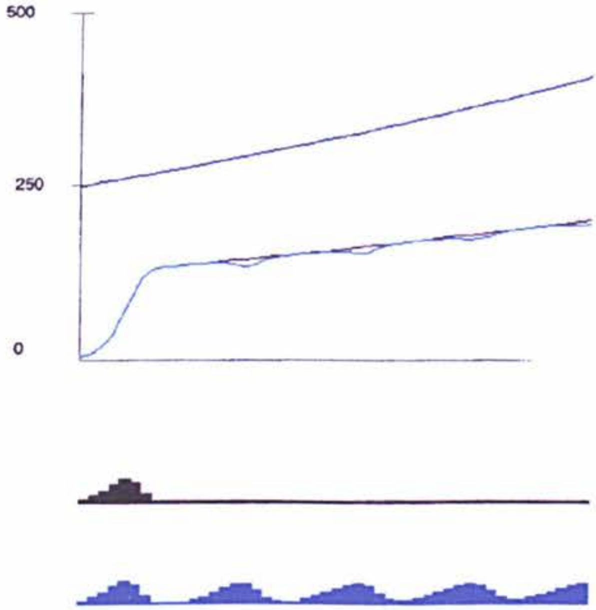
Growth Multiplier	1.5
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	10
Nmax Rate of Growth/Decline	0.01

Cummulative Output	Number of Iterations
268.6233	50

863.1995

LT = Lifetime of the Product G = Growth multiplier

Fig 14ad GM LT10_G2.0



09/02/2002
19:30:17

Growth Multiplier	2
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	10
Nmax Rate of Growth/Decline	0.01

Cummulative Output	Number of Iterations
407.0465	50

1524.572

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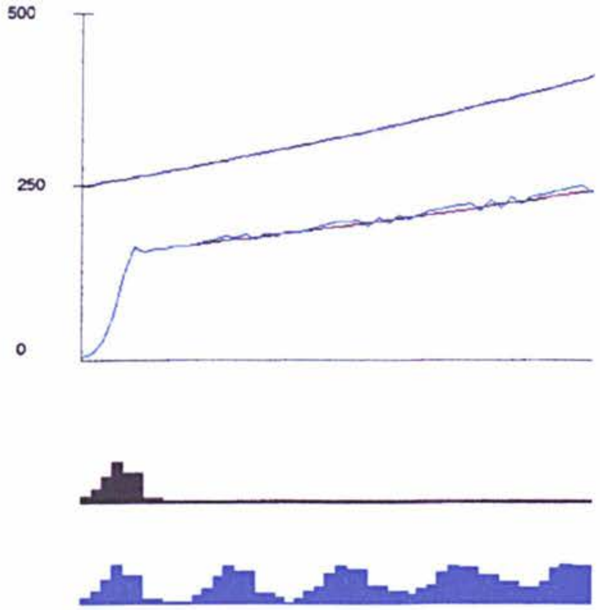
Fig 14ae GM LT10_G2.5



09/02/2002
19:32:23

Growth Multiplier	2.5
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	10
Nmax Rate of Growth/Decline	0.01

Cummulative Output	Number of Iterations
503.3515	50

2253.72

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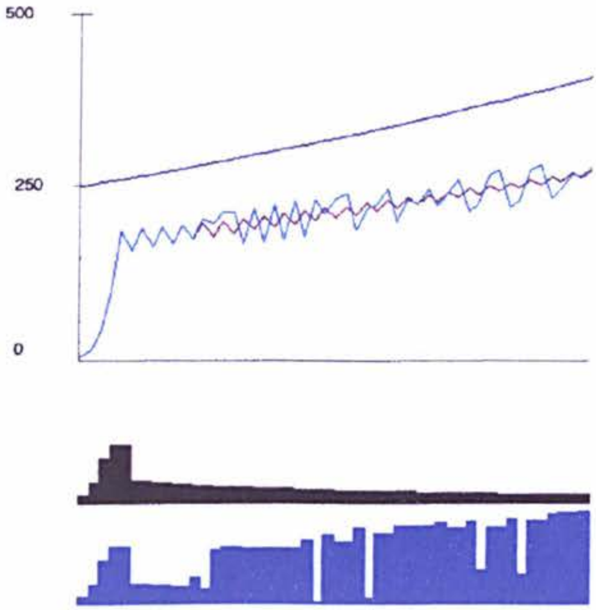
Fig 14af GM LT10_G3.0



09/02/2002
19:33:47

Growth Multiplier	3
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	10
Nmax Rate of Growth/Decline	0.01

Cummulative Output	Number of Iterations
1168.818	50
5304.858	

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Figures 20ag to 20s relate to a Marketplace that has a steadily decreasing level of demand of -1% per growth cycle

Fig 14ag DM LT1_G1.5

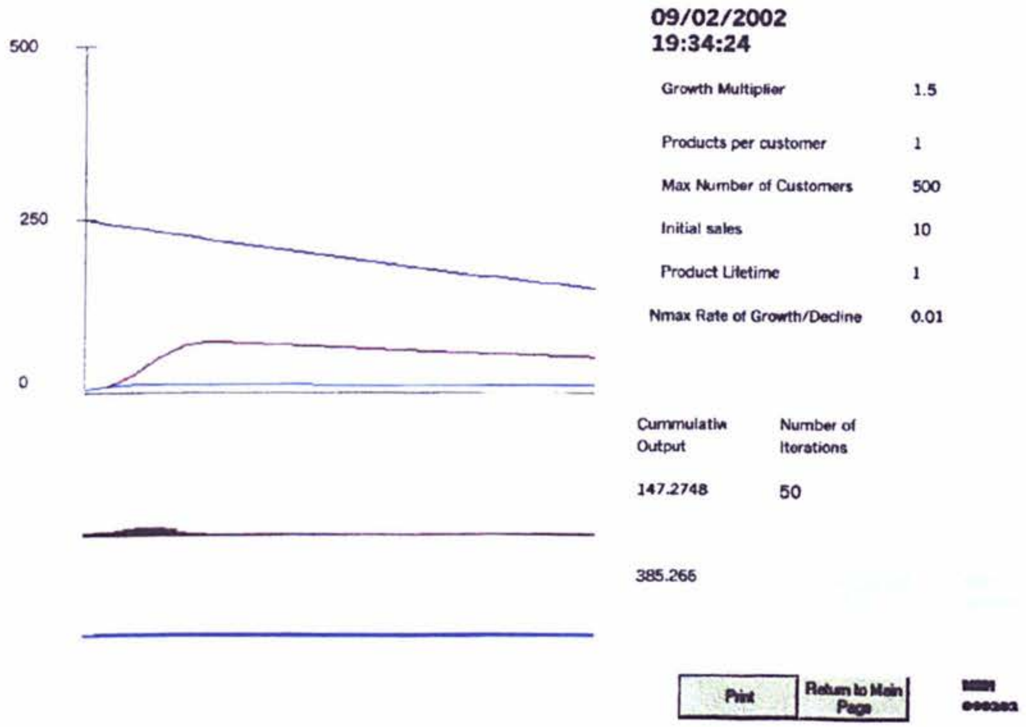
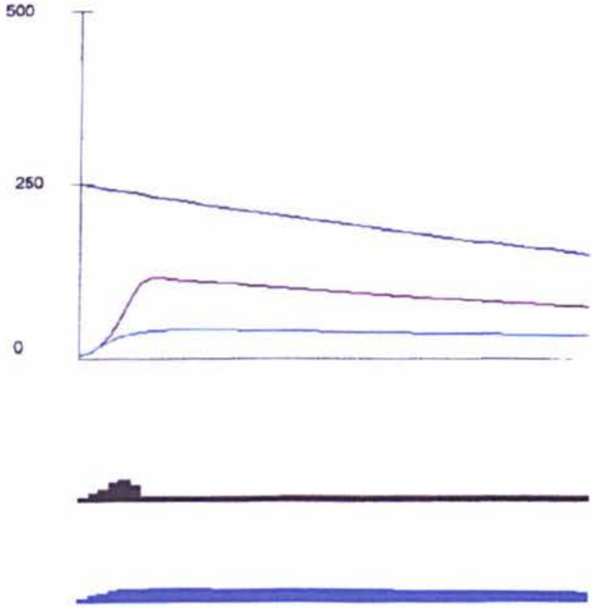


Fig 14ah DM LT1_G2.0



09/02/2002
19:36:38

Growth Multiplier	2
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	1
Nmax Rate of Growth/Decline	0.01

