Adaptive Knowledge Dynamics and Emergent Artificial Societies: Ethnographically Based Multi-Agent Simulations of Behavioural Adaptation in Agro-Climatic Systems

by

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Abstract

The goal of this research is to enhance an ethnographic understanding of agricultural adaptation to environmental change, within the context of an anthropological theory of 'adaptive dynamics' [Bennett, 1976], using computer-based techniques. An agent-based model was developed to investigate the 'transitional' adaptive strategies of farmers in south-east England based on data collected during fieldwork. Using ethnographic evidence, the model included the interactions of differing structures of knowledge relating to possible environmental change. This resulted in a variety of adaptive, non-adaptive and indeed mal-adaptive responses by agents in the system and thus, differing degrees of success for individual actors and the group as a whole. The choices made in response to change and their consequences were analysed. Success was measured in terms of minimising vulnerability, achieving sustainable adaptation and meeting economic objectives. Adaptive responses classified using criteria proposed by John W. Bennett [1976], under the heading of adaptive dynamics and incorporated within an agent-based model, allowed a refined understanding of the ethnographic data that was collected, exposing new insights and areas for further investigation. The agent-based model illustrated the importance of Bennett's model in illuminating the benefits of indigenous strategies for successful adaptation and sustainability.

The broad scope of this research means that it is aimed at an interdisciplinary audience. It is organised such that each chapter will contain a general introductory overview which requires little specialist knowledge, while further reading will entail greater technical detail, which will assume some specialist knowledge. Specialist areas covered include simulation toolkits, declarative programming software and social science research methodologies amongst others. This research is intended to be a guide for non-computing anthropologists to understand the potential in developing simple computer models to complement and support their traditional research methods. Experienced modellers may also benefit from specific techniques described from the social sciences domain, such as the participatory knowledge engineering process developed using ethnographic techniques, which may enhance conventional modelling approaches.

CHAPTER 1

Introduction

The fundamental idea underlying simulations in anthropology is to assess the performance of social models (particularly those created used the ethnographic model of data collection) in the context of more 'well-understood' models, such as those from the natural sciences [Fischer, 1994]. The aim of this research is to illustrate how computer-based methods can be used to illuminate ethnographic description to aid an understanding of such social models and their interaction with other models and sub-models, since it is often the structure and relationships between them that are of importance, rather than their content [Fischer, 1994]. This will be achieved through the use of computing tools and a theoretical framework which is rooted in ecological anthropology as an abstraction of observed behaviour. It is imperative that we evaluate the usefulness of the application of simulation-based computer modelling techniques to the anthropological research domain, by assessing their value in better understanding ethnographic data. This study shows that the creation of simple computer-based models can enhance social science research, and specifically that both computer-based methods and fieldwork-based research can mutually benefit from each other. The synergy of both methodologies will be shown to be extremely useful. Fischer [1994] writes that the integration between quantitative and qualitative methodologies has been unsuccessful in the past due to the failure to address the *fundamental* differences between social science and natural science phenomena. Thus, these interdisciplinary domains are bridged through the use of an anthropological theory of adaptation and innovative participatory knowledge elicitation tools which allow the fusion of the qualitative, ethnographic and quantitative, environmental components within an *agent-based* simulation, to relate cultural knowledge to *context* and the behaviours that emerge in the model, as advocated by Fischer [2002].

Such an approach could be useful in mainstream anthropology to combine fieldwork-based and more formal components. Computational methods are no longer dependent on the aggregation of variables which would make them inappropriate for anthropological analyses, which are inherently 'agent-oriented' (though until the past twenty-five years they have been articulated in 'summed-over' terms) [Fischer, 1994b, 1994d]. The possibility to represent and maintain individual agents and the relations between them, also creates opportunities to apply anthropological theory and methods to a much wider range of computational methods (Chapter 5).

Thus, computer modelling techniques combined with theoretical anthropological approaches will aid a better analysis of behavioural *processes* with respect to adaptation and *transitional* behaviour. An ethnographically-based simulation of past and present adaptation may inform adaptation in the future, transitional issues and whether new problems arise as a result of old solutions. This may help to identify important properties about the system under study which may not be possible using traditional social science research methods if only because these are too time-consuming. The *process* of adaptation is not dependent upon behaviour as such, but references to structures and knowledge relating to these structures, which may be maintained by observable behaviour. One of the advantages of using an agent-based model as a tool for analysing social science theory and empirical observation, lies in the potential to discover new areas of enquiry and analysis, within the context of these theories, while at the same time, possibly informing both observation and the theoretical foundation. The design and implementation of the combination of methods used in this study will be explained in more detail in Chapter 3, Chapter 7 and Chapter 8.

1.1. Research objectives

Specifically, the aim of this research is to assess the relevance of an anthropological theory of adaptation developed by J.W.Bennett [1976] to a case study site of farmers adapting to their environment in south-east England. This 'agent-oriented' theory, referred to as here the *adaptive dynamics* framework, is described in Bennett's book *'The Ecological Transition'*, in a chapter called *'Adaptation as a Social Process'* [Bennett, 1976]. The framework is used as a simple abstraction of strategies invoked by farmers adapting to changes in their economic, social and climatic environments over time, as understood during the course of interviews (Chapter 4). This study will demonstrate the advantages of a multi-disciplinary research approach since the reflexive, iterative computer-aided process of interview, analysis and simulation resulted in unexpected new insights and questions for further research, within this theoretical context.

Thus, the main objectives of this research are:

1) To investigate the relevance of the adaptive dynamics framework to how farmers adapt to changes in environmental and economic contexts.
2) To use and evaluate agent-based methods for modelling farmer knowledge and interactions with their changing context.
3) To integrate conventional ethnographic methods with knowledge-engineering techniques.

An agent-based model is a program of self-contained entities called agents each of which can represent a real world object such as an individual or a household. The data required for such a model is ideally suited to data-intensive ethnographic fieldwork needed in anthropological research. Hence, the combination of these methods is quite a natural, yet innovative approach. Furthermore, other computer-based techniques which are described in Chapter 6 provide a robust and effective method to formalise and verify qualitative ethnographic data, for use in an agent-based model.

Artificial Intelligence (AI) is a multi-disciplinary area in which the goal is to represent intelligence (usually human intelligence) in the modelling environment of a computer and expert systems are computer-based models that simulate human expertise in a given area (domain) (Chapter 6). The process of collecting the data necessary for such a model and formalizing it for representation in an expert system is referred to as *knowledge engineering*. In order to alleviate weaknesses in current expert system development and to eliminate the knowledge elicitation and knowledge engineering 'bottleneck', common in this type of research, Wooten and Rowley

[1995] have used Wood and Ford's [1993] interview model which is derived from the methodology primarily used by anthropologists and specifically from James Spradley's work, *The Ethnographic Interview* [1979] (Section 2.9). This applies some of the skills known by anthropologists and ethnologists to the knowledge elicitation process (Chapter 6) and thus supports the general theme of this research which will be to use a fusion of qualitative and quantitative techniques to create a more effective exploratory research process overall.

Bennett's framework of *adaptive dynamics* [1976] was chosen as an intermediate method of formalising the ethnographic data (Chapter 4) on farmer adaptation, since it has features which compliment and fulfil both the agent-based modelling methods and the ethnographic research. Namely, agent-based modelling illustrates how macro-level behaviour can emerge from various types of rules which inform decisions at the local, individual level. Bennett's framework is 'agent-oriented' in its conceptualisation and also operates on two, similar levels. One, which describes low level, short-term, action-response behaviour, which has outcomes described here as *primitive effects*, and a further level which describes higher level, longer term *patterns* of strategic behaviour, referred to as *strategic designs*. The latter are the result of a combination of the former, over time. The framework appeared to correspond well to the ethnographic data that was collected during the course of this study (Chapter 4) and thus this qualitative data was mapped onto Bennett's framework (Chapter 5) and formalised into simple local level rules (Chapter 6). The agent-based model was then used to establish which high level patterns of strategic behaviour emerged, as a result of local responses and whether such emergent phenomena accounted for a clearer understanding of the original ethnographic data.

This process has resulted in two very simple, but useful models, the Adaptive Dynamics Model (ADM) and a slightly modified version of this, referred to as the Learnt Adaptive Dynamics Model (LADM), where the dynamics of response *and* indigenous knowledge can be analysed. Specifically, the *adaptive dynamics* involved in climate change-related behaviour within agriculture, human-environment interaction and impacts for the individual and the group can be investigated. However, from an anthropological perspective, we are concerned with how such strategies emerge over time *as a part of* cultural process and the structural relationship *between* adaptive knowledge and the cultural context [Fischer, 1994].

There has been much discussion among experts in the field of social simulation (see 'SimSoc' discussion list: http://www.jiscmail.ac.uk/lists/simsoc.html), regarding the purpose of agent-based models. That is, whether they should be built as an implementation of theory, as theory-building tools or whether observation is altogether more important than theory. This research creates a model with a feedback process between observation and theory. Here empirical observation is understood using a theory - Bennett's model of Adaptive Dynamics - which claims to describe with the phenomena under study, and which is appropriate for dealing with agent-level data (other possibilities for representing this data are discussed in Section 5.3). Furthermore, both the *participatory* computer-aided tools used (Chapter 6) and results of experiments run with the model (Chapter 9) allow domain experts to disambiguate their perceptions and the researcher's understanding of the domain, and in this way, a clearer understanding between observation and theory can emerge. That is, empirical observations which are abstracted and modelled provide results within the context of Bennett's theory, which provides insights and raises new questions, which, when applied to one's understanding of the domain can enhance it or even provide new data for the model in an iterative process (Section 9.8).

The field of social simulation has also identified the need for a declarative modelling language to represent qualitative features within target systems. Indeed, there has been some discussion among developers of specific simulation toolkits to produce such 'plug-ins' for their software in the future. However, since this was not available at the time that this research was conducted, the Java Expert System Shell (Jess) [Friedman-Hill, 2001] (Section 3.5) has been used as a plug-in for the Repast [Collier, 2001] agent-based simulation library (Section 3.4). During the participatory knowledge engineering phase of the research, the successful implementation of this declarative module was useful for domain experts to be able to validate the researcher's understanding of their decision-making processes. Furthermore, in the agent-based model, it allowed the creation of qualitative categorisations using Bennett's framework, with less loss of information. As such, by qualitatively categorising strategic designs according to observed empirical primitive effects defined by Bennett (Chapter 5), unexpected variations in behaviour and response could arise within a multi-agent environment, allowing further analysis within the ethnographic context. And, as Spradley [1979] writes, it is the analysis of the regularities and variation in human behaviour, which is the goal of scientific anthropology.

However, it should be acknowledged that some complex systems will remain unpredictable even if an understanding of the influences of behaviour within the system is achieved. *Social science is less concerned with prediction than with identifying how behaviour evolves and influences other processes.* Since the study of complex systems is an attempt to better understand systems which are difficult to grasp analytically, often the best available way to investigate such systems is to simulate them [Gilbert and Troitzsch, 1999]. Furthermore, purely quantitative prediction is difficult in matters of human thought and its relation to action; stochastic prediction is likely to remain the norm. This is, in part, because 'rules' are not rules of action, but indicators of possible courses of action and are influenced by both the goals of the agent and the reliability of the agent's categorisation of the context, which relates to the different rules.

1.2. Background information

Other research in the field of agricultural adaptation to environmental and climatic change has long stated the need for new approaches. For example, after a decade of research aimed at designing a large-scale decision support system incorporating the effects of climate change on agriculture and farm management, the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) produced a report, [Tsuji and Balas, 1993] suggesting future project extensions that support the research presented here. Their report emphasises the need for a whole farm model to analyse the impacts of climate change. This should include a 'shell, socio-economic, soil and climate databases, and crop and household decision models' (Figure 1).

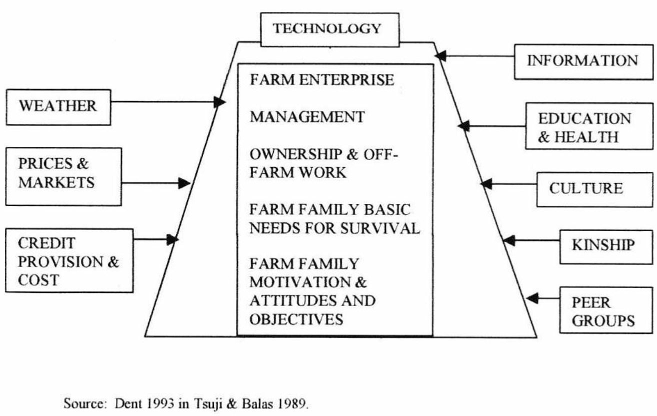

FIGURE 1. Structure for a whole farm model suggested by the IBSNAT report Source: [Dent and McGregor, 1993] in [Tsuji and Balas, 1993].

'The climate and soil databases are already well known. The socio-economic database (Figure 2) is not yet explored but will have endogenous and exogenous elements: endogenous data will include land tenure arrangements, economic status and resources, family size, age and education and a range of cultural factors including traditional values and

beliefs; exogenous factors will include credit provision and cost, market prices for inputs and products, and availability of extension services. These data would be managed within the rules-based household decision model' [Tsuji and Balas, 1993].

The proposed expert system for this research could potentially contain many of the endogenous and exogenous elements described in the *socio-economic database* (Figure 2) to assess the implications of investing in a specific set of options when presented with differing environmental, cultural and socio-economic scenarios using Bennett's [1976] framework as applied to indigenous responses/categories. Furthermore, an agricultural knowledge base to which contextual information could be added could eventually be developed to be applicable in a wide variety of climates and in different socio-economic and geographical contexts in future research since farm family motivation, attitudes, objectives and culture could be considered by using a combination of social science and physical science methodologies (e.g. see Gladwin's Elimination by Aspects methodology which is described in Section 6.5).

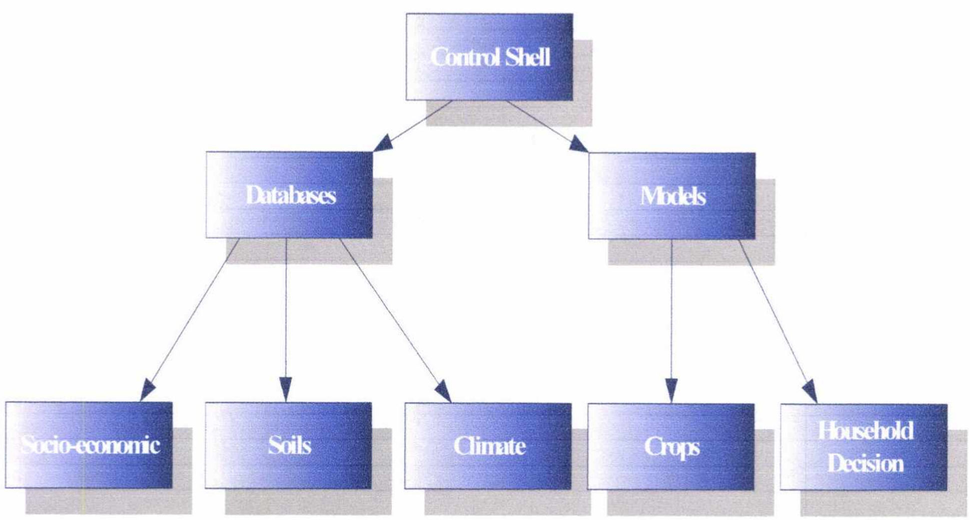

FIGURE 2. Socio-economic household decision model
Source: Dent and McGregor [1993] in Tsuji and Balas [1993].

However, the effects of environmental change *as well as* socio-economic transitions are clearly important in the context of agricultural production particularly when we consider future projections of population dynamics. For example, global population figures are expected to more than double, to at least 10 billion by the year 2060, meaning that food production will have to increase three to four times between 1990 and 2060, at a rate of 2 per cent per year to fulfil nutritional requirements [Chen and Kates, 1996]. Though the exact impact of climate change on agricultural production is uncertain, the level of population growth that is expected, and present projections of future climate change, demand that issues of adaptation are urgently addressed. It is widely accepted by climatologists that even if emissions targets set by the Kyoto Protocol are met, it is too late to prevent the effects (Section 1.2.2) of a doubling of carbon dioxide in the atmosphere. However, while the net effect on agriculture could be extremely negative, some areas may benefit from the effects of climate change (Section 1.2.1).

Over the past decade, much research has been conducted in the field of climate change and agriculture, and indeed there is now an increasing literature on adaptation mechanisms and response strategies as well as recognition that there is a need for an interdisciplinary emphasis in climate impacts research [for example, see Smit et al., 1996, Smith, 1997, Smithers and Smit, 1997 for research focusing on farm-level adaptation]. The research described here combines expertise from different domains to produce a knowledge representation tool, which will illustrate the outcomes of particular adaptive options within the agricultural domain, in the context of the *adaptive dynamics* framework. Using a simulation to model the effects of these alternative strategies, with respect to changes in precipitation and temperature, the expert knowledge will present viable options, incorporating differing perceptions to climate change. Clearly, there is a need for the scientific modelling of climate change scenarios, but in the past these have rarely been allied to a comprehensive assessment of the local-level decision-making processes of subjects in the study areas, such as indigenous farmers. Thus, there remain areas for investigation which are unexplored in this field of research which can only be met by large-scale interdisciplinary efforts.

1.2.1. Possible climate change scenarios

Climatologists predict that those areas of the world which will be most severely affected by climate change over the next fifty years will be low latitude countries such as Africa and the southern United States including the Corn Belt, but also the Canadian Prairies [Tsuji and Balas, 1993, Parry, 1990, Parry and Carter, 1998]. However, more studies are being conducted to investigate the way in which these and other countries may adapt to climate change and the global, social and economic repercussions this will have on other areas of the world.

The Intergovernmental Panel on Climate Change (IPCC) has reported [IPCC, 2001] that for the range of scenarios developed for the IPCC assessment (assuming no major reduction in greenhouse gas emissions), global mean surface air temperature is projected to increase between 1.4°C and 5.8°C by 2100, relative to 1990. There is clear evidence that globally averaged surface temperatures have increased over the 20th century 0.6 $\pm$ 0.2°C [IPCC, 2001], with a warming of 0.2°C to 0.3°C over the 40 years up to 1994 [Tegart et al., 1990]. Much of this warming has been concentrated in two periods, between about 1910 to 1945 and since 1976 [IPCC, 2001]. The warmest decade since the 1860s has been the 1990s [Parry and Carter, 1998], while 1998 was the warmest year on record. Climate predictions indicate that warming will vary by geographical region, with varying degrees of precipitation although there will also be changes in the variability of climate and in the frequency and intensity of extreme climatic events.

1.2.2. Effects on agriculture

A northward shift in productive agricultural potential in mid-latitude Northern Hemisphere countries has been predicted by climatologists [Parry, 1990]. It has been suggested [Parry, 1990] that a 1°C increase in mean annual temperature would tend to advance the thermal limit of cereal cropping in the mid-latitude northern hemisphere by about 150-200km. However, while warming may extend the margin of potential cropping and grazing in mid-latitude regions it may reduce yield potential in the core areas of current production as higher temperatures encourage more rapid maturation of plants and shorten the period of grain filling. Thus the grain produced could be of poorer quality than that produced at present [Parry, 1990].

There is much more uncertainty about greenhouse gas-induced changes in rainfall than there is about temperature, including changes in its spatial pattern and its distribution throughout the year. Thus, Tegart et al. [1990] admit that it is difficult to identify possible rainfall-induced shifts in the climatic limits to agriculture. Relatively small changes in the seasonal distribution of rainfall can have disproportionately large effects on the viability of agriculture in tropical areas, through changes in the growing period when moisture is sufficient and thus through the timing of critical episodes such as planting.

An IPCC study [Tegart et al., 1990] on the impact assessment for changes in agricultural production in Europe suggests that in areas of north west Europe such as Ireland, the UK, northern France, the Netherlands, Belgium and Denmark, yields of grass and potatoes would tend to increase under higher growing season temperatures, assuming sufficient increases in precipitation to counter higher rates of evapotranspiration. Many responses of crop plants to climate change will be common to particular groups of crops allowing generalisations to be made.

However, the IPCC have stated that climate impact assessment modelling is difficult because it is typically non-linear and non-static and determining true climatic impact is further complicated by human responses to the impact itself. This supports the need for an integrated socio-economic analysis, which will allow feedback of the effects of these responses to the environment [Tegart et al., 1990]. Thus, this may support the use of agent based modelling techniques to explore the possible socio-economic impacts of basic environmental change (such as changes in temperature or precipitation) on decision-making using observed ethnographic data. For example, other projects such as the *Climate Outlooks and Agent-Based Simulation of Adaptation in Africa* (CLOUD) project [CLOUD, 2004], which follows on from Ziervogel's work in Lesotho [2004], are using more sophisticated climate, crop and adaptation modules within an agent-based model to assess possible climate impacts on small-scale farmers in South Africa.

Clearly, though various types of adaptation will take place as a result of climate change, these will be constrained by socio-economic and political factors [Parry and Carter, 1998]. However, Bennett emphasises that the process of adapting is similar everywhere, though technological and capital inputs may differ [Bennett, 1976]. It is this *generic process* of adaptation, the decision-making involved, the triggers which initiate it and the effects of adaptive constraints that this research intends to address. The importance of these factors is reinforced by climatologists such as Parry and Carter, who write:

> *'...climate change in the future will be influenced by concurrent economic and social conditions and the extent to which these create a resiliency or vulnerability to impact from climate change'* [Parry and Carter, 1998].

1.2.3. Global and regional adaptations

Globally, regions most at risk from the negative effects of climate change are predicted to be Africa (Maghreb, West, Horn), southern Asia, western Arabia, south-east Asia, North America (Mexico and Central America) and South America (parts of eastern Brazil). Regions which are both net food exporters and which could be affected by a reduction in soil water availability are parts of Western Europe, North America (southern US), and South America (northern Argentina) and western Australia. Though a doubling of carbon dioxide could have beneficial effects to some crops in certain parts of the world, overall output from the current major grain producers could decrease under the warming. For example, the USA's domestic needs could still be met, but as US grain production may be reduced by 10-20 per cent, exports would probably decline and production may also decrease in the Canadian prairies and in the southern former Soviet Union countries [Parry, 1990]. Thus, food-exporting regions could be adversely or positively affected by the projected changes in climate, and since the amount of traded food could be altered, prices may also be affected. The major roles in the world food system are played by only a few food–exporting countries [Parry, 1990]. Clearly, these major food-producing countries are enormously important to the world food system in their key role as holders of large food stocks.

Tables 1 and 2 list major cereal importing and exporting countries around the world. Of the importing countries, most receive more than five million tons each year and clearly, large net importers which are also developing countries may be the most vulnerable.

TABLE 1. Major imports of cereals. Source: [FAO, 2004]

Major cereal importers	Cereals 2002/03 (million tons)
Japan	26.5
China	9.2
Taiwan Province	6.3
Korea, Rep.	13.1
Mexico	12.3
Egypt	11.7
Saudi Arabia	8.7
Iran, Islamic Rep. of	3.9

TABLE 2. Major exports of cereals. Source: [FAO, 2004]

Major cereal exporters	Cereals 2002/03 (million tons)
USA	74.3
EU[a]	22.6
Russian Fed.	18.3
Argentina	18
Australia	14.2
Canada	10.7
Thailand	7.7
South Africa	1.2

a. Excluding trade between the EU member countries. Up to 2003/04 15 member countries, from 2004/05 25 member countries.

Though the UK, as a small proportion of the EU figure (Table 2), exports very little in comparison with its competitors, the UK grows the most amount of food per capita, per hectare in the world. More intensive agriculture cannot be carried out with current crops, thus a global deficit in grain production could only be compensated for by introducing the right crops, for future climates, at the right time, to maintain consistently high yields.

Therefore, one area of interest when considering possible climate change impacts is the producer-consumer dialectic. If the United States, a major world producer of grain and thus referred to as a 'breadbasket country', is affected by several severe droughts over a number of years, as currently predicted, it seems possible that the global configuration of consumers and producers will significantly alter, and thus alter the state of the global economy also. Other countries may be able to partially offset a USA deficit in agricultural production, but with an ever-increasing world population there may still be a shortfall in world-wide production levels. Other so-called 'breadbasket countries', the major net exporters of grain, are Canada and France and they are also predicted to be negatively affected by climate change. However, as mentioned earlier, some of the impacts of climate change on crops could also be positive, depending on geographical region.

If rainfall increases sufficiently, the UK and the Low Countries may increase their grain production due to the thermal shift of crops normally grown in warmer climates. This could place these countries at a competitive advantage, if concurrent adaptive measures are taken. Output could also increase in Australia if there is a sufficient increase in summer rainfall to compensate for higher temperatures. Regions near the low-temperature limit of grain growing in the Northern Hemisphere could experience increased production, such as the northern Canadian prairies, Scandinavia, and north former Soviet Union countries. In the Southern Hemisphere regions would include southern New Zealand and southern parts of Argentina and Chile. However, Parry concludes that because of areas that are affected by inappropriate soils and terrain, increased high-latitude output will probably not compensate for reduced output at mid- and low-latitudes.

Thus, with the added uncertainty that climate change represents, the sensitivity of the world food system is clear. In a good productive year, world food production exceeds demand by about 20 per cent. However, a relatively short run of poor yielding years could use up all current stocks. For example, while 1987-88 world wheat and coarse grain stocks stood at 353 million tons (mt), they fell to 248 mt in 1988-89 and were estimated to be at 249 mt in July 1989 as a result of the 1988 heat wave and drought that affected the Great Plains and the Corn Belt. Stocks of wheat in the US fell from 49 mt in 1986-87 to 34 mt in 1987-88 and to 17 mt in 1988-89. In this case, factors affecting stocks in North America also affected world food stocks and world prices [Parry, 1990]. Therefore, a relatively small change in percentage production by the 'bread-basket countries', as a result of climate change, would result in a severe impact on the quantity, price and type of food products bought and sold on the world market.

1.2.4. Historical UK climate

In terms of the UK climate, specifically, distribution of rainfall varies from East to West and with height. Parker [1986] writes that areas with about 760mm (30in) of rain are favourable for a wide range of crops, and those with 1520mm (60in) are sub-marginal agriculturally [Parker, 1986]. Drought can be classified into two types: absolute, when there are 15 or more successive days without rain and partial when there are 29 or more successive days with a total rainfall averaging not more than 0.025mm a day. Agricultural drought (when water shortage results in damage to growing crops rather than simply slowed growth) may set in during partial drought. Once a year, on average, an absolute drought occurs in the South of England. In northeast Scotland this occurs once in five years. Temperature in July decreases from south to north but the situation is different in the winter due to high regions over the continent, resulting in easterly winds often making the eastern half of Britain cooler than the west, at this time of year [Parker, 1986].

There are several historical case studies of extreme weather events in Britain and climatologists predict that such events will become more frequent [IPCC, 2001]. Since the end of the Second World War, the British climate has produced a surprising number of 'extremes' in terms of the existing climatic record [Parker, 1986] and there have also been several extreme weather events in more recent years [Met Office, 2004]. These data are summarised in the Table 3.

TABLE 3. Extreme climate events in the UK [Parker, 1986, Met Office, 2004].

Year	Event
1946, 1947	Severe winters (coldest February on record).
1953	UK east coast flood (greatest storm surge on record for the North Sea - 2.74m in Essex, 2.97m in Norfolk, 3.36m in the Netherlands)
1962/63	Coldest winter on record since 1740
1963/64	Driest since 1743.
1974/75	Mildest winter since 1834.
1975/76	Possibly worst drought since 1556. Temperatures over a 24-day period exceeded the highest monthly mean for 300 years (a culmination of a 16-month dry spell - the longest ever recorded over England and Wales since 1727).

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1978/79	Long and severe winter lasting from end of December 1978 to first week of May 1979.
1979	Wettest spring since 1727.
1982	Drought especially in Wales.
1985	Scotland experienced more than 200% of normal rainfall in the summer and very few dry days.
1987	'Great Storm' - most severe storm for nearly 300 years.
1982,1995	Lowest temperature of -27.2 °C recorded at Braemar, Grampian, 10 January 1982 and 11 February 1995
	Altnaharra, Highland, 30 December 1995
2000	Flooding (wettest autumn since records began in 1766 - 503mm in total).
2003	The UK record of 37.1 °C at Cheltenham on *3 August 1990*, was beaten by a number of stations on 10 August 2003, with Brogdale near Faversham (Kent) reporting the highest at 38.5 °C.

1.2.5. Attitudes to climate change and perceptions of risk

However, one of the most problematic aspects of this research is the attitude of local farmers themselves towards the prospect of climate change as there is much scepticism of the 'global warming' hypotheses put forward by scientists over the years (this has been ascertained through discussions with local farmers (Section 3.1.1) and a survey (Section 6.4.1)). However, the objective to explore adaptation options and *transitions* will focus on how weather events have been dealt with in the past, to suggest how their effects could successfully be absorbed in the future. In this way it hopes to reveal existing mechanisms for adaptation that may be exploited and optimised for future benefit. Preliminary analysis of cropping data for the last 30 years indicates that certain crops were eliminated from the farm rotation during the 1980s and the extent to which social, economic and climatic variables affected these cropping decisions or indeed how dependent they are on each other will be investigated further.

Interviews at a site in Kent revealed the acknowledgement of farmers, of the potential to grow crops with higher thermal requirements, due to the northward shift in productive potential as described by Parry [1990]. However, there remained a reluctance to do so due to the uncertainty associated with such a major shift in cropping patterns. It is an understanding of the way in which these options are assessed by the subjects of the study, how they are rationalised and how the final decision-making process evolves, that is the key to the development of effective long-term coping strategies. An important aspect of this type of research is assessing sources of knowledge that are currently considered reliable by the subjects of the study, in an attempt to emulate this reliability. Currently this includes reference literature such as the Farm Management Pocketbook [Nix, 1998], which has been used to access general data on all aspects of the farming enterprise and is used by farmers to assess the (climatic) requirements, costs and potential income of growing particular crops, including new and unknown crops.

1.3. Anthropology and multi-agent simulation

It is proposed that the use of even very simple agent-based models in some areas of anthropology can help to illuminate ethnographic description and thus provide a valuable contribution to the current mainstream discipline. Bennett's framework could also be applicable to the study of social phenomena that exhibit similar general characteristics to the research addressed here, due to its generic nature. It is a useful method of formalising interview material and could serve as an important transitional phase for use in a simulation. While Bennett's model has merely facilitated a formal representation of the modeller's understanding of domain knowledge and does not claim in any way to exhaustively represent it, there are many advantages in creating a formal representation of ethnographic data. The benefits of mapping and modelling a complex adaptive system using this framework lie in the ability to identify characteristics - macro-level strategic patterns/ designs - which are important to the functioning of a successful system and its essential underlying components - strategies with primitive effects. These micro-level effects can also be easily identified within an agent-based modelling environment, which can then allow the analysis of the interaction of models of adaptation developed from the social sciences domain with environmental models from the physical sciences domain as mentioned in Section 1.1.