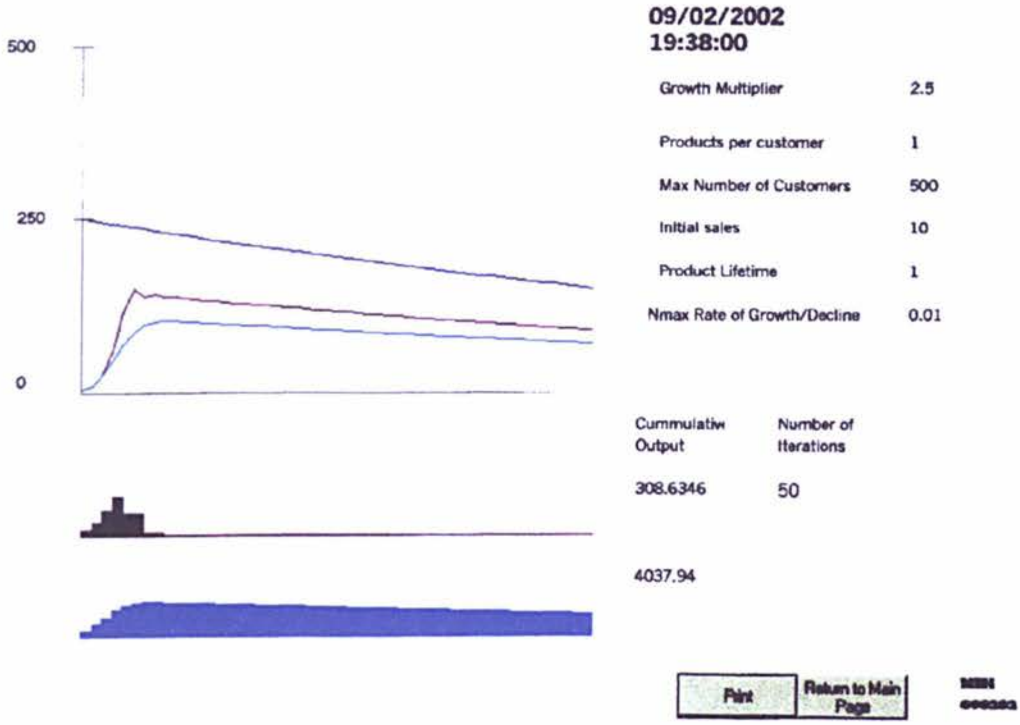
Cummulativ Output	Number of Iterations
234.7509	50

1647.072

Print | Return to Main Page

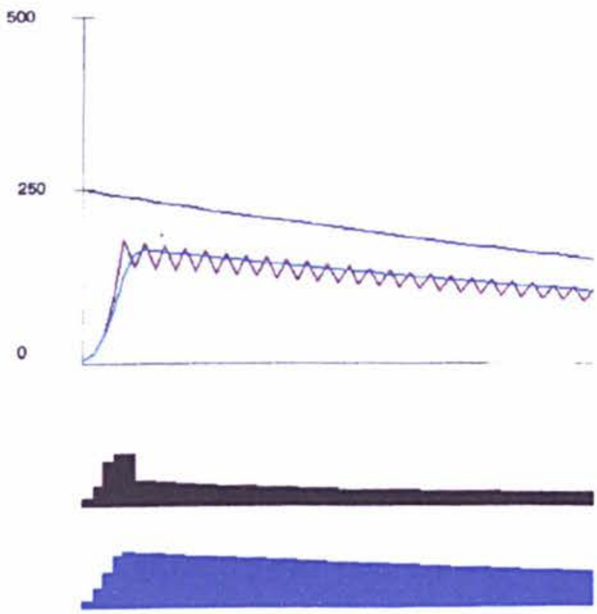
LT = Lifetime of the Product G = Growth multiplier

Fig 14ai DM LT1_G2.5



LT = Lifetime of the Product G = Growth multiplier

Fig 14aj DM LT1_G3.0



09/02/2002
19:39:22

Growth Multiplier	3
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	1
Nmax Rate of Growth/Decline	0.01

Cummulative Output	Number of Iterations
1418.613	50

6219.649

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Fig 14ak DM LT1_G3.5

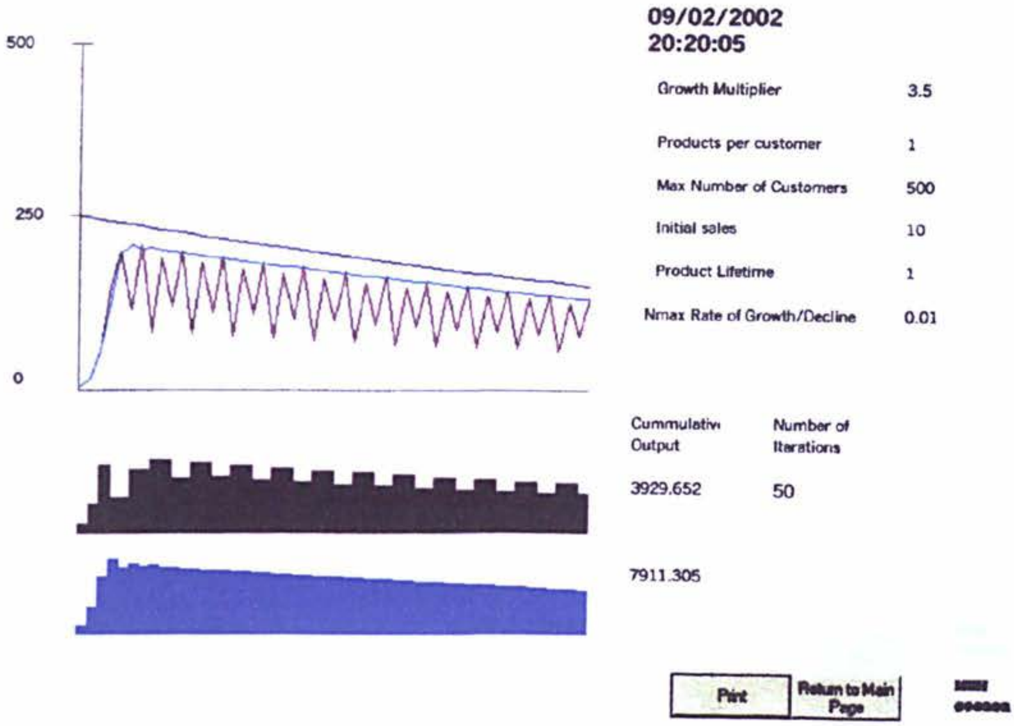
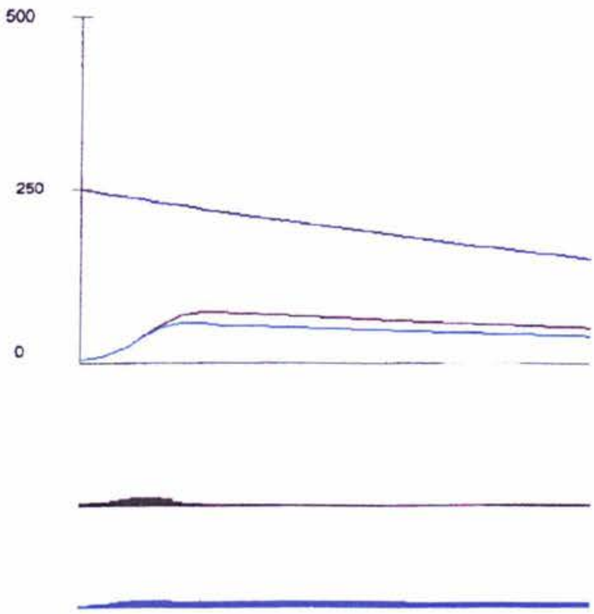


Fig 14al DM LT5_G1.5



09/02/2002
19:34:59

Growth Multiplier	1.5
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	5
Nmax Rate of Growth/Decline	0.01

Cummulativ Output	Number of Iterations
147.2748	50

710.3383

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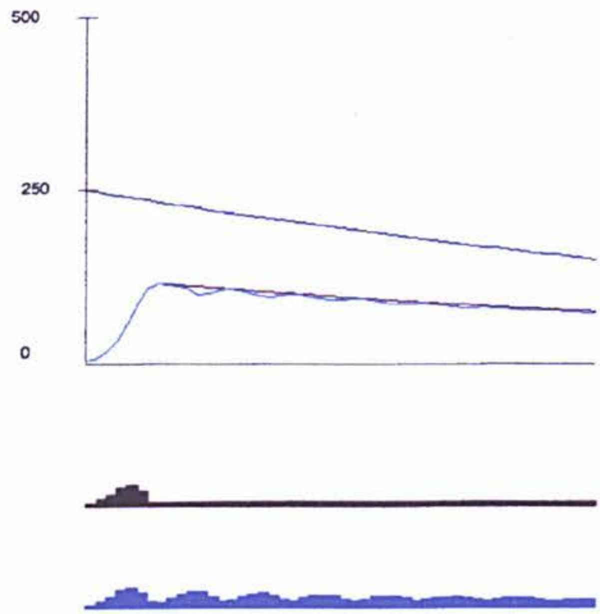
Fig 14am DM LT5_G2.0



09/02/2002
19:37:08

Growth Multiplier	2
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	5
Nmax Rate of Growth/Decline	0.01

Cummulative Output	Number of Iterations
234.7509	50

1445.826

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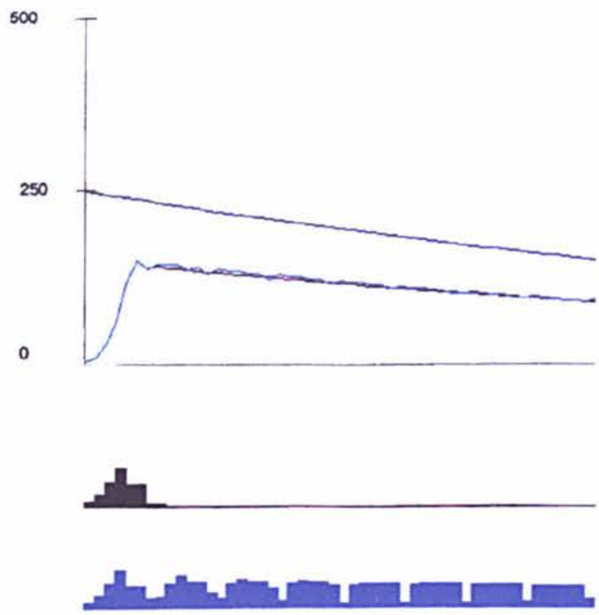
LT = Lifetime of the Product G = Growth multiplier

Fig 14am DM LT5_G2.5



09/02/2002
19:38:26

Growth Multiplier	2.5
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	5
Nmax Rate of Growth/Decline	0.01

Cummulativ Output	Number of Iterations
308.6346	50
2387.532	

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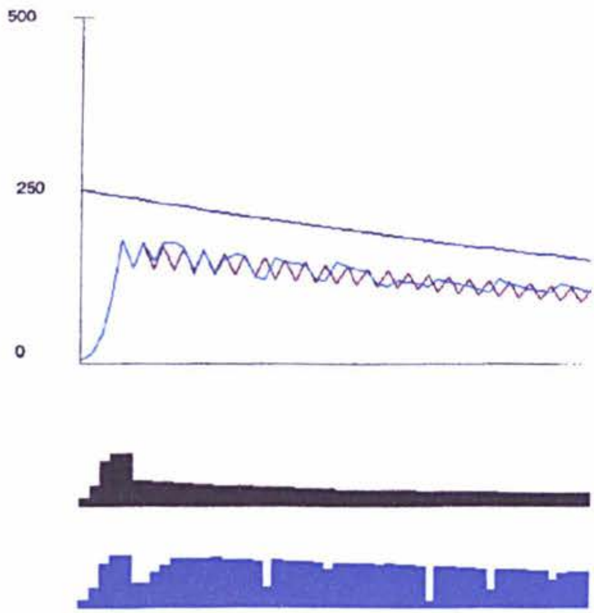
Fig 14an DM LT5_G3.0



09/02/2002
19:39:53

Growth Multiplier	3
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	5
Nmax Rate of Growth/Decline	0.01

Cummulative Output	Number of Iterations
1418.613	50
4711.868	

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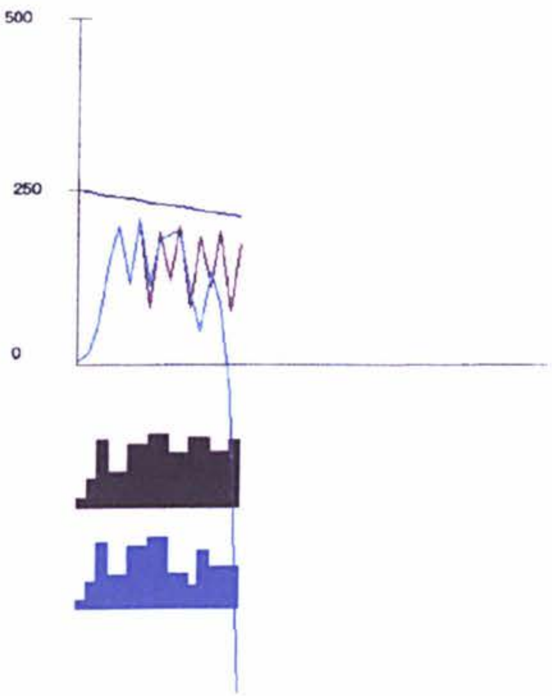
LT = Lifetime of the Product G = Growth multiplier

Fig 14ao DM LT5_G3.5



09/02/2002
20:21:13

Growth Multiplier	3.5
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	5
Nmax Rate of Growth/Decline	0.01

Cummulativ Output	Number of Iterations
1495.053	16
1454.113	

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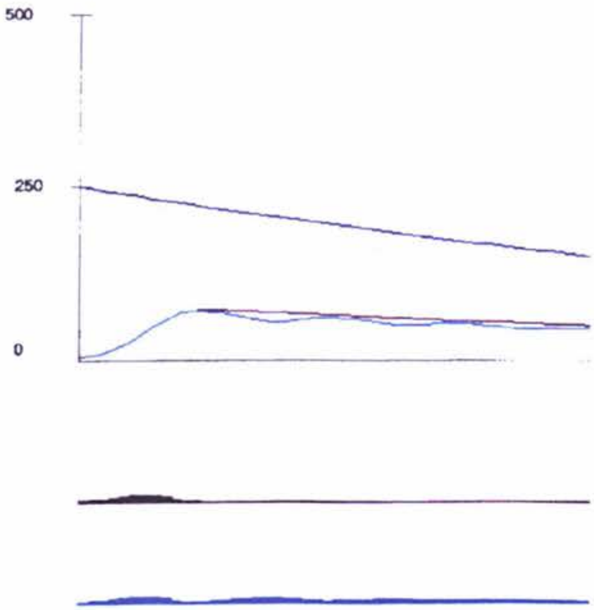
LT = Lifetime of the Product G = Growth multiplier

Fig 14ap   DM LT10_G1.5



09/02/2002
19:36:11

Growth Multiplier	1.5
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	10
Nmax Rate of Growth/Decline	0.01

Cummulative Output	Number of Iterations
147.2748	50

475.4616

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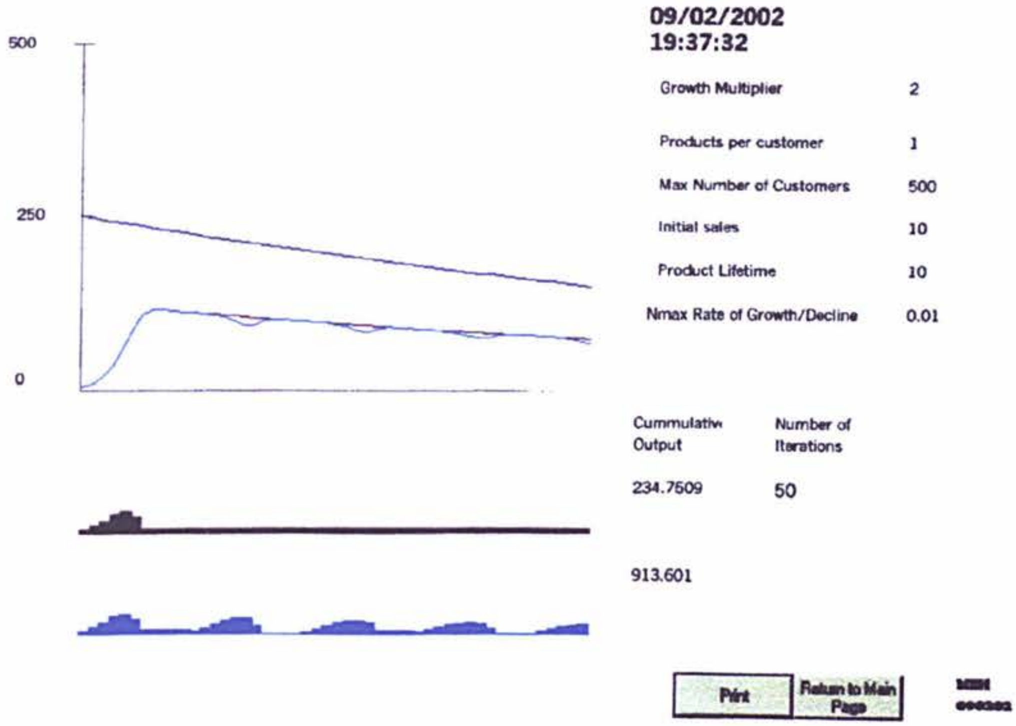
LT = Lifetime of the Product   G = Growth multiplier