Anthropological studies using simulation having been increasingly helping to explore social situations which would otherwise be difficult, such as religious ceremonies or rituals [Ellen, 1984]. However, Fischer [2002] writes that before the introduction of computers, simulations had long been used by anthropologists to validate their hypotheses against observed ethnographic data and to investigate proposed models of understanding. The most important application of simulations in anthropology to date has been to evaluate the interrelationships between demographic structure and real or hypothetical social structure or cultural practice. For example, Buchler and Fischer [1986] have used simulation to choose between different models of land allocation for horticulture in New Guinea and Fischer [1980] has investigated the relationship between cultural models for agricultural planning and crop yields [Fischer, 1994]. Social anthropology often uses data which are impossible to quantify or sample and where it is impossible to demonstrate the validity of scales that measure values of interest to anthropologists. Since simulation has applications to both quantitative and qualitative problems it has important implications for a discipline such as anthropology which is non-experimental, yet rich with qualitative comparative studies and thus provides a mechanism to explore problems which may not otherwise be observed [Zeitlyn and Fischer, 2002]. Agent-based modelling, in particular, offers the opportunity to create populations with qualitative data and structural relationships between individuals rather than creating a population and individual agent characteristics as simple quantitative aggregates [Fischer, 2002]. This is a great advantage to an agent-oriented discipline such as anthropology which is based on data-intensive comparative ethnography.

Furthermore, Fischer [1994] writes that simulation is also the ideal platform to extend current knowledge-based methods to anthropology. Kippen [1998] has used a knowledge-based simulation to represent indigenous knowledge about the improvisation of *tabla* music to which indigenous experts could make adjustments, criticise and suggest refinements. Fischer's own research demonstrates that a detailed knowledge-based model can produce classificatory results regarding arranged marriages that are comparable to indigenous thinkers and indeed are acceptable to them [Fischer and Finkelstein, 1994]. Though knowledge based models do not necessarily claim to represent cognitive processes they are useful as a formal representation method for ethnographic data and possibly for components in simulations.

As explained in the introduction to this chapter, the aim of agent-based social simulation (ABSS) is to understand the emergence of macro phenomena (such as group dynamics e.g. Bennett's categorisation of strategic designs (Section 5.6)) on the basis of models developed using micro phenomena (such as individual dynamics or the primitive effects of strategies described by Bennett (Section 5.5)). The development of an ABSS represents the intersection of three fields in agent-based modelling and as shown in Figure 3 the field of social science makes an important contribution to the design of such models [Davidsson, 2002]. In this study, interdisciplinary methodology including several areas of anthropological theory have been used to enhance the model such as cognitive, ecological and developmental anthropology.

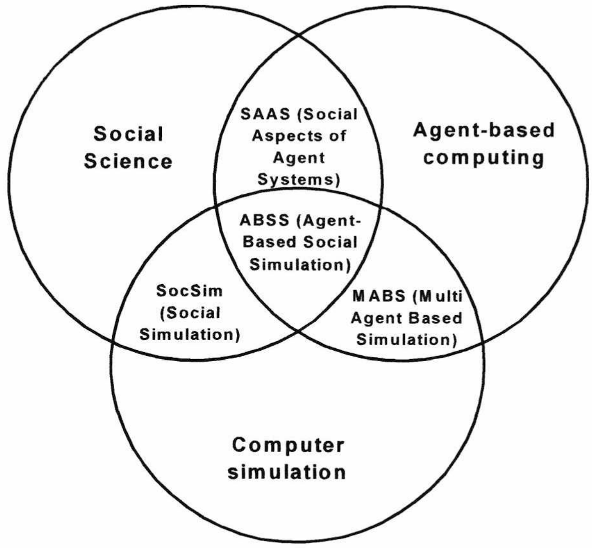

FIGURE 3. **Context of the study [Davidsson, 2002]**

For example, ethnographic methodologies and the large anthropological literature on eliciting knowledge [Gladwin, 1983, Read and Behrens, 1989, Sinclair et al., 1993, Spradley, 1979, Werner and Schoepfle, 1987, Wood and Ford, 1993, Wooten and Rowley, 1995] have guided interviews with domain experts. The design of a successful model, which is built from empirical data such as interview material, requires knowledge engineering as an important transitional stage from the ethnographic data to formalisation for use in a simulation. However, the formalisation of interview material into rules is not necessarily a reflection of what people think or of domain knowledge itself, but rather a formalisation of one's own understanding and interpretation of people's behaviour. That is, it could be a logically equivalent model (e.g. it may produce the same results, even if not in the same form), if it is a model which does attempt to use indigenous categories. Nevertheless, formalisation is necessary so that exploratory analysis can be done in order to investigate the domain further.

1.4. Summary

The model described in the following chapters combines qualitative anthropological data with an expert system and an agent-based simulation in order to explore Bennett's framework of adaptive dynamics as an abstraction of empirical adaptation mechanisms in the target system. The model illustrates adaptive patterns based on ethnographic data which lessen vulnerability to 'events' such as market and climatic variability within the context of Bennett's framework [1976]. It explores transitional phases, such as the transition to warmer climate crops and the effects of various strategies on individual and group dynamics.

However, some social scientists, and particularly anthropologists, object to modelling approaches that lead to reductionism due to a failure to consider context and the move away from 'holistic' approaches [Fischer, 1994]. This study aims to show that simulation in general, and agent-based simulation in particular, is a promising avenue in the social sciences, since it does potentially allow the exploration of the evolution of these models in the *context* of their *interaction* with other models and thus *is* a more holistic approach. That is, simulations illustrate how systems of different orders interact with each other and we are often interested in the structure, organisation and interaction of these sub-models more than their content [Fischer, 1994].

Furthermore, agent-based models allow us to examine the consequent behaviours of individual strategies on a group. They permit the representation of incremental complexity (i.e. where models include more and more factors and their contextual interactions) and facilitate the identification of critical situations that can lead to prediction outside the simulation. That is, the ability to demonstrate that some values for the system under study are salient enough to drive phenomena and not simply be a contributing factor [Fischer, 1994].

However, it is difficult to validate qualitative models although most models are provable if constructed correctly (e.g. see the Kaes project [Read, 1990] which models the structure of kinship terminologies). The difficulty lies in proving the connection between model and phenomena - particularly where value-based judgements contribute to complexity as in the case of human action or where the complexity of the situation makes it difficult to locate the contribution of specific agents to the phenomena under investigation. However, there is no reason why at a micro-level we cannot make statements about what we believe we know, and evaluate this with respect to what we think should be the outcome. Analysis should at least be subjectable to a test of the internal consistency of the representation, and thus our understanding of the domain [Fischer, 1994].

Nevertheless, the result of any simulation is only a descriptive model and any explanatory power that it has will be constrained by the assumptions made, which in this case, will be the ethnographic data, the researcher's understanding of it and the level of implementation of the model.

Furthermore, such a model will be a simplification of the system under study and in many cases will not represent any 'real' system but will be intended to generate model data for an 'ideal' world which data can be compared to, noting where it corresponds to, and departs from the ideal world. This can help to establish a sense of important contextual drivers within the domain and new areas for investigation which can be further validated with the model.

Chapter 2 reviews some of the literature in the disciplines that are of importance to this study revealing the relationships between them and the advantages that a fusion of methodologies can provide. Based on the review of work already done in these areas and the target system to be investigated, a detailed discussion of the research methods used, including a survey of software available for creating the model will be documented in Chapter 3.

More specifically, Chapter 3 includes a discussion of the way in which the informant was selected, an introduction into how the ethnographic data was translated into a formalised structure and the way in which it was incorporated in an agent-based model. It also discusses the agent-based modelling software, Repast [Collier, 2001] and the Java Expert System Shell (Jess) [Friedman-Hill, 2001] that has been used as a declarative module within the simulation toolkit.

An account of the ethnographic data that was collected during interviews and computer-aided fieldwork is provided in Chapter 4. The ethnographic data which has directed the design and requirements of the model was formalised using Bennett's theory of *adaptive dynamics*, to abstract and classify strategies utilised in the target system.

The principal components of Bennett's framework and the ways in which it has been applied to the ethnographic data will be described in more detail in Chapter 5. The knowledge elicited and documented in Chapter 4 is analysed using a range of ethnographic and knowledge engineering techniques resulting in innovative participatory computer-aided tools, which are described in Chapter 6.

The design of the model is documented in Chapter 7, while Chapter 8 reviews the technical implementation including agent architecture, some examples from the source code and a discussion of the limitations of the model. Verification, validation and interpretation of the results of the model are discussed in Chapter 9 while conclusions, possible applications and future work are explored in Chapter 10.

As mentioned, the second chapter reviews some of the literature which has influenced this study. It discusses some of the relevant principles of cultural and economic anthropology, cultural ecology, climate impacts literature, cognitive anthropology and the use of simulation in anthropological research. Literature relating to the diverse range of methodologies used to satisfy the qualitative and quantitative modelling in this study will highlight the value that a synergy of interdisciplinary methodologies can provide. This may enhance an understanding of the interaction of social and environmental models, potentially relating cultural knowledge to context and the behaviours that emerge, to better understand ethnographic data.

CHAPTER 2 Literature Review

The use of computational methods to analyse anthropological problems has great potential for important impacts on the development of ideas in anthropology. Until recently it could be argued that this impact would be restricted to relatively small domains of anthropology because of the restrictions of representation computers were subject to. Most methods depended on the 'summing over' of human activity which makes it inapplicable for the detailed anthropological study of many areas of human behaviour [Fischer, 1994b, 1994d]. However, with the rise of computer representations based on maintaining individual agents and the relations between them, this barrier is no longer as high. Conversely, this also opens up opportunities to apply anthropological theory and methods to a much wider range of computational techniques in other areas which have not themselves been very cognisant of anthropology in the past. Thus we are now in a position to advance both anthropological theory by exposing it to much work in other areas, and to advance modelling in these other areas by applying the individuated approach that much of anthropological theory addresses.

An interdisciplinary survey of the literature will emphasise the benefits of utilising a combination of computer modelling techniques and anthropological theory and methodology in an ethnographic study of agricultural adaptation to climate change, which may allow the analysis of the *interaction* of qualitative and quantitative models as recommended by Fischer [1994] (Section 1.3).

There are many differing definitions of *adaptation* in the field of cultural ecology and anthropology and these will be discussed in Section 2.2. However, the most prevalent reasons for this type of investigation are stated by Tol et al., [1998] who confirmed that none or very little attention has been paid to the *process* of adapting to climate change and it is argued that this requires a multi-disciplinary approach. An analysis of the *processes* involved encompasses the need to address the *constraints of adaptation* given the *varying possible objectives* of the decision-maker, the *capacity to adapt*, and the *perceived risks* of climate change itself [Tol et al., 1998]. Furthermore, change is constant and thus adaptation is an ongoing process. While larger contextual frameworks may be relatively stable, micro-adaptation is constant. This is one of the sources of difficulty in modelling human societies - as soon as people approach their goal, the conditions around the goal or the goal itself change *and* different people trying to adapt to a situation, or adapt a situation to their goals, are interacting with each other. Thus, adaptation is a complex process. Additionally, it should also be noted that the personal capacity, will and desire to adapt are also affected by socio-cultural *contexts*. The inherent complexity of such an analysis can in part be overcome by taking advantage of the wealth of comparative anthropological data and the holistic nature of anthropological theory that makes it the one of the best placed social sciences for interdisciplinary theory building, particularly in a highly unpredictable field such as one analysing adaptations to environmental change.

Since the socio-cultural costs of adaptation have rarely been studied, even less has been determined about the benefits of the adaptive strategies. If damage studies do include costs of adaptation, they are usually the total cost associated with specific adaptation and climate change scenarios. The marginal benefit of incremental adaptation can only be determined through the comparison of scenarios involving different levels of adaptation, but the same level of climate change [Tol et al., 1998]. Anthropological approaches to studying the process of adaptation, borrowing from cultural ecological perspectives, and specifically using Bennett's theory of 'human adaptive dynamics' (Chapter 5) [1976] will contribute to the study of the benefits of particular adaptation strategies and particularly incremental adaptation which could potentially be done under different scenarios. Theory from cognitive anthropology will also aid an empirical analysis of the goals of farmers and their perceptions of risk as both of these factors will affect their capacity and/or willingness to adapt, as mentioned. There are few studies which do not make assumptions about farmer responses and adaptations, rather than base their analyses on real behavioural or ethnographic evidence [see Smit et al., 1996, Smithers and Smit, 1997, Segerson and Dixon, 1999 for some exceptions] and therefore there is a need to empirically investigate how farmers do respond, adapt and adjust to environmental change and how they have done so in the past.

The present methods used in climate impacts analysis can benefit from an interdisciplinary approach, grounded in social science theory. For example, the use of spatial and temporal analogues is quite common in climate research [Glantz, 1991]. Using this technique, analogue scenarios are constructed by identifying recorded climate regimes which may resemble the future climate in a given region [IPCC, 2001]. Spatial analogues are regions which have, at present, a climate analogous to that anticipated in the study region in the future. Temporal analogues utilise climate information from the past as an analogue for possible future climate [IPCC, 2001]. However, while this is a very interesting method, it has been argued that spatial analogues ignore process altogether and can be problematic when applied in different social and geographical contexts [IPCC, 2001]. Temporal analogues are difficult to study [Tol et al., 1998], especially since response to past climate events may not accurately reflect longer-term meteorological trends and thus future pathways of response and adaptation may be obscured or overlooked [IPCC, 2001]. It has been suggested that the lack of emphasis on *process* deems such methods even less suitable for advising policy makers on anticipatory adaptation [Tol et al., 1998].

The computer modelling techniques combined with theoretical anthropological approaches discussed here, do not claim to solve these problems or to fully meet the needs of policy makers. However, in the process of illuminating ethnographic data on agricultural adaptation using computer-aided tools, we can address issues such as the *costs of adaptation*, both social and economic, the costs of *transitions* and the *process* involved, which is so crucial (Chapter 5). Therefore, it will be argued that the fusion of quantitative agent-based modelling methods, artificial intelligence techniques and the collection of qualitative anthropological empirical data will produce a useful research tool for the analysis of adaptive strategies within agriculture. The complexity of the problem requires the interdisciplinary background reviewed in this chapter.

2.1. Evolutionary adaptation

To begin with, it is useful to discuss differing aspects of adaptation in the most *fundamental* terms of evolutionary biology and its constituent processes to compare with higher level descriptions of human-environment adaptation/interaction as described by Bennett [1976] and other anthropologists. This will also serve as a basis upon which to understand why evolutionary processes such as genetic algorithms have been used in evolutionary computation to solve complex problems, as described in Section 2.11.2.

Ridley [2003] writes that in evolutionary terms, natural selection is the only known explanation of adaptation though it is not the only process that causes evolution. Adaptation can either be defined historically or by current function. That is, it is a characteristic that has evolved by natural selection to perform its modern function, or one that has evolved by natural selection whether or not its modern function is the same as the one it first evolved to perform. Darwin [1859] defined evolution as gradual, evolving in many small steps and Darwinian selection is cumulative, not random. That is, it is more likely that a *random* jump in genetic space will end in death, but the smaller the jump the *less likely* death is and the more likely that the jump will result in *improvement*. Such single step variation is shown in the similarity between parents and offspring [Dawkins, 1996].

However, adaptations in nature are not perfect, as a result of various constraining factors. For example, natural selection may be a slow process, and *time lags* can cause a species to be less than perfectly adapted as the environment is changing at a faster pace than the species can adapt (see Section 5.6.3 for *time lags* in human-environment adaptation). The environments of all species change continually because of the other species they compete, and cooperate with. Each species has to evolve to keep up with these events, but at any time they will lag behind the optimal adaptation to their environment.

In addition to this, some natural populations may be imperfectly adapted because accidents of history have directed their ancestors in what may later become the wrong path [Ridley, 2003]. That is, what is adaptive at one point in time, may not serve a successful adaptation mechanism in the future, when conditions change. Natural selection proceeds in small, local steps and each change has to be advantageous in the short term (e.g. Section 5.5.1). It is possible for natural selection to climb to a local optimum, where the population may be trapped because no local change is advantageous (e.g. Section 2.11.2), although a large change could be. Therefore, adaptations are also a set of trade-offs between multiple functions, multiple activities, and the possibilities of the present and the future. Furthermore, adaptation may be imperfect because the mutations that would enable perfect adaptation have not arisen.