Fig 14aq DM LT10_G2.0



LT = Lifetime of the Product G = Growth multiplier

Fig 14ar DM LT10_G2.5

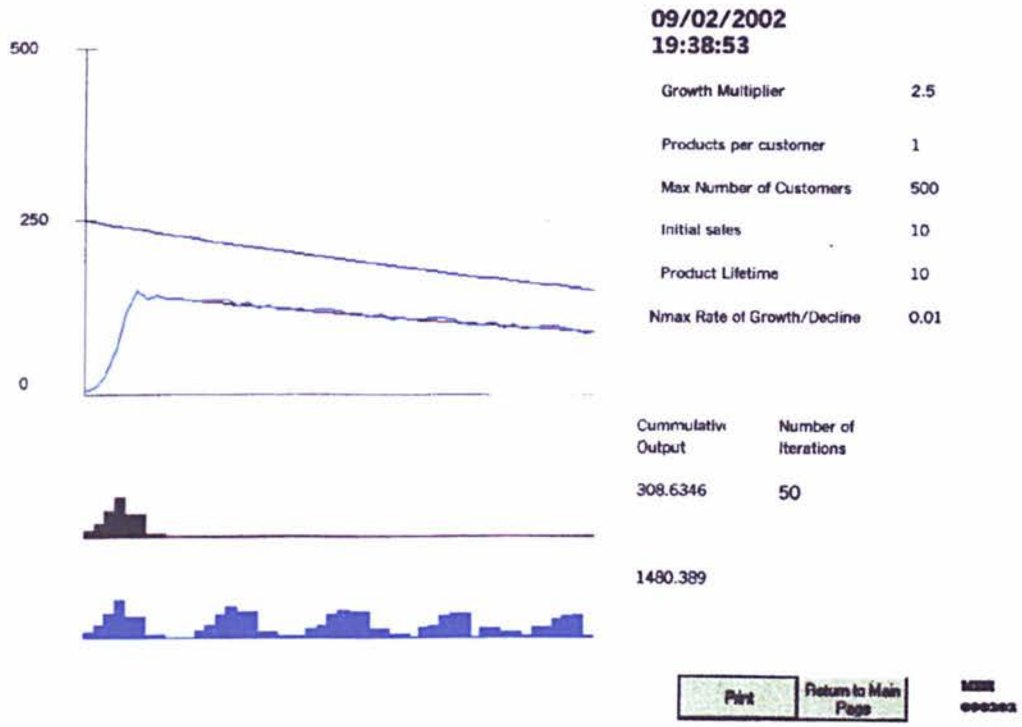
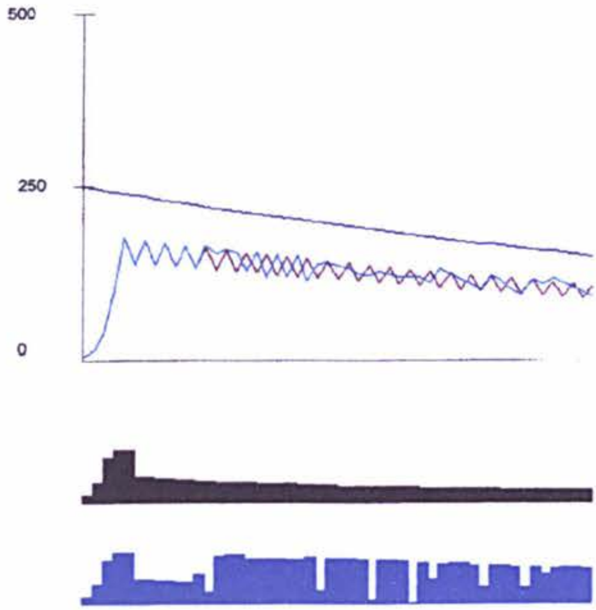


Fig 14as DM LT10_G3.0



09/02/2002
19:40:25

Growth Multiplier	3
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	10
Nmax Rate of Growth/Decline	0.01

Cummulative Output	Number of Iterations
1418.613	50
3474.938	

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Figures 20at to 20ba relate to a Marketplace that receives an upward shock of +5% on the 25th growth cycle (there are 50 cycles in the total simulation)

Fig 14at LT1_G2.0

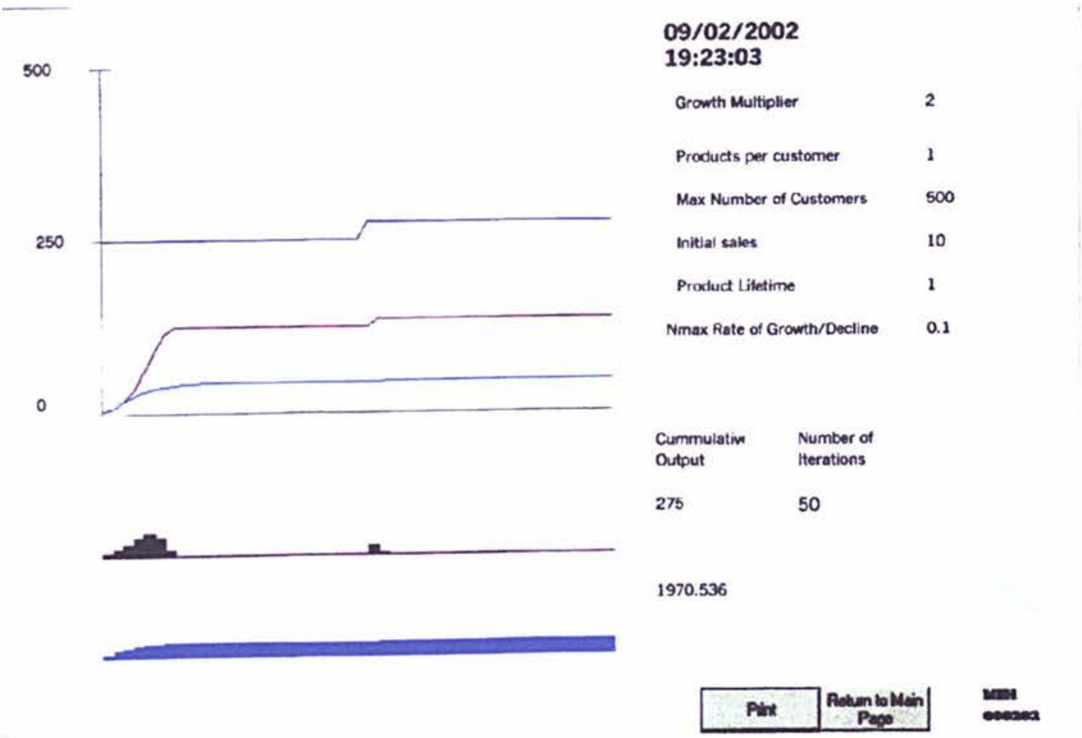
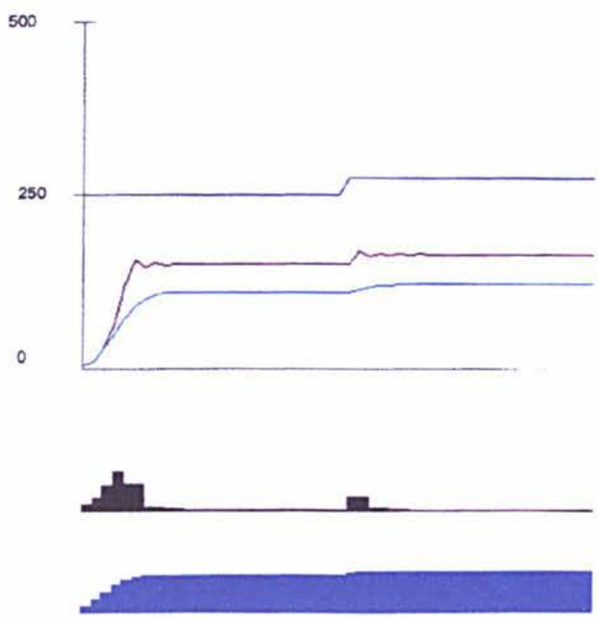


Fig 14au LT1_G2.5



09/02/2002
19:19:43

Growth Multiplier	2.5
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	1
Nmax Rate of Growth/Decline	0.1

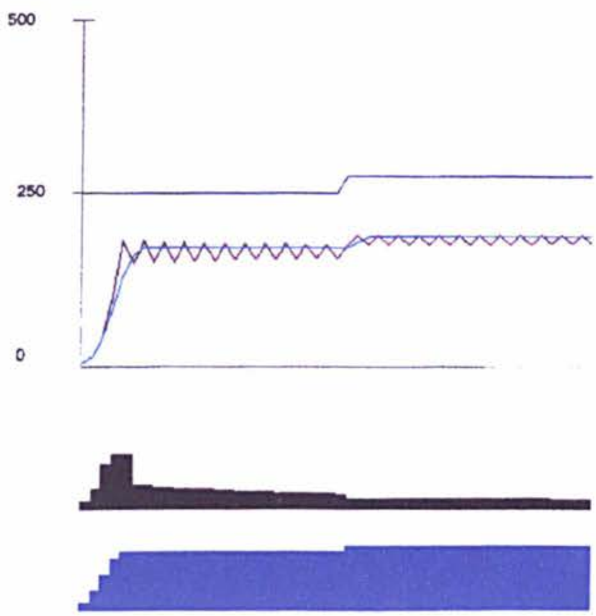
Cummulative Output	Number of Iterations
377.4399	50

5332.971

Print | Return to Main Page

LT = Lifetime of the Product G = Growth multiplier

Fig 14av LT1_G3.0



09/02/2002
19:15:02

Growth Multiplier	3
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	1
Nmax Rate of Growth/Decline	0.1

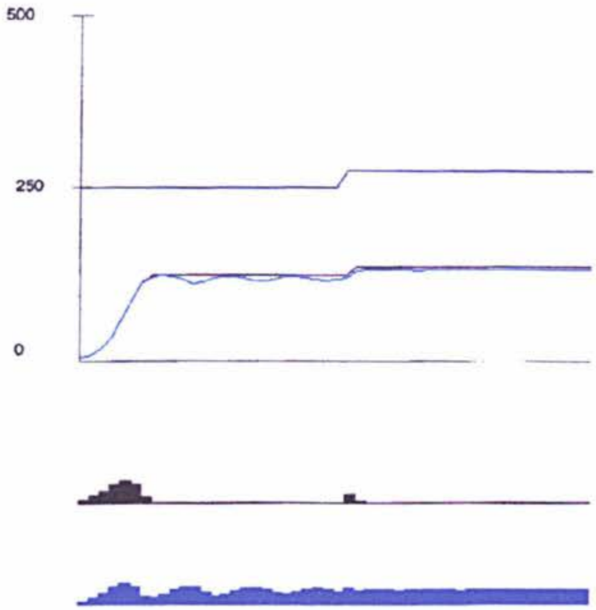
Cummulative Output	Number of Iterations
1230.704	50
8378.711	

Print | Return to Main Page

LT = Lifetime of the Product G = Growth multiplier

Fig 14aw LT1_G3.5

Fig 14ax LT5_G2.0



09/02/2002
19:23:39

Growth Multiplier	2
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	5
Nmax Rate of Growth/Decline	0.1

Cummulative Output	Number of Iterations
275	50

2003.031

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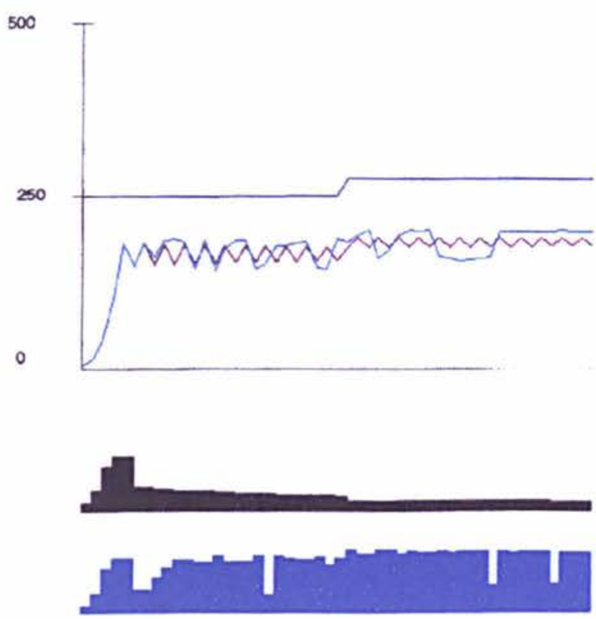
LT = Lifetime of the Product G = Growth multiplier

Fig 14ay LT5_G2.5

LT = Lifetime of the Product G = Growth multiplier

Fig 14az LT5_G3.0



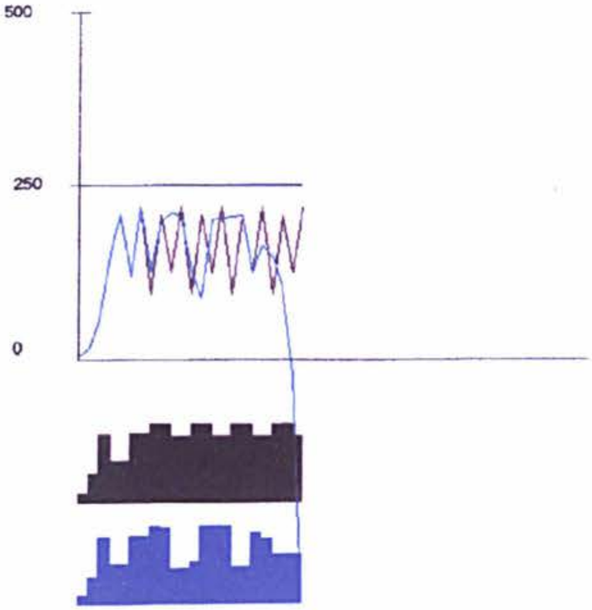
09/02/2002
19:16:15

Growth Multiplier	3
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	5
Nmax Rate of Growth/Decline	0.1

Cummulative Output	Number of Iterations
1230.704	50
6204.09	

Print | Return to Main Page

Fig 14ba LT5_G3.5



09/02/2002
20:31:25

Growth Multiplier	3.5
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	5
Nmax Rate of Growth/Decline	0.1

Cummulativ Output	Number of Iterations
2251.081	22

2585.366

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Figures 20bb to 20bi relate to a Marketplace that receives an downward shock of -5% on the 25th growth cycle (there are 50 cycles in the total simulation)

Fig 14bb LT1_G2.0

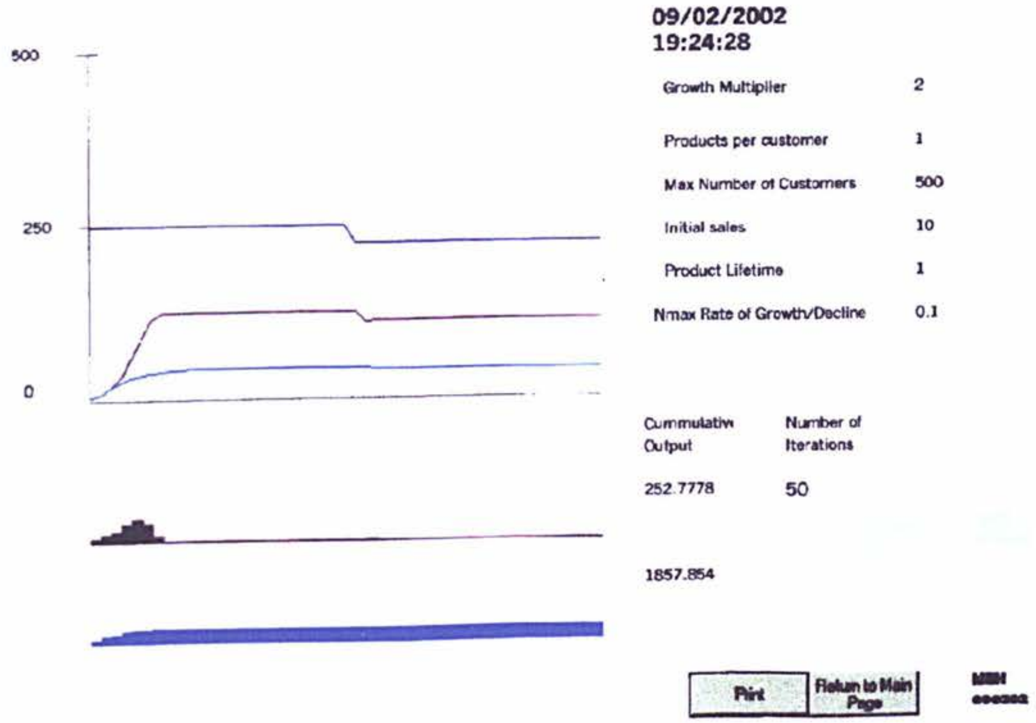
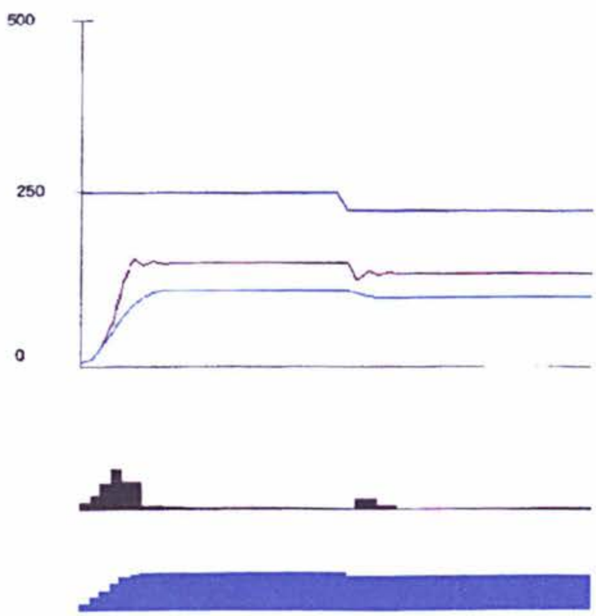


Fig 14bc LT1_G2.5



09/02/2002
19:21:35

Growth Multiplier	2.5
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	1
Nmax Rate of Growth/Decline	0.1