For particular characters, adaptation and constraint can be alternative explanations. Likewise, differences in the form of a character between species may be due to adaptation to different conditions or to constraint. Forms that are not found in nature may be absent because they are selected against *or* because a constraint renders them impossible [Ridley, 2003]. Therefore, the imperfections of living things are due to genetic, developmental, and historical constraints, and to trade-offs between competing demands. If a character is viewed in isolation it will often seem poorly adapted. However, the correct standard for assessing an adaptation is its contribution to the organism's fitness in all the functions it is employed in, through the whole of the organism's life.

Thus, adaptations can be recognised as characters which appear to be too well fitted to their environment for the fit to have arisen by chance and therefore are characteristics that help their bearers to survive and reproduce. They are purposive and often complex. However, they cannot be simultaneously optimal for all the levels of organization in life. What is optimal for the organism may not be optimal for its population. The same conflict arises in human-environment interaction where the adaptations of one group may result in negative impacts for others.

2.2. Human-environment adaptation and interaction

When considering adaptation among human societies, Julian Steward's [Steward, 1995] renowned definition of cultural ecology was

> *the study of the adaptive processes by which the nature of society, and an unpredictable number of features of culture, are affected by the basic adjustment through which man utilizes a given environment.*

This one-sided, environmentally deterministic view has long been criticised. A less rigid definition of cultural ecology was sought which emphasised the interdependent relationship between culture, society and the environment [Ellen, 1982]. Clearly it is important to investigate the relationships of people to their physical and social surroundings using scientific methods which can enable generalizations. At one level, we must aim to understand individual adaptation and the individual decision making processes. However, at another level, we must understand how individuals in social groups make decisions about natural resources and how these resources are 'socialized' and themselves become critical elements in social relationships. This has applications via the analysis of macro-micro phenomena in complex adaptive systems and there are examples of these relationships in ecological anthropology [Ellen and Fukui, 1996, Wilbert, 1996]. For example, the Warao Indians, documented by Wilbert [1996], had a well developed weather religion, which effectively protected them from the seasonal hunger and recurrent famines that were prevalent in the remote area of the Orinoco Delta that they inhabited. Part of their adaptive 'toolkit' in this precarious environment included 'transformation stories' which Wilbert describes as an 'ecological mythology' or a 'blueprint of interrelationships between humans and their environment which reveals a treasure of adaptive wisdom'. Translation of this oral history across successive generations became necessary for the Warao due to their isolation in the Delta and their need to know of its finite resource potential. In this way the Warao managed to transform a hostile environment into a viable habitat [Wilbert, 1996].

Butzer [1990] defined contemporary cultural ecology by emphasising 'how people live, doing what, how well, for how long, and with what human and environmental constraints'. Cultural ecologists argue that the possibilities and the constraints of the resource base, and the local environment that a group uses is extremely important for certain features of that society. Thus, adaptation means *responding to change in order to survive and prosper better.* This could refer to the development of better technologies such as ploughs to cope with increased food needs or to the continuing changes made to farming patterns, such as the introduction of different crop types over time as climate or soils change. Netting [1993], like Wilbert, believes that ethnoscientific knowledge is usually well developed and it is this knowledge which allows people to adapt and survive in marginal environments. As a result, Netting emphasises the importance of the accurate elicitation of what people know about their local environment and how they behave within it in small scale systems. Netting [1993] has discussed numerous adaptive strategies employed by small-holder farmers, enabling comfortable survival in otherwise marginal environments. Similarly, research has been conducted by Bennett in the Canadian Plains, among small Hutterite communities [Bennett, 1966] (Section 5.7).

Agricultural economists approach the analysis of farming systems from the standpoint of meeting supply and demand for food and other goods, and making rational decisions about prices and resource allocation, and their approach emerges in 'farming systems research'. Steward's [Steward, 1995] early work was criticised for its lack of consideration of the impact of human behaviour on the environment. It was felt that these impacts were an important manifestation of a truly interdependent natural-human system. Herein lies the significance of more recent 'ecosystem' studies since these explore such interrelationships [e.g. Ellen, 1982, Butzer, 1990]. It has been argued, for example, that the effects of farming on soil quality, vegetation, water resources and pests and disease vectors should be examined when conducting fieldwork in particular places. Therefore, using the 'system' as a basis for study is often helpful. From this perspective, soil erosion and other environmental problems can often be accounted for.

The best known example of an ecosystem based analysis is Rappoport's [1968] ethnographic account of the New Guinea Maring who raise pigs for slaughter once every seven years in a huge ritual festival. Rappoport argues that these rituals are central to the functioning of this society. The meat resulting from this practise is distributed to all members of the community, and actually contributes to efficient flows of energy among the Maring. Known as the 'Kaiko' ritual, it occurs when women, who tend the pigs, are unable to cope with the number of them. These occasional feasts re-distribute much needed protein to all members of the tribe, and have implications for reducing warfare with neighbouring groups. However, Rappoport does not mention the Maring's own views on their 'adaptive strategy', or whether they consciously recognise it as such [Rappaport, 1968].

One of the values of the cultural-ecological approach is in comparing different types of farming systems. For example, in the past the image of hunter gatherers held by Western people was often one of extreme poverty, primitivism, and of people constantly on the bare limits of survival [Ingold et al., 1991]. However, cultural ecologists have demonstrated the falseness of these images [Lee, 1969]. Richard Lee's studies of the Kalahari Bushmen in the 1960s illustrated through exhaustive fieldwork that the San Bushmen did not work an unreasonable number of hours and did not have a marginal existence. Average labour inputs sufficiently met food requirements and were sufficient to support the tribe, and its old, infirm and young children. He also showed that it was the exhaustion of local food sources which forced the relocation of camps. For this mobility to succeed, a flexible social structure was needed - small, flexible bands. If bands had too many people, the carrying capacity of the desert would be exhausted and clashes with neighbouring groups could occur. The San therefore regulated their own population by adaptive means [Lee, 1969] (see Fischer's [1986] simulation of Lee's model).

A criticism of cultural ecology has been its need to examine social change and to recognise the importance of past experiences, historical behaviour and context at the macro-level, even when studying small-scale societies, at the micro-level. This is vital to understanding, as are the '*ecological transitions*' of regions and of societies [Bennett, 1976]. Thus historical work is needed to elicit past problems and their solutions (Chapter 5). For example, the effects of different government systems, various forms of taxation and subsidies, and the increasing globalisation of international markets are factors which should be considered in an analysis of adaptation, even at a micro-scale. The results of micro-regional scale studies which ignore these issues, may be that their results are not generalizable to larger areas. Important regional-scale, macro-economic processes such as trade patterns and the effects of regional, national and international dynamics and hierarchies of power should not be ignored in such studies [for example, see Ellen and Glover, 1974, on trade networks in the Molluccas].

2.3. Bennett's model of 'adaptive dynamics'

In contrast to previous definitions of adaptation in cultural ecology, Bennett writes that adaptive behaviour always takes place in a cultural milieu of compromise and decision-making which emphasises the emergence of new problems from the solutions to past ones. The way in which Bennett approaches ecological adaptation as *those actions that are taken to satisfy human objectives*, has been translated into a technical framework which will be used to model some of the complex decision making processes involved in the agricultural domain. In this study, by illustrating the comparative consequences of decisions taken, an assessment of whether new problems are generated by the use of old solutions can also be carried out. This directly addresses the criticisms that studies of cultural ecology neglect an analysis of historical change. This again refers to the continuous process of adaptation where problems emerge not simply as a result of individual-environment interactions but due to the complexity of individual interactions and that which emerges from them. *Cultural adaptation* occurs when an adaptive pattern emerges between individuals, which is reproducible for a time, due to cultural transmission.

Adaptive processes are *emic* in that they refer to intellectual constructions made by observers' of the consequences of adaptive behaviour especially strategic action and strategies over periods of time. The question of whether actors in an adaptive system can perceive processes at work (such as the Maring of New Guinea [Rappaport, 1968]), is a question of the extent of their ability to objectively assess past experiences and formulate strategies to accommodate a range of future circumstances. It is possible that the actors in the system do *perceive* adaptive processes and an anthropologically based model may help to illuminate such strategies if they exist, or to suggest them based upon previous patterns of (perceived) successful adaptation. Even if adaptive strategies or goals are specified in terms of reaching past ideals (that may never have existed), this represents a transition from the present and therefore people must be aware at some level that they are in the process of changing, not being [Fischer, 1994d].

Unlike this study, Bennett consciously moves away from an analysis of adaptation in conjunction with causal factors such as climate. However, his concern to maintain a greater focus on goal-oriented, 'purposive behaviour', will also be incorporated in the model in this study. Bennett writes that the basic question for the social sciences is to determine to what extent the domain classification of thought, inter-human activity and adaptation are integrated in a concrete social context or society. It is this question of integration that is addressed in the model using an expert system to embed the rules related to this particular domain of activity. Bennett uses the term *adaptive dynamics* to refer to human behaviour, as designed to achieve goals and satisfy wants, *as well as* the resulting *impact* of adaptation for the individual, society and the environment. However, the *process* of adaptation is not dependent upon behaviour as such, but references to structures and knowledge relating to these structures, which may be maintained by observable behaviour. In this sense, Bennett describes adaptation as a *generic, cross-cultural process* which can be compared in different contexts and this will be explained in greater detail in Section 5.4. Thus behaviour represents the physical instrumental aspects of adaptiveness, but not the underlying principles of the behaviour, which are not necessarily apparent or associated with it. It is a set of mental or cultural relations that form the basis of the association and the recognition of this and a suggested formalised representation of it, within Bennett's framework, is the foundation for this study. According to Bennett there are two major analytic modes of adaptive behaviour:

- **Action by individuals** designed to accomplish ends or effect change in the instrumental contexts of life, such as a farmer trying to increase his yield or obtain a standard yield.
- **Interactive / transactional behaviour** of the individual with other individuals in groups (e.g. social exchange) usually governed by rules of reciprocity and by various normative value components. This is designed to accomplish ends and some of these will be instrumental as in the case of co-operative labour and machinery exchange among farmers. However, a great deal of transactional behaviour pertains to social ends.

Both levels of behaviour described by Bennett - that of the individual and group - can be modelled within a multi-agent simulation using a complex adaptive systems approach. However, individual actions and social transactions can be further divided into two levels of analysis:

- The **microsocial**, which concerns the study of behaviour in specific contexts of purpose (innovative, manipulative, coping) of which there are formal and informal manifestations.
- The **macrosocial** which consists of the meaning of such behaviour for social systems including processes of change resulting from many actions and transactions such as the use of second-order concepts (see Section 5.6).

The simulation underlying the present research illustrates these two levels of analysis. The aim of a complex adaptive systems approach is to analyse macro-social phenomena which emerge as a result of micro-social properties. Thus, the system aims to fulfil the need stated by Bennett and other critics of traditional ecological analyses, to fuse macro and micro-social study in order to study human adaptation successfully, while including social and historical context and not ignoring past experiences.

2.3.1. Tolerance thresholds

Underlying processes of strategic action, are familiar but poorly understood mechanisms. If we are to understand the basis of changes in ecological relations we need to know the level of deprivation that humans are willing to accept before the search for alternative paths will begin. Deprivation (see Section 2.5 for similarity to risk) can be measured in terms of **minimal tolerance** and **habituated tolerance** (levels which societal conditioning has taught the individual to prefer and want). Responses therefore vary by 'culture' but the process of adjusting behaviour to contextual habituated tolerances is cross-cultural [Bennett, 1976]. However, for a contextual socio-cultural understanding of minimum and habituated tolerance empirical data must be collected and analysed (see Chapters 4 and 6).

2.3.2. The costs of adaptation

Opportunity costs are assessments made by people of the emotional, social and economic costs of shifting to a new strategy when existing ones are threatened [Bennett, 1976]. According to Bennett, there needs to be a method of measuring these opportunity costs as influences on behavioural change. Bennett has semi-formalised certain adaptive processes in a way that they can be used as a basis for the analysis of this problem. The comparative 'real-world' examples that Bennett seeks will be achieved using participatory knowledge elicitation techniques during structured interviews with farmers, the domain experts [Bennett, 1976] (Chapter 4).

2.4. Models of strategic choice

In similarity to Bennett's formalised model of adaptive decision-making, there is also a large amount of literature on strategic choice in the business and management field. This will be reviewed in order to provide a comparison with Bennett's strategic model of adaptive dynamics in Chapter 5. Thus, in the following discussion, references to commercial organisations can be applied in much the same way to farming enterprises and the relevant decision-making processes involved.

Wilson and Gilligan [1997] write that the characteristics of strategic decisions for commercial organisations involve:

1. The scope of an organisation's activities and thus the definition of its boundaries.
2. The matching of the organisation's activities with the opportunities of its substantive environment. Since the environment is continually changing it is necessary for this to be accommodated via adaptive decision-making that anticipates outcomes – as in playing a game of chess.
3. The matching of an organisation's activities with its resources. In order to take advantage of strategic opportunities it will be necessary to have funds, capacity, manpower, etc. available when required.
4. Major resource implications such as acquiring additional capacity, disposing of capacity, or allocating resources in a fundamental way.
5. Influences by the values and expectation of those who determine the organisation's strategy. Any repositioning of organisational boundaries will be influenced by managerial preferences and conceptions, as much as by environmental possibilities.
6. Long-term organisational direction.
7. Complexity, since they tend to be non-routine and involve a large number of variables. As a result their implications will typically extend throughout the organisation [Wilson and Gilligan, 1997: 18].

The business view of strategic choice analyses strategical and tactical decision-making as only one part of a broader problem-solving process. This broader view consists of three key aspects: analysis, choice and implementation [Wilson and Gilligan, 1997: 19].

1. *Strategic analysis* focuses on understanding the strategic position of the organisation, which requires that answers be found to such questions as:

   (a.) What changes are taking place in the environment?

   (b.) How will these changes affect the organisation and its activities?

(c.) What resources does the organisation have to deal with these changes?

(d.) What do those groups associated with the organisation wish to achieve?

2. *Strategic choice* has three aspects:

   (a.) The generation of strategic options, which should go beyond the most obvious courses of action.

   (b.) The evaluation of strategic options, which may be based on exploiting an organisation's relative strengths or on overcoming its weaknesses.

   (c.) The selection of a preferred strategy which will enable the organisation to seize opportunities within its environment or to counter threats from competitors.

3. *Strategic implementation* involves translating decisions into actions, which presupposes that the decisions/strategic choices were made with consideration to *feasibility* and *acceptability*. The allocation of resources to new courses of action will need to be undertaken, and there may be a need for adapting the organisation's structure to handle new activities [Wilson and Gilligan, 1997]. E.g. employees may have to learn new skills or new technology may need to be installed to implement the strategy.

The elements of strategic problem-solving described by Wilson and Gilligan [1997] above are summarised in Figure 4.

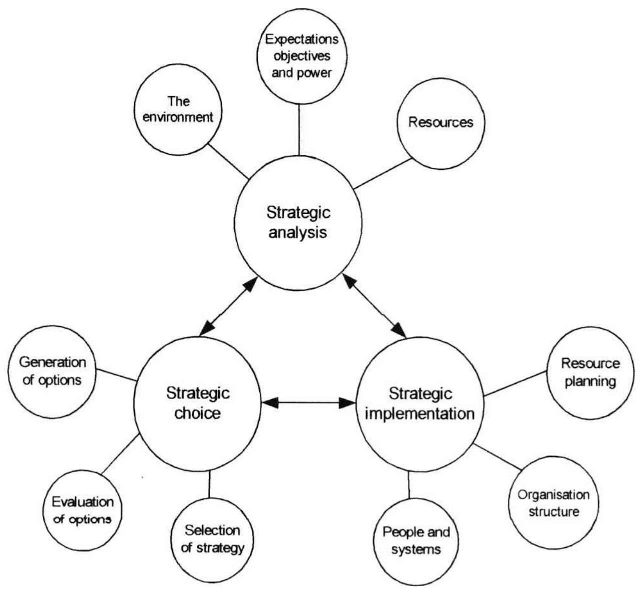

FIGURE 4. A summary model of the elements of strategic management Johnson and Scholes [1988] in Wilson and Gilligan [1997: 19].