Cummulativ Output	Number of Iterations
360.8739	50

4852.39

Print | Return to Main Page

LT = Lifetime of the Product G = Growth multiplier

Fig 14bd LT1_G3.0

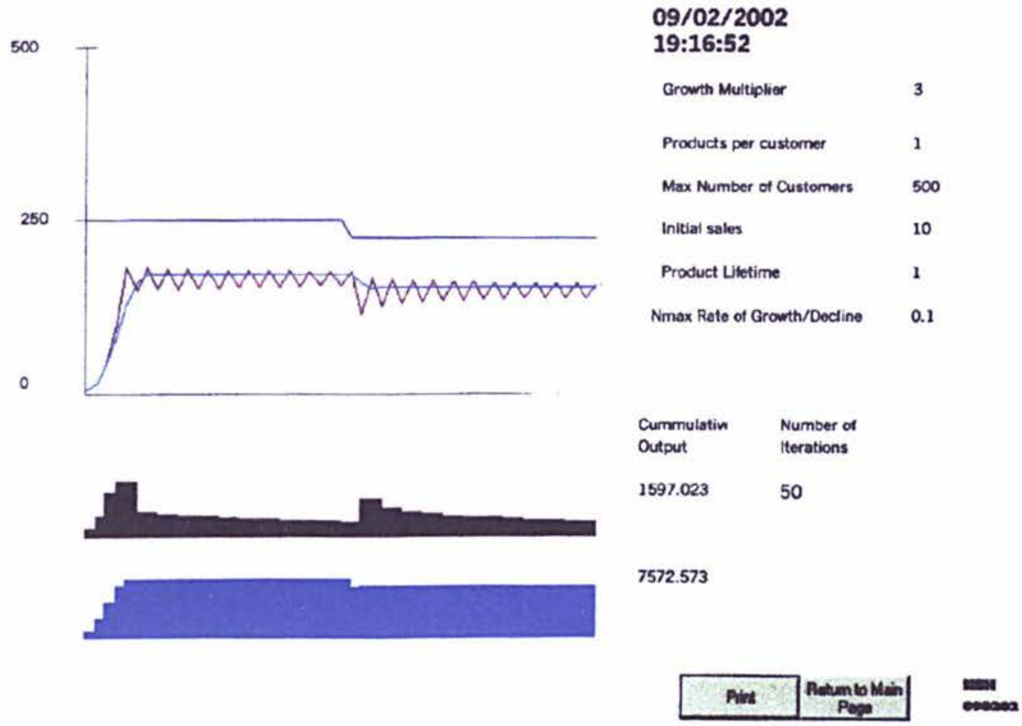
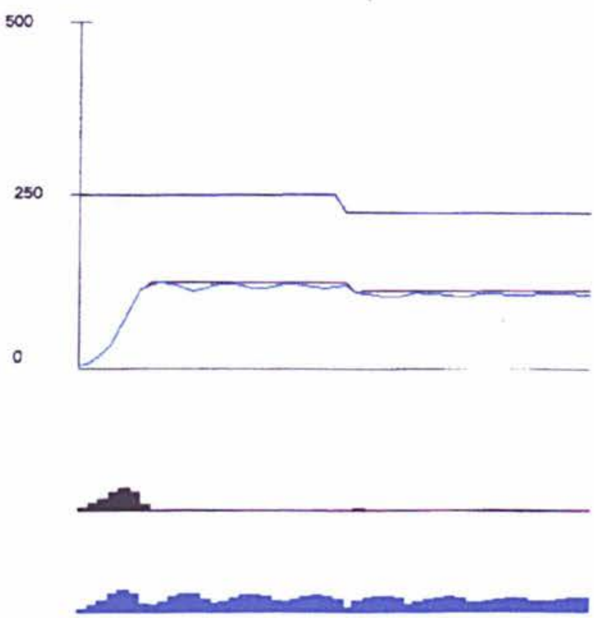


Fig 14be LT1_G3.5

Fig 14bf LT5_G2.0



09/02/2002
19:24:51

Growth Multiplier	2
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	5
Nmax Rate of Growth/Decline	0.1

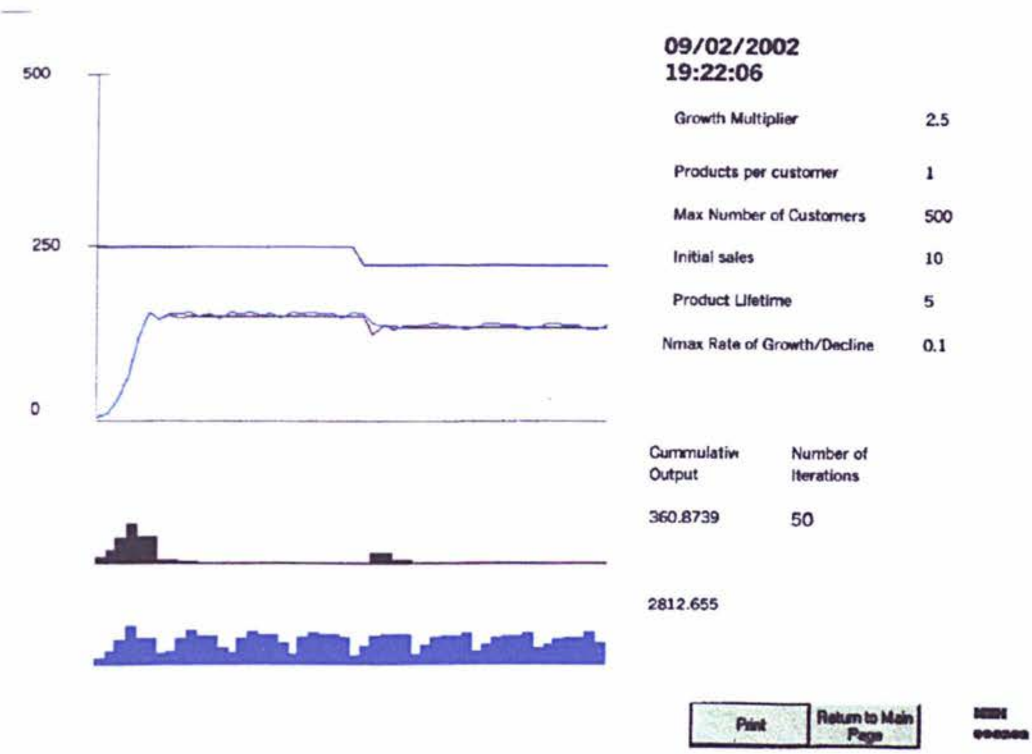
Cummulative Output	Number of Iterations
252.7778	50

1793.125

Print | Return to Main Page

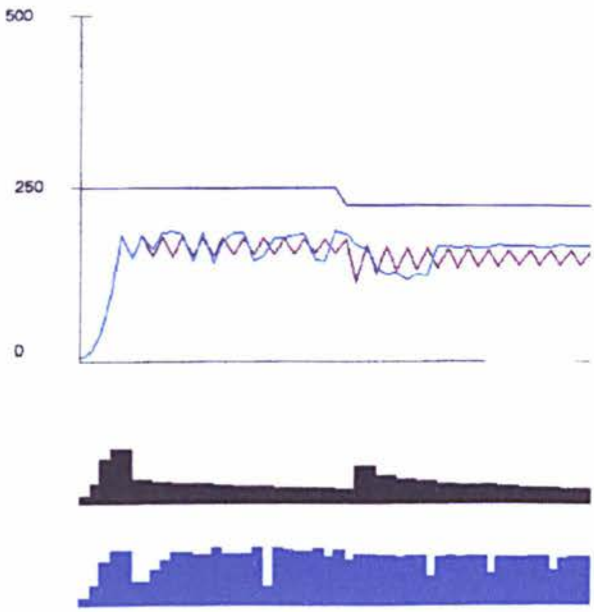
LT = Lifetime of the Product G = Growth multiplier

Fig 14bg LT5_G2.5



LT = Lifetime of the Product G = Growth multiplier

Fig 14bh LT5_G3.0



09/02/2002
19:17:18

Growth Multiplier	3
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	5
Nmax Rate of Growth/Decline	0.1

Cummulative Output	Number of Iterations
1597.023	50
5583.541	

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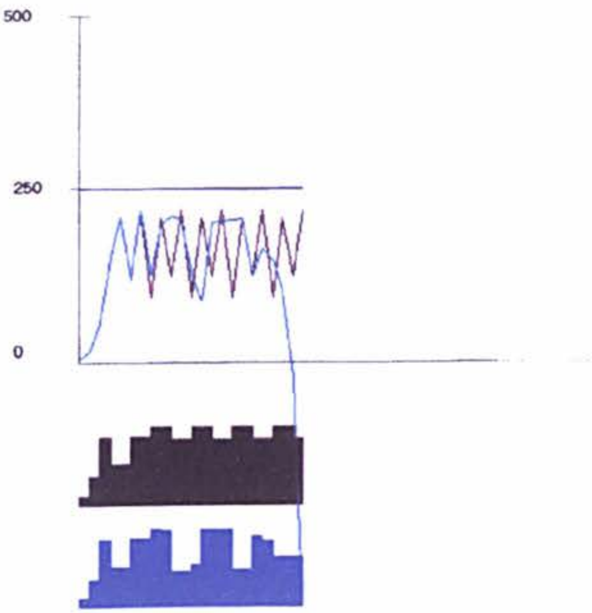
LT = Lifetime of the Product G = Growth multiplier