Wilson and Gilligan [1997] emphasise that 'strategy' is not synonymous with 'long-term plan' but rather consists of an enterprise's attempts to reach some preferred future state by adapting its competitive position as circumstances change. While a series of strategic moves may be planned, competitors' actions will mean that the actual moves will have to be modified to take account of those actions.

This view of strategy can be contrasted with an approach to business management that has been common. In organisations that lack strategic direction there has been a tendency to focus on *efficiency* and cost cutting, defined as the relationship between inputs and outputs, usually with a short time horizon (Section 5.5.1), rather than on *effectiveness*, which is concerned with the organisation's attainment of a goal, including that of desired competitive position (Section 5.6.6). While efficiency is essentially introspective, effectiveness highlights the links between the organisation and its environment [Wilson and Gilligan, 1997] (see Chapter 5 for a comparison with Bennett's model).

A summary of the main combinations of efficiency and effectiveness is presented in Figure 5.

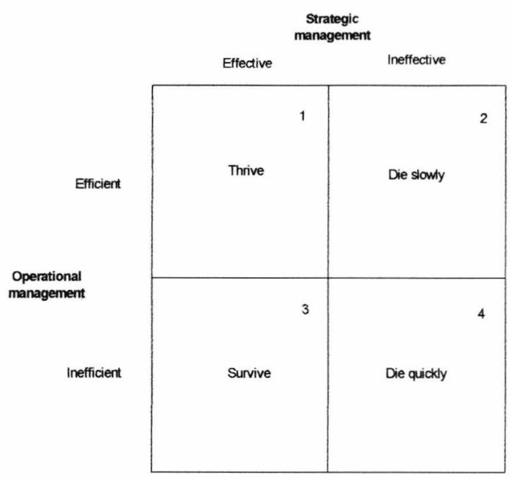

FIGURE 5. Efficiency versus effectiveness [adapted from Christopher, et al., 1987 in Wilson and Gilligan, 1997: 21].

An organisation that finds itself in cell 1 is well placed to thrive, as it is achieving what it aspires to achieve with an efficient output/input ratio. However, an organisation in cell 4 is doomed as is an organisation in cell 2 unless it can establish some strategic direction. It is important to note that cell 2 is a worse position than cell 3 since, in the latter, the strategic direction is present to ensure effectiveness even if too much input is being used to generate outputs. To be effective is to survive whereas to be efficient is not in itself either necessary or sufficient for survival. In summary, Wilson and Gilligan state that an emphasis on efficiency or effectiveness is clearly wrong. However, determining *what* is 'effective' will be dependent on the goal of the organisation [Wilson and Gilligan, 1997].

2.4.1. Strategy formulation

The goal of the enterprise will to some extent be governed by *context* and in similarity to Bennett's definition of adaptive strategy, this is a determining issue in the choice process. This is illustrated in Figure 7 where logically viable options exist only where the differing requirements of intent and assessment are most fully met.

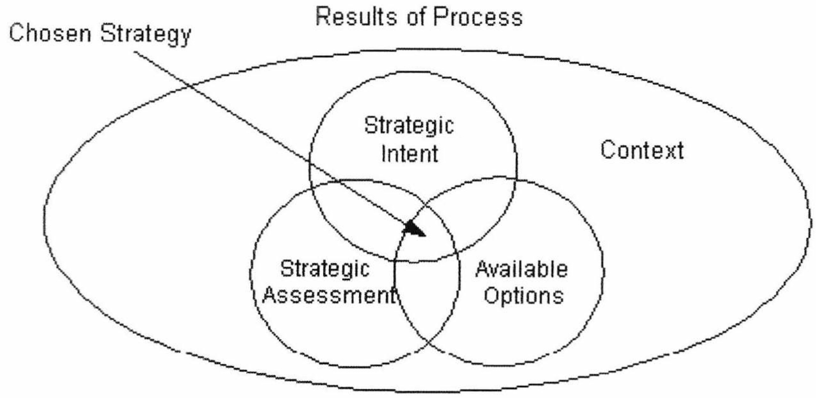

FIGURE 6. Results of the strategy formulation process [Macmillan and Tampoe, 2001: 134].

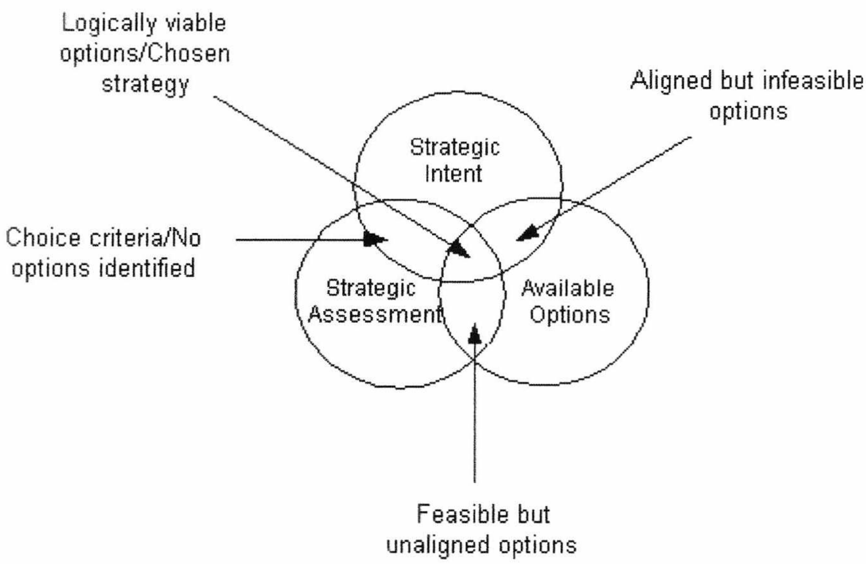

FIGURE 7. Choosing a strategy from among strategic options [Macmillan and Tampoe, 2001: 134].

The areas where any two circles overlap are important. The criteria for choice derive from intent and assessment. Feasible options may exist which are not aligned to strategic intent, raising the question of whether the strategic intent should be changed. Infeasible options may seem highly attractive and may have powerful supporters, so the reasons why they are infeasible may need to be carefully argued with clear evidence. Choices of what not to do may sometimes be as important as choosing what to do [Mintzberg, 1998a].

Macmillan and Tampoe [2001] write that in reality the procedure for choosing a strategy may be structured more similarly to Figure 8.

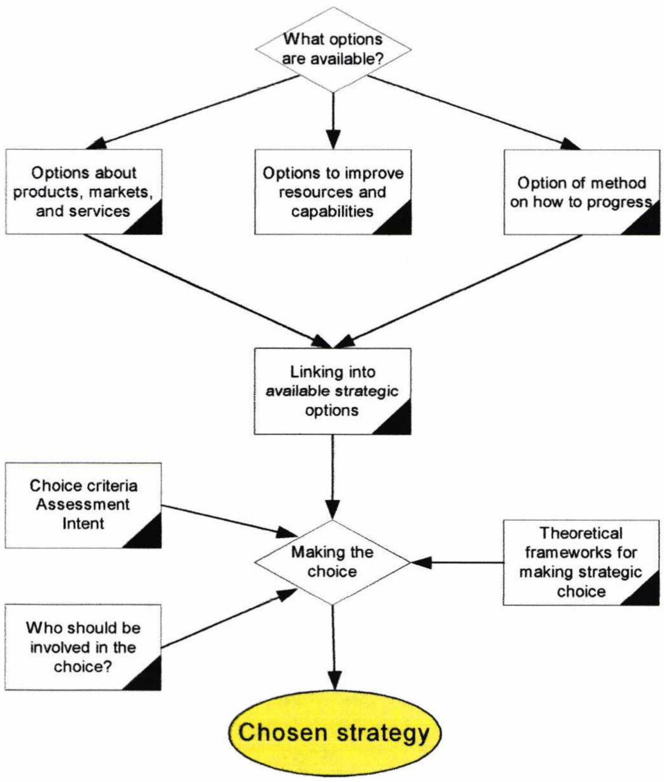

FIGURE 8. Structure for making strategic choice [Macmillan and Tampoe, 2001: 135].

Figure 8 shows three types of options - products/service/markets, resources/capabilities, and method of progress - that are typical in the choice process but not necessarily exhaustive [Macmillan and Tampoe, 2001]. The most obvious type of option relates to which products or service to offer in which markets, a framework which would naturally also apply in the case of commercial farmers supplying domestic and international markets.

For comparison, Figure 9 is a diagram first suggested by Igor Ansoff [1987] for structuring decisions to align products with markets.

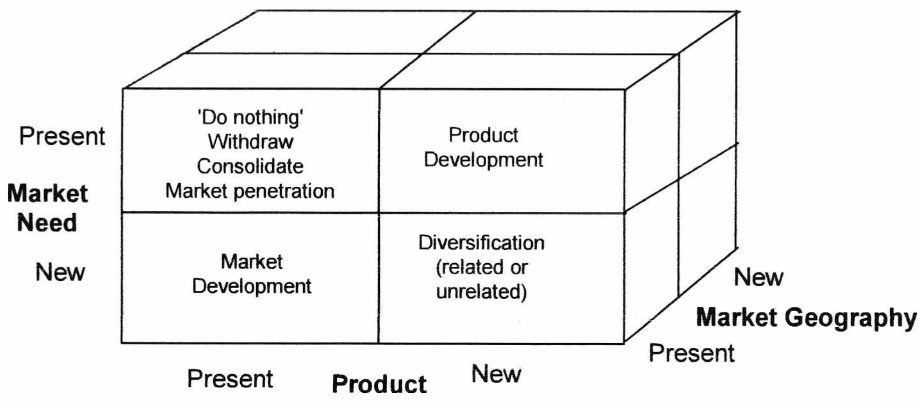

FIGURE 9. Options for markets and products. Source: I.Ansoff, Corporate Strategy (Penguin, 1987), 110. Reprinted with permission of Ansoff Associates in Macmillan and Tampoe [2001: 137].

The axes of the diagram are product, market need and market geography (geographical location). The model defines four cells for the present market geography. The top-left of these cells represents the present status of the enterprise. The possible future choice about products and markets can be represented as movements within or away from this cell. Macmillan and Tampoe [2001] define the choices as:

- **'Do nothing'** - that is, continue with present strategies. This strategy is important as it is usual to compare any proposed change with the 'do nothing' option as a baseline. The 'do nothing' option is rarely viable for the long term as it is likely that competitors will gradually take the market by improving their products, their processes, or their relationships.
- **'Withdraw'** - leave the market by closing down or selling out. This appears to be a negative option but may be necessary to focus available resources into areas of greater strength. It is common in declining markets to see some competitors selling out to others that can operate the combined operation more cheaply.
- **'Consolidate'** - attempt to hold market share in existing markets. This is a defensive option, which usually involves cutting costs and perhaps prices. It is more common in markets that are mature or beginning to decline.
- **'Market Penetration'** - increase market share of the same market. This is a more aggressive option and usually involves investing in product improvement, advertising, or channel devel-

opment. Acquiring the businesses of competitors who are withdrawing from the market may be a necessary related resource option [Macmillan and Tampoe, 2001: 136-137].

Other possible options (which involve moving out of the front left-hand top cell of Figure 9) are either to develop or acquire new products (product development) or to address new market needs (market development) [Macmillan and Tampoe, 2001].

Entry into new markets with new products is referred to as 'diversification'. It may be of two types - 'related' and 'unrelated'. The former divides into backward, forward, and horizontal integration. Backward integration is a move towards suppliers and raw materials in the same overall business. An example of this would be a grocer growing his own vegetables. Forward integration is a move towards the market place or customers in the same overall business - a farmer selling his own produce to the public at a farmers' market, for instance. Horizontal integration is a lateral move into a closely related business such as selling by-products. An example of this is a farmer managing other farms, in effect 'selling' resources such as skill, knowledge and machinery. Diversification which is not of any of the above types is 'unrelated'. Usually this still has some degree of synergy (or fit) with the original business, such as the ability to share facilities. However, the 'fit' is less often than expected, and thus less synergy is achieved than anticipated [Whittington *et al.*, 2000].

Though research may measure how successful different forms of market or product development are in general, strategic choice has to focus on the relative attractiveness of available options. If the present position is bad enough, even relatively risky alternatives may be preferable to doing nothing. Therefore, strategic options about building skills and experience may have to precede choices to enter new markets or to develop individual products. Thus, consideration may be necessary regarding *capability options* first and market options second, in order to look for ways to build unique competencies and then to seek markets and products to demonstrate them [Kaplan, 2001].

Options about product/markets, resources/capabilities, and the method of implementation, as shown in Figure 8, have to be combined into a much smaller number of strategic options. This may be a bottom-up or top-down process. The bottom-up approach implies linking what might be done in detail into potential strategies that seem to make wider sense. The top-down approach means testing general ideas of future direction against detailed options. In practice, identifying a smaller number of strategic options is likely to combine top-down and bottom-up thinking [Gertner, 2000]. Similarly, Bennett's framework also incorporates a combination of bottom-up and top-down approaches, allowing the identification and linkage of low-level options with larger scale strategic processes.

Importantly, strategic options must also pass two tests based on the logic of Figure 6 and Figure 7. They must be:

- *Aligned* in that they conform to the strategic intent i.e. they aim to achieve the desired long-term goal.
- *Feasible* in that the capabilities and resources necessary for success can be made available. i.e. that it will work. This test is likely to draw on the analysis of the strategic assessment. The tests of feasibility require serious consideration of what will be required to implement the necessary changes [Macmillan and Tampoe, 2001].

A third test goes beyond logic and relates to the acceptability of the chosen option. Acceptability means that it will win the approval of both those who will have to approve it and those who will have to implement it [Mintzberg, 1998]. In addition to this I would argue that such options must also win the approval or at least, acceptance, of those whom they will affect. This is one of the aspects of social power. However, while people accept even if they do not approve this can also be a source of change and adaptation, as the factors that led to acceptance can break down over time.

According to Macmillan and Tampoe [2001], any strategic option has to pass all three tests to be viable. If more than one strategic option passes these tests, they may have to be compared with each other to choose the 'best'. This judgement has to take into account both tangible characteristics such as *risk* and *return* and less tangible matters such as alignment with *values* and *culture* [Mintzberg, 1998a]. In practice, the number of strategic options is rarely large. Furthermore, the tests, though important, cannot be completely objective.

In summary, strategic choice involves comparing strategic options both logically and politically (considering what is *acceptable* to all parties concerned). Strategic options have to be aligned, acceptable, and feasible. Clearly, it is simplistic to treat strategic choice solely as the logical comparison of strategic options. The *process* of decision-making is also social and cultural. It is important that those who will be crucial to implementing the strategy support the choices made [Mintzberg, 1998], as well as those who will be affected by it, if these two groups are different.

2.5. Risk and vulnerability

While context inevitably affects the strategic choice process, perceptions of risk and vulnerability are also important factors to consider, since they will influence the *acceptability* of chosen options. Thus, perceptions of risk and vulnerability will be considered both in the context of an anthropological study of an historic agricultural society, as well as in a more quantitative manner in Section 2.5.1.

2.5.1. Quantification of risk

A note prepared for the Intergovernmental Panel on Climate Change (IPCC) Expert Meeting on Risk Management Methods attempted to define the basic concepts involved in the measurement of climate risk and vulnerability in agricultural production, due to an apparent lack of consensus within current literature [Gommes, 1998]. A quantitative approach to defining risk as a loss rather than as a probability of occurrence of a damaging event was used. For a given factor (or stress):

(EQ 1)

$$\text{Average loss/annum} = \text{Average number of events/annum} \times \text{Average loss/Event}$$

For each intensity, this can be rewritten as:

(EQ 2)

$$\text{Total Risk}_{(\text{loss/annum})} = \sum_i (\text{Frequency}_i \times \text{Vulnerability}_i)$$

Gommes writes that *loss* in the equations above can refer to different units of measurement, such as loss of production, income, life and so on, thus incorporating different aspects of vulnerability. A common denominator is useful for expressing a combined loss which may itself be due to several different factors, though such aggregation clearly has disadvantages also. According to Gommes' definition above, he asserts that total risk and impact are approximately synonymous [Gommes, 1998]. This calculation is included in the model developed for this research to provide additional information regarding chosen strategic options as it has the potential to incorporate differing components of vulnerability (Section 8.1.7).

2.5.2. Perceptions of risk

In contrast, Hegmon's work in the late 1980s was an attempt to understand the *relationship* between social organisation and risk and the effectiveness of social insurance strategies as means of reducing risk. Although the means of reducing risk in the historic Pueblo (Hopi) agricultural society of Hegmon's study may be quite different to that of modern agricultural societies the strategies must be acknowledged as a basis for comparison. Hegmon's use of simulation techniques also warrants further discussion.

The main types of strategy observed by Hegmon were buffering mechanisms which distributed risk over time, space or among people. However, Hegmon argues that buffers did not always reduce risk, and thus she attempted to evaluate when and how buffers succeeded in doing so. Buffers relied on their consistent implementation year after year, and thus the simulations designed by Hegmon demonstrated that the reduction of risk through the use of buffers depended upon the *pattern* of variation of 'bad years'. Grain storage, for example, was not necessarily a reliable mechanism since resources could diminish rapidly in a bad year [Hegmon, 1989].

As a result Hegmon found that variation was an important but seemingly inconsistent factor in her analyses, and that whether the Hopi managed to cope with the 'bad years' was of more significance. That is, risk depended on the pattern of variation of 'bad years' at least as much as on the average variation or variance. In Hegmon's terms Hopi clans could be characterised as 'resilient' rather than 'stable'. The ability to cope with variation was termed 'resilience' and defined by Holling [1973: 14] as a measure of 'the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationship between populations or state variables'. Hegmon [1989] writes that variation is common in 'resilient' ecosystems. The 'resilient' strategies employed by the Hopi had a high probability of succeeding and/or absorbing change through bad years by at least allowing some households to survive, even if others failed, resulting in less perceived vulnerability. More specifically strategies such as **restricted sharing** did not cause the interdependence of the whole group, as a **pooling strategy** might. The consumption patterns are the same in these strategies but differ in amounts of inter-household sharing. **Independence** involves no sharing, while **restricted sharing** involves sharing of household surplus only and **pooling** involves complete sharing in small groups [Hegmon, 1989]. Though pooling would be characterised as a stable strategy, it could also cause losses to the *whole* group and thus was perceived as a strategy with higher risk. In contrast restricted sharing served as a buffer even in multiple bad years and thus provided an *intermediate* degree of overall variation.

Therefore, Hegmon concluded that in such analyses of strategic action, the **pattern** and **degree** of variation are important variables.

In comparison to Gommes' more conventional approach, Hegmon shows why average risk or loss is meaningless unless one can withstand the critical thresholds. The continuity of a system is a sequence or process while average loss simply states what will happen if a system remains continuous for a time interval.

2.6. Using anthropology to study farming systems

The conventional way of analysing the impacts of agricultural policy interventions is by focusing on the farm household as the unit of analysis, termed as *farm household modelling*. This is based on the new household economics (NHE) theory, first introduced by Becker [1965]. The *unified household model* assumes that households act as a unified unit of production and consumption which aims to maximise utility subject to its production function, income and total time constraint. With a single utility function for the household, there is an implicit assumption that no conflict exists within the household and hence the objective is to maximise a unified preference function. This involves the aggregation of individual utility functions according to certain rules, or assuming that all members have the same utility function, whereby maximising household utility would be similar to maximising individual utility [McGregor et al., 2001].

The *bargaining framework* offers an alternative approach to the study of household decision making where differing preferences are recognised. Conflicts that may arise among household members are resolved through a bargaining process which guarantees a self-enforcing utility function. The obvious advantage of this approach over the neo-classical unified preference approach is that it allows for a means by which differences are reconciled via differential utility functions (Manser and Brown, [1980] and McElroy and Horney, [1981] in McGregor et al., [2001]). A main factor of this model is the identification of 'threat points'. This could be, for instance, the utility level which is guaranteed to the individual if no agreement or bargain is achieved (McElroy and Horney [1981] in [McGregor et al., [2001]).

However, as stated by McGregor et al. the shortcomings of normative economic theory which is the basis of many 'hard' systems paradigms for modelling decision making, are that they assume that the household or decision makers maximise utility subject to various constraints [McGregor et al., 2001]. Though these assumptions may be necessary for mathematical analysis it is questionable whether they will lead to valid conclusions at the micro level. The rich nature of farm household decision-making cannot be described by normative models and thus factors which should be considered may be overlooked [McGregor et al., 2001]. For example, the use of Gladwin's 'Elimination by Aspects' methodology [1983] (Section 2.10) might enable the socio-cultural and socio-economic customisation of farmers with differing goals, since

> *...another key problem for policy makers and designers of aggregated models is that farm households are not homogeneous in the physical and economic constraints they face, nor in the social and psychological factors they consider...A better description of the types of factors being considered by farm households and the relative importance of these factors can sometimes be provided by studies based on anthropological, psychological or sociological theories. These types of studies can provide a rich picture of farmers' decision-making processes that can stand alone, or alternatively, add to, help interpret, or complement the findings of 'hard' systems studies* [McGregor et al., 2001].

An adequate account must assess the dynamics of response when assessing the success of a policy, since all farmers in an area will not respond to a policy simultaneously. In systems such as those studied by McGregor et al. [2001], farmer preferences are represented by a simple scale, and therefore represent an approximation of the consequences of the rate of changes in farmer preferences. McGregor et al. [2001] write that more appropriate results may be generated using indigenous knowledge and/or knowledge based systems [e.g. Edwards-Jones and McGregor, 1994 and Sinclair et al., 1993 on knowledge based systems among Nepalese farmers]. Hence McGregor concludes that there is a need to develop a pluralistic approach to the integration of micro- and macro-level responses to policy and technology adoption, particularly using a combination of 'hard' and 'soft' science approaches and indigenous knowledge [McGregor et al., 2001]. This supports the use of the multi-disciplinary approach in this study and some of the methods used will be discussed further in Section 2.8 and Section 2.9.

As mentioned in Section 1.2, Dent and McGregor [1993] recognise the social and cultural emphases which should accompany a modelling approach to farming systems research. They acknowledge that 'grassroots views' are rarely considered in the decision making process at national or regional levels, when new policies are formulated, and that these underlying weaknesses work against the philosophy and practical application of farming systems research. Dent [1991] attempts to address the key areas integrating research on adoption, which he believes to be social and cultural driving forces, acknowledging that these should accompany traditional crop modelling methods. The type of simulation that Dent proposes would explore the processes and interactions of farm decisions, farm family behaviours and the socio-cultural network involved. He suggests varying attributes in the farm scenario such as alternative technologies, alternative market scenarios, credit opportunities and levels of extension support. Creating this type of scenario and including factors such as the relative merits of technology, education, credit facilities, culture, and peer group information would allow planning of the adjustments that would be required to assist, for example, the adoption of a new technology. This could then be implemented before the technology is introduced, to increase the probability of successful adoption. He implies that the central decision relates to land use and that this in turn influences the pattern of farming which ensures to some degree the costs and output from the farm. Dent attempts to show that the choice of crop, the area allocated to it and the cultivar selected are related to the pressures from peer groups, cultural norms, religion and tradition and that these factors do shape family objectives and thus the farm household [Dent, 1991].

2.7. Climate impacts literature

Much climate impacts research in the 1970s focused on the cause and effect relationships between the climate and a response to a climatic event from the human environment/ecosystem. Known as the 'impact approach' this was characterised by simple regression models, which were used to establish a statistical relationship between the climatic event and the related impact. However, it became clear that this approach was too simplistic and again that the complex combination of processes that led to these responses had been ignored. Moreover, Parry and Carter [1998] have recently asserted the need for an increased multi-disciplinary approach to the study of a topic as vast as climate change impacts analysis.

Since the 1970s there has been a gradual shift in the climate debate, which does place a greater emphasis on the interaction between climate and human activity, providing a new space for socio-economic analyses and a focus on the detailed research that has been conducted in the fields of human ecology and environmental anthropology. Parry uses the example of the 1930s drought on the Canadian prairies to emphasise the need for an interdisciplinary approach to climate impacts analysis (CIA). To summarise, the 1930s drought was considerably more damaging to farmers on the Canadian prairies due to the additional constraint of the desperate economic recession that *preceded* the start of the drought. Additional factors which reduced crop yields included the practice of widespread ploughing of soils prone to wind erosion, which increased the amount of windblown dust in the area. In this case economics, weather and farming technology combined to create a set of *severe socio-economic impacts that may have been compounded by the Depression and were emphasised by the drought*. It is precisely for reasons such as these that socio-economic analyses are required, as the pre-configured socio-economic vulnerability of a community will define how successfully it will be able to cope with the impacts of climate change when they occur [Parry and Carter, 1998].

An aid to this type of analysis may be Maunder's framework for tracing the impacts of droughts in the Great Plains of the United States [Maunder, 1989]. The tracing of micro-to-macro level effects and vice-versa may aid previous cultural-ecological analyses which have ignored macro-level processes. Since the consequences of a drought depend on differing socio-economic and political contexts, Maunder's framework illustrates the alternative paths that a drought could take in each socio-economic scenario and its possible local and global effects. Different thresholds are used to translate the various impacts into different sectors of society. Thus differing capacities to absorb stress levels by each sector of society can potentially be contextualised. For example a reduced wheat yield does not usually directly affect a society, though a change in the price for wheat does.

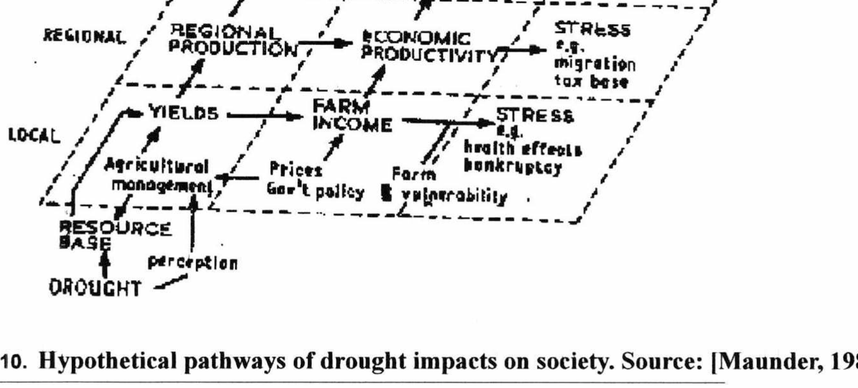

FIGURE 10. Hypothetical pathways of drought impacts on society. Source: [Maunder, 1989]

Figure 10 illustrates a framework for tracing the impact of drought occurrence in the Great Plains of the United States. It shows the pathways that drought impacts could take from local to global levels in agricultural, economic and social systems. The original disturbance originates from a meteorological event, becoming an agricultural drought, when agricultural production falls below a perceived threshold. The agricultural drought then translates into a drought impact when the stress is detected in the economic, social and political sectors. The degree of stress is influenced by market prices, government policies, farm stability and the extent to which the drought is seen as a local, regional or global problem [Maunder, 1989].

Parry [1990] has identified three broad types of adaptive possibilities within agriculture. These are changes in **land use**, **management** and **crop and livestock husbandry**.

2.7.1. Changes in land-use

Three types of land-use change are likely to have the greatest effect:

Changes in farmed area

Parry predicted that an extension of the farmed area should be expected where warming tends to reduce climatic constraints on agriculture, such as in high-latitude and high-altitude areas, if other environmental factors and economic incentives permit. Expansion is envisaged to be most marked in the Former Soviet Union and northern Europe, as terrain and soils will permit further reclamation. Warming may also induce an upward extension of the farmed area in highland regions [Parry, 1990].

In regions where reduced moisture availability leads to decreased productive potential, particularly where agriculture is at present only marginally productive, there may occur a significant decline in acreage under use, e.g. in parts of the eastern Mediterranean if projected decreases in rainfall are correct, and also possibly in western Australia. In the south-eastern USA increased heat stress and evaporation losses may reduce profitability to the point where commercial cropping becomes non-viable. For example the cropped acreage in the southern Great Plains of the USA is estimated to decline by between 5 and 23 per cent under a warmer and drier climate, with a doubling of carbon dioxide. This may be partially compensated for by increases in cultivated areas in the Great Lakes region [Parry, 1990].

Parry writes that similar shifts of land use have been suggested for the southern hemisphere. However, all the general effects described will be influenced at local levels by regional variations in soil, by the competitiveness of different crops and by regional patterns of rainfall which cannot be predicted at present [Parry, 1990].

Changes in crop type

To those with higher thermal requirements. If countries in the northern hemisphere, where output is limited by temperature rather than rainfall, substitute current crops with those which have traditionally been grown in warmer southern climates a fuller use of the extended and more intense growing season, would ensue and this should allow higher yields. Various impact assessments have considered this as a predictable response in the USA, UK, Japan and New Zealand. This may mean that these countries will potentially play a larger role in the global food production system, and occupy a larger share of the global market.

To drought tolerant crops. Where rainfall is the climatic constraint on output, or where increases in temperature could lead to higher rates of evapotranspiration and thus to reduced levels of available moisture, there may occur a switch to crops with lower moisture requirements. Parry writes that lack of information on changes in rainfall makes speculation hazardous. However, a switch from spring to winter varieties of cereals would be one strategy for avoiding losses resulting from more frequent dry spells in the early summer, as winter sowing allows a better root system to be established, before the dry seasons, e.g. in Scandinavia and the Canadian prairies [Parry, 1990] (see page 133 for empirical evidence of the use of this strategy).

2.7.2. Changes in management

Increases in irrigation requirements are likely and given the predicted increased rate of groundwater depletion, this will probably lead to higher costs of production and the consequent use of less water demanding practises to increase irrigation efficiency.

Changes in farm infrastructure will also result from regional shifts in farming types and altered irrigation requirements. These will in turn require major changes in capital equipment and agricultural support services. However, Parry writes that due to the large costs involved, only small, incremental adjustment may occur [Parry, 1990] (see Section 5.5 on Bennett's definition of similar cumulative strategies).

2.7.3. Changes in crop and livestock husbandry

Parry [1990] writes that alterations in the timing of farm operations such as ploughing, sowing, harvesting, fertilising and pest and weed control are likely to occur to adjust to a new set of climatic conditions (see Section 4.5.7 and Section 4.5.4 for empirical evidence of pest control required after flooding conditions).

2.7.4. Differing levels of adjustment and adaptation

At a more abstract level, Parry and Carter have identified three types of possible autonomous adjustment - inbuilt, routine and tactical adjustments [1998]. **Inbuilt adjustments** refer to the physiological adjustment of an exposure unit (in this case, plants) to a climatic condition. **Routine adjustments** are the daily responses that are initiated in reaction to changes in the climatic system. This for example would include altering the sowing date of certain crops as growing seasons change in response to climatic variability. Finally, **tactical adjustments** represent a major shift in behavioural responses to climate change, and would normally only occur after a series of (climatic) events convincing enough to invoke a change necessary to reduce an increasing risk (e.g. the buffering mechanism as described by Bennett in Section 5.6.3). Parry and Carter provide an example where a run of years with below-average rainfall in a semi-arid region may persuade farmers that cultivation of a drought-resistant crop such as sorghum is more reliable than a drought-sensitive crop such as maize, in spite of its lower yield than maize in favourable conditions (e.g. Ziervogel [2004]). Impact models are increasingly attempting to incorporate autonomous adjustments, such as those described above.