Fig 14bi LT5_G3.5



09/02/2002
20:32:38

Growth Multiplier	3.5
Products per customer	1
Max Number of Customers	500
Initial sales	10
Product Lifetime	5
Nmax Rate of Growth/Decline	0.1

Cummulative Output	Number of Iterations
2251.081	22

2585.366

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LT = Lifetime of the Product G = Growth multiplier

Appendix 9 : Simulation of a Polya urn process with a limited size of the urn

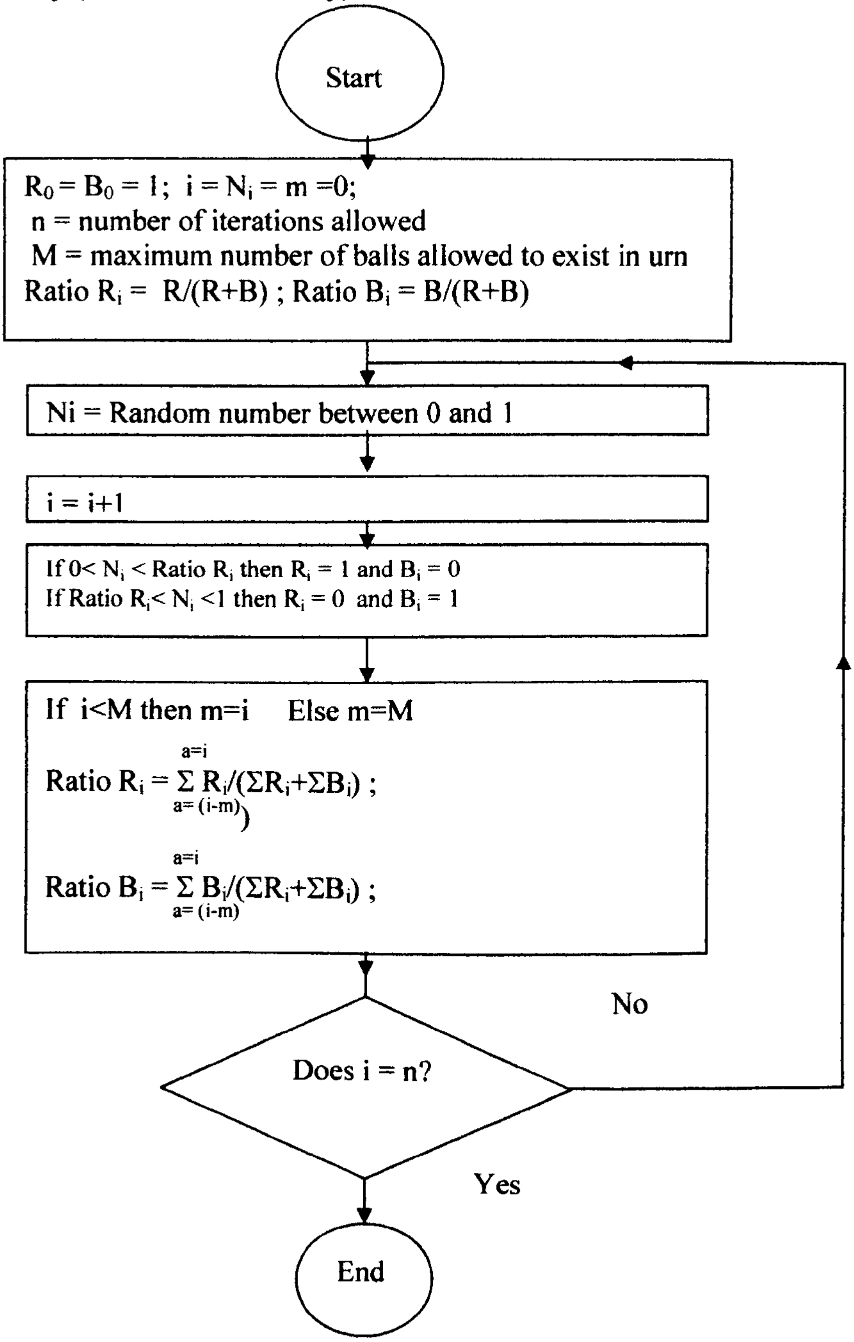
The Polya urn as a metaphor for memory

The process that will be described in this section is just one of many that could have been used as a metaphor of memory. One of its characteristics is that it incorporates a rule that allows the system to forget items completely through lack of use. However, alternative scenarios could have been considered. For example, a situation whereby lack of use reduced the influence of an item in memory without ever loosing it altogether. This could have been achieved by limiting the urn to a finite size and introducing a function causing balls to shrink over time, such that there was always room to add a new one. In such a process the relative volumes of the coloured balls could be used to govern the probabilities of selection of a particular colour, rather than just the ratio of the numbers of balls.

Polya urn process with limited capacity

A flowchart describing a Polya urn process that has been modified so as to limit the size of the urn is shown Figure 33. In this process only a limited number (m) of the most recently added balls are allowed to remain in the urn. The residue of balls is determined through a first in first out (FIFO) rule.

Figure 33 Flowchart of the extended Polya urn problem with limited urn capacity (i.e. limited memory)



A program was created in Microsoft Visual Basic to demonstrate the extended Polya Urn problem (see accompanying CD in back cover). The program allowed up to five different coloured balls to be present in the urn at the initial condition and could undertake up to four hundred cycles (orbits) for each process run. Each ball entering the urn was allowed to remain in the urn for m cycles of the process before it disappeared; where the maximum value for m was 50. Section 8.2 presents the outcomes of running the program, together with a commentary on the results.

Results of simulation number

Simulation number one is an extension of the Polya urn'. The original problem demonstrated a process whereby the series of sequential outcomes converged towards a specific value, but each time the system was restarted convergence was to a new random value. A histogram of the outcomes from the original process would be flat showing that all outcomes are equally probable.

The new problem, which limits the size of the urn and removes balls as well as adding them, on a first in first out basis produced a set of characteristics that were quite dissimilar to the original problem.

Simulation number one was run many times to explore the outcomes from the program. The number of orbits varied between 100 and 400 and the memory capacity of the urn varied between 5 and 50. The results are shown in Table 33 and Figures 34a to 34d.

Table 31 Extended Polya relationship between the strength of attractor and memory size and the number of iterations needed to achieve a monopoly

(note. The numbers in bold italics show the ratio of monopolistic outcomes: 1 = 100%)

No of Iterations	6	7	8	10	15	20	25	30	50	100
Memory =5	***0.354***	***0.386***	***0.446***	***0.552***	***0.776***	***0.866***	***0.942***	***0.98***	***0.992***	***1***
No of Iterations	11	15	20	25	50	150	200			
Memory = 10	***0.188***	***0.254***	***0.496***	***0.774***	***0.954***	***0.989***	***1***			
No of Iterations	21	50	100	150	200	300	400			
Memory = 20	***0.072***	***0.324***	***0.576***	***0.728***	***0.83***	***0.919***	***0.974***			
No of Iterations	51	100	200	400						
Memory = 50	***0.036***	***0.1***	***0.214***	***0.407***						