It is known that changes in potential yield are likely to result in changes in land use, and this will also be affected by changes in price. A study using a world food model to simulate the supply and demand dynamic that would be invoked when different countries experience changes in yield, incorporating data on potential unfarmed areas and world crop prices has been carried out [Rosenzweig and Parry, 1994]. Conducted at the three levels, the first simulation assumed unrealistically, no farm-level adjustment or adaptation to climate change. Minor farm-level autonomous adjustments were implemented at the next level, which included changes in planting date, increases in irrigation and in variations of currently available crops. Finally, major adjustments were included such as the expansion of irrigation systems and the development of new cultivars. Thus adaptations were considered at two possible levels, the first representing easily available options such as shifts in planting date, referred to as Type I adaptation [Rosenzweig and

Parry, 1994] or routine adjustments [Parry and Carter, 1998], and the second representing more substantial change such as larger shifts in planting date, increases in irrigation, and the development of new crop varieties, referred to as Type II adaptation [Rosenzweig and Parry, 1994] or tactical adjustments [Parry and Carter, 1998]. Conclusions of the study revealed that only major adjustments led to significant reductions of climate change impacts.

A study by US National Centre for Atmospheric Research (NCAR) [Rosenzweig, 1990] modelled the impact of climate change on the world food system using the International Futures Simulation Model (IFS). The Futures Market evaluates a crop before it comes to harvest, and trades on the basis of this price. The study concluded that year-to-year variations in yield due to weather could be an important source of instability in world food supply, even if changes in mean climate due to greenhouse gases are gradual. This is highly significant, as the attitude of many people to climate change, is that it is over-dramatised, that it will only affect a small segment of the world population (see Section 5.6.3 on buffering and step-functions), and that any effect will happen very slowly. However, changes in the frequency of destructive weather events such as droughts and warm spells due to long-term climate change, present the greatest risk as they will be the most difficult type of change to absorb, and are thus likely to have critical effects on food security. The increased frequency of extreme weather events is an assessment of future climate change which was accepted even by those sceptical of general climate change scenarios in the interview process in this research (see Section 4.3.12 for empirical evidence). The NCAR study estimated that the world agricultural system had the capacity to absorb about two-thirds of the potential of a slow change in climate by adjusting land area under production, land area under different crops and the intensiveness of production as a response to altered crop prices. However, less stability was evident in the face of an immediate, short-term change in yield, such as could result from a pattern of adverse weather events.

2.8. Cognitive anthropology

The qualitative and quantitative aspects of this research require specialised methodologies. Keesing [1987] notes that more than a decade ago he had foreseen the potential of the positive collaboration between the fields of artificial intelligence and cognitive anthropology. Like Bennett, he questions whether decisions are made in the present by interpreting the solution to problems experienced in the past (which would be referred to as **tactical adjustments** in the climate impacts literature as discussed in Section 2.7) as well as by applying generalised models of all possible alternatives [Bennett, 1976] (see Section 5.4). This also parallels some of the work carried out by Glantz on the use of temporal analogues [1991], where solutions are sought from the experiences of similar problems faced in the past.

D'Andrade [1987] admits that one of the difficulties associated with cognitive anthropology is that, at present working out just a single model takes a large amount of time. D'Andrade estimated that most of the cultural models described in "Cultural Models in Language and Thought" [D'Andrade, 1987] took over a year of research and analysis. Most of these models were taken from American culture in which the anthropologist already had the advantage of knowing the language and understanding the culture. It would probably take two or three times as long to carry out the equivalent analyses in a different language.

Though the obvious advantage of carrying out cognitive modelling in the local region is that there is no language barrier to overcome, the agricultural domain of rural England remains culturally unfamiliar to the researcher and thus prescribed ethnographic methods and knowledge elicitation techniques have been adapted, customised and followed. In order to prevent potential 'miscommunication', methods used in the fields of anthropology, cognitive science and artificial intelligence can be usefully employed. However, understanding a cultural theory requires more than just a formulation of its general principles, but an understanding of that to which the theory is applied and how this may relate to other theories [D'Andrade, 1995]. Acquiring such an understanding supports an interdisciplinary approach to cognition and decision making processes. In similarity to Bennett's assertion that the *processes* of adaptation are generic (Section 2.3), D'Andrade writes that although cultural models are diverse, the logical processes are the same, and thus, given the goals of a particular group of people and their ability to adapt, decisions made in the agricultural domain should be comparable [Bennett, 1976, D'Andrade, 1995].

> *If humans use logic to reason, then the content of the problem should not affect the reasoning. However the content of many "logic" problems has been found to have drastic effect on the ability to reason* [D'Andrade, 1995: 199].

Thus, although decision-making processes may be comparable in different geographic regions, the ability to carry them out may differ due to contextual socio-economic configurations, as well as due to different social beliefs and attitudes leading to discrepancies between what people say they do and what they actually do.

An example of a cultural cognitive model built upon individual experience and tactical adaptation over time, is the Caroline Islands navigation model discussed by Thomas Gladwin [Gladwin, 1970]. Gladwin gives a detailed account of the physical and conceptual technology used by the navigators of Micronesia, who sailed great distances across the Pacific, accurately locating tiny islands in a world that is less than two-tenths of one percent land. Micronesian navigators regularly travelled between islands as distant as 450 miles, and shorter trips of approximately 150 miles were made routinely. The use of star tracks (determined by the points at which various stars rise and set) and a reference island which created segments, referred to as *etaks,* resulted in a multi-schematic model. This allowed the navigator to estimate his position, since the shift of the reference island through different star tracks divided the journeys into eight unequal segments. However, although this is an explicit framework, not everything about the model is stated.

Thus, to address Geertz's [1973] concerns regarding the complexity of studying that which is in people's minds, Gladwin suggests two techniques for validating the reality of a postulated cognitive model; first, to describe the model to expert informants for their comment and second, to collect new kinds of data for testing to see if the model remains intact [Gladwin, 1970] (see Section 6.4.3 for an example of this type of testing). While these suggestions do not eradicate concerns about the difficulty of studying people's perceptions, motivations and decision-making behaviour, the involvement of informants throughout the data-collection process as described by Gladwin [1970] is highly beneficial. Data *should* remain open to refinements by the informants themselves, to provide as far as possible, an accurate representation of domain knowledge. This has been attempted during the knowledge elicitation phase in this research and will be described in greater detail in Chapter 6.

2.9. Knowledge engineering

Wooten and Rowley [1995] advocate the use of anthropological interview strategies during the knowledge elicitation phase of expert system development in an attempt to reduce the time required to collect data, which is a classical bottleneck in the development cycle. They utilise the Wood and Ford [1993] interview model, which is based on ethnographic research methods and specifically a book entitled 'The Ethnographic Interview' by anthropologist, James Spradley [1979]. Since knowledge engineering is a lengthy process involving both knowledge acquisition and knowledge representation, effective and efficient knowledge elicitation techniques are invaluable as this can be the most time-consuming phase of the research and these methods have long been used in anthropology. The importance of the knowledge engineering phase of the research will be demonstrated in the discussion of the results of the knowledge-based model (Chapter 9) which was built upon the basis of the ethnographic data collected through interviews (Chapter 4) and innovative participatory knowledge elicitation techniques (Chapter 6).

'Ethnoscientific' work focuses on the rules which govern indigenous taxonomies and though similar in its formalisation of qualitative data, it preceded 'knowledge engineering' by two decades [Fischer, 1994b, 1994c]. Therefore, the value of that which Werner and Schoepfle [1987] term 'ethnoscience ethnography' as opposed to traditional ethnographic methods has long been advocated as an efficient, practical and scientifically comparable methodology, which most importantly can be evaluated by other social scientists. The main difference of this approach to classical ethnographic studies is that it does not rely on participant observation alone, but also on cumulative systematic interviews *and* observation of knowledgeable consultants. Werner and Schoepfle cite numerous studies where this technique of dividing one's attention between observation and conversation has proved successful e.g. Gladwin [1970]. The most valuable benefit of using such methodology is that the subjects of the study may not be able to articulate certain knowledge into words, or may not view that which is common knowledge to them, as something which might be unknown to the researcher, and thus the researcher will find this type of *tacit knowledge* difficult to elicit during interviews alone. It also aims to address the issue mentioned in Section 2.8 where that which people say, may differ from what they actually do.

Spradley [1979] refers to cultural principles which are used to organize a group's behaviour and interpret their experiences as cultural themes, but these often lay at the tacit level of knowledge. Such themes can aid the identification of different subsystems in a culture as they often connect them. Thus analysing the relationships among cultural themes can help to discover these domains [Spradley, 1979]. Spradley writes that ethnographic analysis consists of a search for (a) the parts of a culture, (b) the relationship among those parts and (c) the relationship of the parts to the whole. Identifying themes means identifying recurrent cognitive principles which are a means for discovering the relationships among domains and the relationship of all the various parts to the whole, since the goals of anthropology include describing and explaining regularities and variation in social behaviour [Spradley, 1979]. Similarly, Fischer [1994] has stated there is a need to understand the *interaction* of models and sub-models of cultural processes with more quantitative models (Chapter 1). The innovative computer-aided methods described in Chapter 6 allow the identification of such recurrent cognitive principles among domains and the cultural themes which may possibly connect them allowing the interaction between different subsystems to be identified (Section 6.3.1).

Furthermore, Wooten and Rowley [1995] state that knowledge elicitation methodologies used in the past may have had the effect of constraining the cognitive processes of the expert, and that the use of better interview strategies, namely those that have long been used in anthropological research, may remove these constraints. They reiterate the importance of understanding four issues in knowledge elicitation: knowledge organisation, problem representation, problem solving abilities and tacit knowledge [Wood and Ford, 1993] (Chapter 6).

The main problem of knowledge elicitation is choosing the 'best' elicitation method, the one which reduces as far as possible the risk of influencing the expert's answer and the possibility of misunderstanding [Wood and Ford, 1993]. To solve these problems Wood and Ford suggest the use of the structured interviewing techniques used in ethnology rather than more sophisticated techniques as these can make assumptions about the way the expert processes thoughts into decisions. In this branch of anthropology it is important to ask the same kinds of questions in different geographical contexts and with different people, as they will ideally be compared in a range of different social and cultural settings. However, the inherent difficulty is that the allowance for open-ended questions means that each interview could potentially progress in different directions. More specifically an effective interview method is to construct a hierarchy of questions that has an equal spread of structured and unstructured questions. General or open-ended questions allow the informant to talk without restriction allowing a review of important points which can be probed further in subsequent interviews, until specific procedural knowledge is gained [Spradley, 1987].

Wooten and Rowley [1995] applied the Wood and Ford [1993] interview model to the elicitation of domain knowledge from financial experts. As many knowledge engineers may not have a full understanding of the specific domain of elicitation, Wood and Ford [1993] developed the four stage model to enable accurate elicitation of the domain expert's knowledge, regardless of the knowledge engineers' depth of understanding. The first stage is that of **descriptive elicitation** during which time extensive interviews should be conducted using the techniques mentioned above (Section 6.1). The declarative knowledge gained during these interviews should be followed up by attempting to identify **structural relationships** within the knowledge, which is the second stage of the Wood and Ford [1993] model (Section 6.2). The third, **scripting** stage is the protocol generating and consultation question phase, in which experts are encouraged to think aloud, and are targeted with specific and cross-examination questions (Section 6.3). Consultation questions should be designed to help understand how an expert organises information about a specific and realistic problem. The advantages of the structured interview are that detailed knowledge can be gained on one issue, which may lead to the discovery of other related concepts. However, while structured interviews provide an insight into the declarative knowledge used by the expert, a disadvantage is that little insight can be gained on procedural knowledge such as rules or problem-solving strategies. Thus additional techniques such as scripting and protocol generation are required. In this study, this was partially fulfilled by the employment of an interactive questionnaire and is referred to by McGraw and Harbison-Briggs [1989] as a type of **constrained information processing task** (Section 6.3.1). Here a minimum set of information is available in order to determine the variables required for the expert's decision making process to proceed. Data from the constrained information processing task was then subjected to a rule-induction algorithm which produced simple rules in the form of decision trees (Section 6.4.2) to discover key concepts and relationships as well as recurrent cognitive principles [Spradley, 1979] within differing knowledge domains to possibly provide an understanding of the ways in which these domains interact. Having explored such key concepts and structural relationships within the declarative knowledge, it is necessary to confirm the knowledge elicited in the fourth **validation** phase which consists of **controls** and **checks** [Wood and Ford, 1993]. The entire four phase model is carefully controlled and aims to minimise bias at each stage. Checks should be used throughout the elicitation process to ensure the knowledge is correctly understood and recorded. Thus, the types of questions asked during the final phase are often more structured repetitions to confirm previous statements. Case studies are also useful to ensure the knowledge engineer has correctly understood the sequence of decisions and the relationships between the concepts used to make those decisions. Additionally, contrasting questions can be used to verify the basis for the distinctions that an expert makes between the use of different terms.

In Wooten and Rowley's example [1995], validation was achieved by revisiting domain experts and running a step-by-step walk through of the computer program. They repeated this process with independent experts who were not involved in the original expert system development and all participants agreed with the recommendations of the prototype. In this study, this was achieved using a participatory 'learning' decision tree program to confirm the understanding of domain knowledge as it was acquired (Section 6.4.3) and to automatically refine and update the decision trees produced from the rule induction algorithm, as necessary. Details on these participatory knowledge elicitation tools can be referenced in Chapter 6.

Thus, Wooten and Rowley [1995] successfully used Wood and Ford's interview model [1993] which is derived from the methodology primarily used by anthropologists to alleviate weaknesses in current expert system techniques. Wooten and Rowley conclude that

> *efforts must continue towards eliminating the knowledge engineering 'bottleneck' that hinders widespread growth and use of ES [expert systems]. By applying some of the skills known by anthropologists and ethnologists the elicitation process results in accurate knowledge available for technical representation.*

2.9.1. Incremental Decision Tree methodology (IDT)

Robert Reynolds [2001] has developed a decision tree methodology similar to the knowledge elicitation process described above, which was used to study the archaeological record of the Etla region of Valley of Oaxaca, Mexico to monitor the role of conflict in chiefdom and state formation. More specifically he has used decision trees as a vehicle to test the hypothesis that armed conflict plays a role in the creation of complex societies such as chiefdoms and possibly states, as suggested in other literature. Reynolds [2001] aimed to test the suitability of this model to the Oaxacan case and its potential use as the basis for a more general model of state formation. This hypothesis was operationalised in terms of archaeological record of the region under study and required salient aspects of the model to be expressed.

Trends in settlement decision-making patterns using techniques from the 'Machine Learning' subfield of Artificial Intelligence were used to create decision trees. Reynolds' goal was to produce a decision tree that was able to predict correctly whether or not a site was likely to have evidence for raiding in a given time period for a given region of the valley. The machine learning algorithm selects the subset of variables that are most effective in generating the trees. The algorithm used is known as ID3 and belongs to a family of ID algorithms where ID stands for the Induction of Decision Trees and these were developed by [Quinlan, 1987]. See Section 6.4.3 for an example of a similar process used in this research where the ID3 algorithm was used to create decision trees of rules in the domain.