Figure 34a

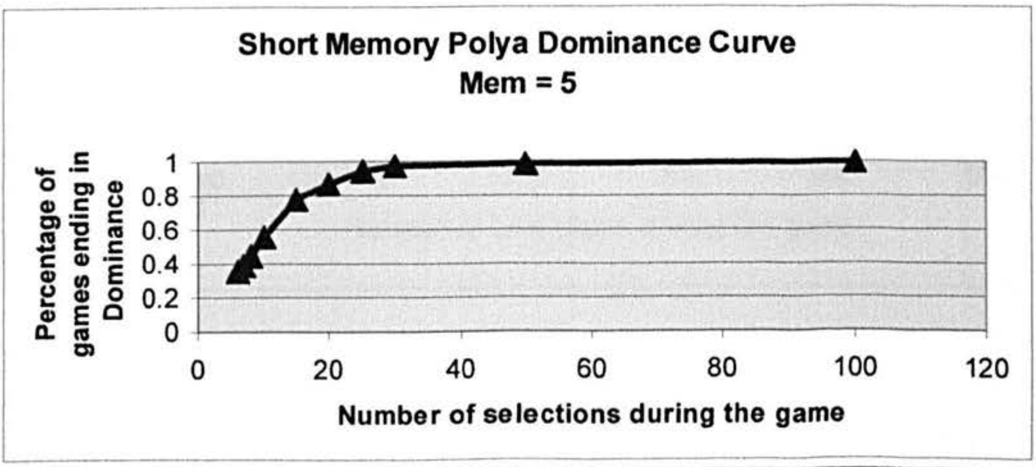


Figure 34b

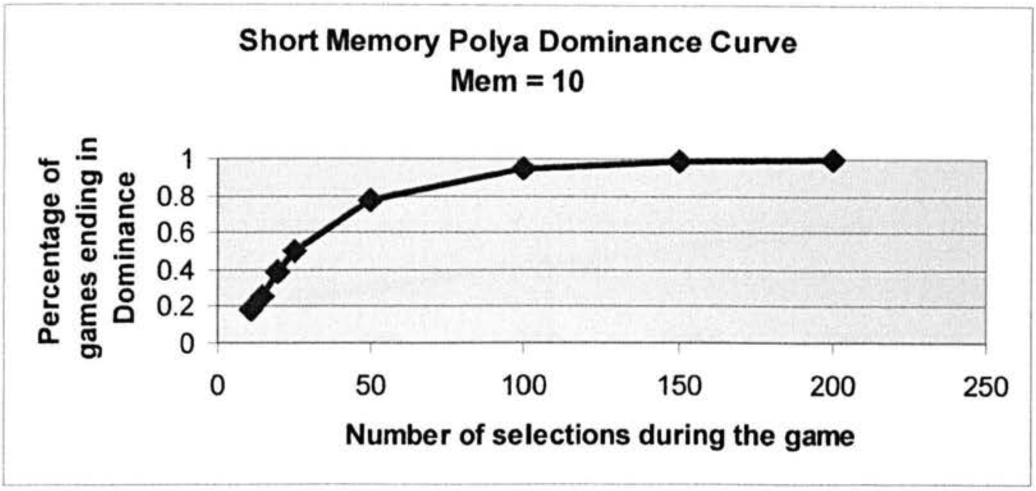


Figure 34c

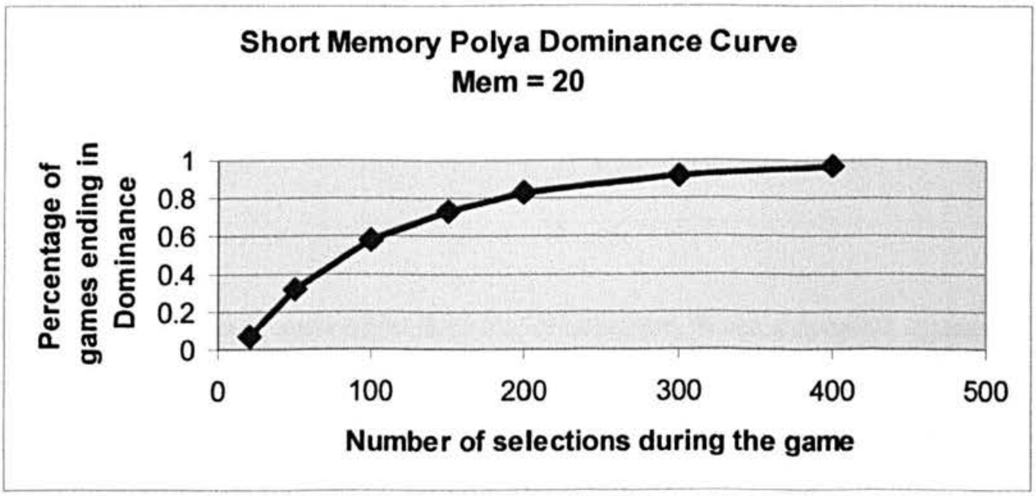
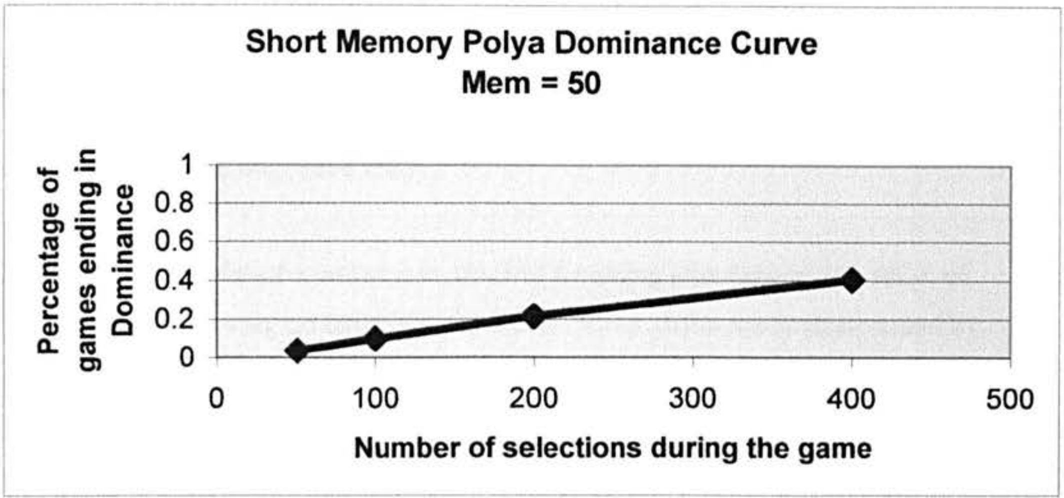


Figure 34d



Although not proven, the conjecture is made here that any Polya process with a finite limited memory will always produce a monopoly condition if sufficient iterations are undertaken. If true, then it makes the Polya with memory a interesting complimentary process to the original, since both are confined within the interval [0,1], but the original formulation can have any value of outcome except 0 and 1 whilst the modified version with limited memory can have outcomes that are only 0 or 1 (as the number of orbits tends towards infinity) .

Attractors

The modified Polya process raises the issue of attractors. When a dynamic system, that potentially has many different states, shows a propensity towards certain outcomes (i.e. the outcomes are neither random nor single values) it is said to contain attractors.

Attractors are quite common in life and a metaphor, which has been used by others, explains them rather well. Consider clouds randomly raining over a flat plain. Each time it rains, one specific area becomes wet, but looking at the system over a long period shows that all of the surface is, on average, equally wet or dry. In comparison, if the same pattern of rain clouds existed over a contoured surface, the water would collect in depressions, forming pools, where it would be permanently wet. The system containing the flat plain, shows no attractors, whilst one containing a contoured surface may have many.

In the case of simulation number one, the feature being investigated is a ratio of balls in the urn. Having no balls of a particular colour in the urn is represented by zero percent, whilst having all of an alternative colour in the urn represents one hundred percent. Only balls in the urn are counted and only one urn is involved. Under these conditions, the urn itself is considered as the attractor since all values are confined to the interval bounded by zero and one hundred percent (i.e. 0,1). This statement is fundamental and may be seen as trivial. A second question arises. If the urn is being viewed in its totality as a system, do any other attractors exist within the urn? For the standard Polya process the answer to this second question is no. There are no attractors within the system (although each time the process is undertaken it converges towards a particular state, which could be interpreted as a temporal attractor). Repeating the standard Polya urn process generates outcomes that are randomly distributed within the interval [0,1].

The extended 'Polya process with limited memory' is quite different to the original, in so far as it exhibits two symmetrical point attractors. These attractors create a bias that effects the outcomes of the processes in such a way, that early dominance leads to a monopolistic situation if the process is continued for long enough. A multi-coloured starting point goes through a period of stages where one after another the colours become extinct until a monopoly prevails. If the strength of the attractor is considered to be proportional to the number of cycles needed for a monopoly to be created, then the strength can be seen to increase as the number of balls allowed in the urn decreases. Conversely, the attractors decrease in strength as the numbers of balls in the urn are allowed to increase, presumably to the limit where an infinite urn has no attractors and produces a set of random outcomes.

The specific locations of the attractors may be stated as being the ratios of 0% and 100%, or 0 and 1, or dominance and extinction.

The Polya with memory process has strong parallels with the way that the New Economy marketplace has developed. It does a good job of describing an unregulated capitalist marketplace that has low customer loyalty. To a great degree this describes the New Economy, where customer loyalty is stretched by a proliferation of new firms offering new products that have an ever increasing utility. It is also an environment where products quickly become obsolete and unless their brand is refreshed with a new competitive product it becomes extinct.

This chapter has given an account of a novel extension to an old model. The extended Polya urn process can be used in an algorithm to mimic practical features of a business environment, such as market share. The new process is especially relevant in the current era of rapid change, as it allows a finite limit to be set for the time horizon of influence. This contrasts dramatically with the original version that permanently anchors events to a specific starting point. The new process is more realistic that the old, and it exhibits different characteristics. It is quite possible that there are many other applications that it could be applied to in its present form and further refinements can be envisaged that would tailor it to other situations.

In the next chapter, a complex simulation is depicted that creates the central core of the new applied model of software firms, by combining fitness landscapes and logistic growth.

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