However, Reynolds writes that in future work he would like to use an evolutionary computation approach based upon the Cultural Algorithms program developed in his earlier work [1986] to access variables that may be found near the bottom of decision trees but may be more suitable in creating smaller trees. These variables may not be chosen by algorithms such as ID3 which bias towards variables with many choices as opposed to conceptually more important variables with fewer choices. In the knowledge elicitation process described in Chapter 6, aspects of the domain which were conceptually more important to the domain expert were identified using a series of interview techniques as described by Wooten and Rowley [1995], which also included an interactive questionnaire (Section 6.3.1) to identify salient aspects of the domain, before the ID3 algorithm was applied.

2.9.2. Use of surveys

Validation of the knowledge of elicited during this study (as recommended by Wood and Ford's [1993] 'controls and checks') was conducted after the use of the interactive questionnaire (Section 6.3.1) and before the use of the rule induction algorithm (Section 6.4.2). This was achieved by issuing a survey to other farmers in the local area, to assess the representativeness of the knowledge of the domain expert. The methods used and reasons for the survey will be discussed in Section 3.1.3 and the results are documented in Section 6.4.1.

An example of other research which uses a survey to convert data for use in a knowledge base is Furbee and Benfer's [1983] analysis of the cognition of disease among the Tojolabal Mayans. Here, several methods were used both at the level of sorting data from surveys, data received during interviews and at the level of converting these data into rules for a knowledge base. Furbee and Benfer [1983] used multivariate scaling to aggregate a variety of individual responses to reduce the number of dimensions in their analysis. This allowed the examination of patterns and structure and is one of the most powerful features of multivariate analysis. Moreover, Furbee and Benfer [1983] claim that reduction of error by several multivariate techniques can be a useful first step toward deriving linguistically motivated rule-like explanations. If some components of meaning are widely shared, they may be candidates for stronger weighting, though they may not be a guide for specific behaviour. Furbee and Benfer [1983] cite Frake [1961] who found that whereas the Subanum of Indonesia often differed on specific diagnoses of diseases, they usually agreed on the criteria necessary for reaching a diagnosis. Furbee and Benfer [1983] state that these two situations call for different evaluations of the features shared by informants. However, they admit that the use of multivariate methods has only been successful in producing simple rule-like explanations of human behaviour at a macro level.

To compensate for this they have followed the linguistic procedure of establishing fundamental units of analysis, and examining relations among these units. In this way, Furbee and Benfer [1983] developed 'mental maps' of the Tojolabal Mayans. They calculated a measure of similarity among diseases by counting the number of times a pair of diseases was responded to similarly, and then divided by the total. The result is referred to as a simple matching coefficient (SMC). Once calculated, the simple matching coefficients for the individual sets were then converted to a distance like measure of dissimilarity for multidimensional scaling [Furbee and Benfer, 1983].

2.10. 'Elimination by aspects' methodology

While the knowledge elicitation phase attempts to classify important knowledge attributes of the domain, there may exist several (conscious and unconscious) phases of decision-making before a final decision is reached. In their article on the decision-making of people purchasing a vehicle, Gladwin and Murtaugh [1980] write that people dismiss large categories of automobile *before* beginning to compare cars for the features that they desire. Murtaugh and Gladwin [1980] refer to this phase as the 'preattentive phase' to emphasise that though purposive, these decisions are not always conscious, while in a later article, Gladwin [1983] identifies this as the 'elimination by aspects' phase. Clearly, this is an important dimension of the decision making process, though Werner and Schoepfle [1987] warn that the possible lack of consciousness of the actor, when performing this level of decision-making, may produce inconsistencies, once the actor is made distinctly aware of them. Analysis of the preattentive knowledge elicited during this research or the 'elimination by aspects' phase of decision-making will be discussed in more detail in Section 6.5. McGregor writes that models developed using 'elimination by aspects' methodology have predicted better than 80% of decisions by farmers not included in samples used to develop the models. This involves identifying people with contrasting behaviour but the same belief and finding the reason for the difference [McGregor et al., 2001]. Murray-Prior [1998] has taken Gladwin's methodology one step further and incorporated it into a Personal Construct Theory framework allowing for the simplification of the decision making process with descriptive and predictive capabilities, by the faster identification of superordinate, subordinate and associated constructs. Murray-Prior's original work [1994] focused on wool producers in Australia and revealed that price and attitude to risk were important factors in all decisions. The main contribution of this approach was in understanding how farmers' decision making was affected by changes in prices and why they reacted in the way they did.

For example, farmers in the Australian wool industry interviewed by Murray-Prior [1994] seemed to ignore a great deal of information about changes in relative prices, either unconsciously or as a deliberate strategy. In the longer term they had little confidence in predictions regarding prices and preferred to rely on their own experience. Farmers tended to operate on criteria whereby prices existed in binary on/off states, that is they were either 'high' or 'low', rather than perceiving them as part of a continuous adjustment process. Therefore, price response was much less than might be expected from classical economic theory due to the strategic view taken by many farmers, which was dependent on their own personal goals and an understanding of the *context* in which they operated. McGregor et al. [2001] cite Murray-Prior's results [1994] as an example of the value of using anthropological and psychological methodologies to provide alternative and perhaps more insightful perspectives on farmer decision making. These results relating to farmers' attitudes to prices are directly comparable with empirical data collected during this study (see Section 4.3.6 for a discussion of binary perceptions of the relationship between production and price).

2.11. Simulation

There are various simulation techniques that can be used to account for uncertainty or imperfect information in computer modelling, though not all have been successful in the past. Game theory (Section 2.11.1), algorithms based upon theories of adaptation (Section 2.1), referred to as evolutionary computation such as the use of genetic algorithms (Section 2.11.2) and the Iterated Prisoner's Dilemma (Section 2.11.3) are just some of these techniques, and they will be covered in the following sections. A phenomenon described in cultural anthropology as 'conformist transmission' which also serves to reduce risk and uncertainty in decision-making will be described in Section 2.11.4, while other uses of simulation in anthropology are mentioned in Section 2.11.5.

2.11.1. Game Theory

Bennett [1966] believes that historically, attempts at the application of game theory in anthropology have been unimpressive and unclear in their results though some of the discussion in his 1966 paper used a game playing analogy of Hutterites, ranchers and farmers and the extent to which they participated with external institutions (Section 5.7). However, one player games against Nature where Nature has no agenda, motivation or incentive and where Nature is assumed to be indifferent or neutral have been of little interest to social scientists in the past [Zagare, 1984].

Low's linear programming model [1974] of peasant farming behaviour under uncertainty in south-east Ghana is one method to deal with the states of Nature and is similar to McInerney's work [1969]. McInerney formulated a set of standard linear programming solutions for different states of Nature, calculated the results of each plan in each situation, and then applied game theory criteria. In similarity to McInerney [1969], Low incorporated game theoretic decision criterion though in contrast, Low assumed a particular criterion was already adopted. This meant that a number of solution procedures for constrained game models were proposed, which enabled various rules for decision making under uncertainty to be incorporated into the linear programming models.

The game theoretic decision criterion in Low's model minimised the cost of providing against ruin. The criterion was based on the assumption that in conditions of uncertainty, peasant farmers were concerned to minimise the cost of ensuring a subsistence level of production in all possible states of Nature. A security constraint set was introduced into the linear programming model, which identified the most adverse state of Nature for any solution and required that the level of production in that state was *at least* sufficient to meet subsistence requirements. This cost was minimised when the 'expected' income was maximised subject to satisfying the security constraint set. The model was constructed so that uncertain outputs could be indirectly related to subsistence requirements and within a single problem matrix, any number of constraint sets could be introduced to represent separate uncertainty situations requiring their own definition of the output and states of Nature.

Analysts who have attempted games against nature [e.g. Davenport, 1960] have been severely criticised [e.g. Kozelka, 1969]. Kozelka suggests the use of a Bayes approach as a better alternative. He critiques Davenport's classic article on the use of Game Theory to analyse Jamaican fishing strategies, by suggesting that a decision-theoretic approach would be more suitable than the game theoretic one, arguing that decision-theory concepts may be more useful to the anthropologist. This is because decision-theory does not use the same (often unrealistic) assumptions as game-theory, where in a two-person zero-sum game, the second (minimising) player is both rational (maximising minimum expected utility) and operating in such a way as to diametrically oppose the interests of the first player. Davenport found that the behaviour of the Jamaican village fisherman corresponded to an overall minimax strategy. That is, to make minimum gain as large as possible a mixed strategy was used. Kozelka admits that the outcome of the Bayesian approach to the original problem has produced very different results, but claims they are more realistic. Primarily he is critical of the assumption of two-person zero-sum game theory, which holds that the second (minimising) player is rational and is diametrically opposed to the interests of the first player. In game theory, a rational player operates to maximise minimum expected utility. Kozelka argues that this cannot be applied to Nature as a player, hence, Kozelka's attempt to explore other alternatives. Given Davenport's estimates of average yield per fishing month, Kozelka uses Bayes theory to calculate optimal strategies instead. While ordinary statistical decision theory deals with losses from certain strategies, Kozelka's aim is to calculate gains. He assumes two states of nature - where there is a current, and there is no current. As the fishermen have no way to predict when the current will come or go, he assumes it has the random probability used by Davenport. The fishermen also have three possible actions, which is to keep all their fishing pots indoors, to keep some indoors and some outside and to keep all their pots outside. Using Davenport's game matrix and the prior probabilities for the states of Nature, the expected gain can be calculated. However, from these calculations it emerged that if the fisherman were 'rational', and acted to maximise minimum expected gain, they would always put all of their pots outside, and this is something they never did, in reality. They did in fact use a combination of strategies. He develops the calculation further, without using Davenport's prior probabilities for the states of Nature. Kozelka concludes that if decisions are made on the basis of Bayes strategies one need never consider mixed strategies, or the prior probabilities for the states of Nature and the minimax strategy need not be defined to be optimal. Clearly, whether or not such a result is desirable or realistic depends on one's definition of optimality [Kozelka, 1969].

To address the plausibility of non-optimal solutions, it should be noted that optimal solutions are always local to a system at hand. A given system, if one can identify it, is likely to be optimum for that system, by definition. To the extent it is non-optimal, it is also less like the system under focus. This can happen if it is a system under modification, which will take some time to stabilise, or if we misidentify the system and it is actually another. Optimality is more a 'goodness of fit' test for our theories than a variable property of systems. If the local circumstances of a system change, it becomes a different system. Indeed, a system can be part of a larger system of systems distributed over time (e.g. either adaptive or part of a cycle).

2.11.2. Genetic algorithms

As mentioned in Section 2.1, pragmatic researchers see the power of evolution as something to be emulated in solving complex problems [Holland, 1992]. Advances in computing power have allowed a greater range of problem representation, experimentation and thus the emergence of new research developments. Computer simulations have been used to study evolution over many generations in a matter of hours. Genetic algorithms are an example of this and they will be explained in greater detail.

Natural selection (Section 2.1) eliminates one of the greatest hurdles in software design if we can specify in advance all the features of a problem and the actions a program should take when presented with them. By harnessing the mechanisms of evolution, researchers may be able to "breed" programs (e.g. illustrated by Dawkins, 1996) that solve problems even when we cannot fully understand their structure. Though not without drawbacks (such as being caught in local minima and maxima, as described in Section 2.1 and below), this makes it possible to explore a far greater range of potential solutions to a problem than do conventional programs [Holland, 1992].

Therefore, the genetic algorithm can be used in situations where problems do not have a precisely-defined solving method, or if they do, following the exact solving method would take too long. Such problems are often characterised by multiple, complex and sometimes contradictory constraints, that must be all satisfied at the same time (e.g. the characteristics of evolutionary adaptation described in Section 2.1). The general procedure for a genetic algorithm includes the following steps and illustrated in Figure 11.

1. Create a random initial state. An initial population (bit-strings) is created from a random selection of solutions (which are analogous to chromosomes). The length of the bit-string is dependent on the problem to be solved.

2. Evaluate fitness. The relative success of each chromosome to solve the problem is considered to be its *fitness*. Thus, in order to let a genetic algorithm solve a problem one needs to write a 'fitness function' [Schatten, 2002].

3. Reproduce. Those chromosomes with a higher fitness value are more likely to reproduce offspring (which can mutate after reproduction). Thus, this rule follows the principle of natural selection or survival of the fittest [Jager, 2000] (Section 2.1). The original population which consists of many agents with differing capabilities and fitness will after a number of generations result in a much more homogeneous population.

However, the danger here is that when circumstances change, other abilities may become more important, which may have already been lost in the process of natural selection, as described in Section 2.1. A homogeneous population lacks the adaptive capacity that is required to cope with a changing environment and therefore so does the identical offspring population [Jager, 2000].

Therefore, to include adaptation and to prevent the emergence of a population with a small set of solutions, the *mutation* rule can be included [Jager, 2000]. Mutation ensures the exploration of more possible solutions rather than only known regions, which repeating the previous steps would result in, which could lead to premature convergence of the algorithm, causing the global optimum to remain undiscovered as a result of some local optimum (Section 2.1). Hence, one of the drawbacks of genetic algorithms is that they are subject finding local minima and maxima and stalling there, requiring 'hill climbing' subroutines to explore the space beyond. However, mutation ensures the population is mixed up to bring new information into the set of genes. The rule implies that in the reproduction process each bit has a small chance of flipping and is a powerful way to find new ways to adapt to a changing environment.

Nevertheless, the mutation rule works randomly and is quite slow in finding successful solutions. A much faster strategy in creating new kinds of solutions is the concept of '*crossing over*' where the bit-string of two parent agents is cut at a random point, which is the same for both parents, which produce the offspring. Thus, a combination of crossing-over and selective reproduction on the basis of fitness is a powerful tool to find effective solutions in a very complex environment. To avoid the risk of evolving a homogeneous population it remains necessary to include a small chance of variation [Jager, 2000].

4. Next Generation. If the new generation contains a solution that produces an output that is close enough or equal to the desired answer then the problem has been solved. If this is not the case, the new generation will undergo the same process their parents did. This will continue until a solution is reached [Hsiung et al., 2000].

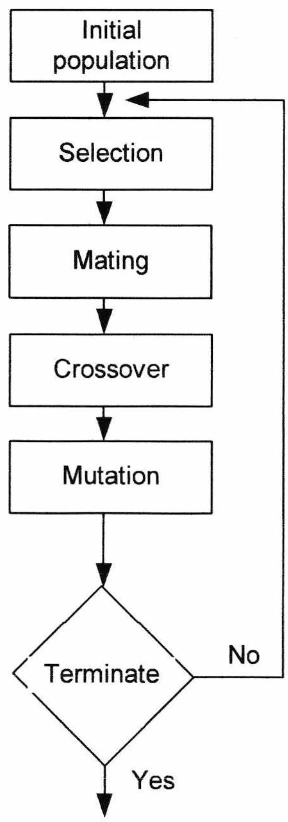

FIGURE 11. Schematic diagram of the algorithm [Schatten, 2002].

Thus, genetic algorithms select and encourage the best emerging solutions after certain, random operations. It is a useful method since one does not need to know how to solve the problem, but simply how to be able to evaluate the quality of the generated solutions.

2.11.3. Iterated Prisoner's Dilemma (IPD)

The game known as the Prisoner's Dilemma illustrates the genetic algorithm's ability to balance exploration against exploitation. This long-studied game presents its two players with a choice between 'cooperation' and 'defection': if both players cooperate, they both receive a payoff; if one player defects, the defector receives a higher payoff and the cooperator receives nothing; if both defect, they both receive a minimal payoff (Figure 12) [Holland, 1992].

More recent work on emergent phenomena in complex systems, such as cooperation between agents or self-organisation in a system of agents, has been the subject of much current literature in agent-based modelling in the social sciences which is based on complexity theory. In some studies [e.g. Lansing, 2001] the subject of cooperation and interactions at a group and individual level have been represented in terms of game theory using the Iterated Prisoner's Dilemma (IPD) problem [Axelrod, 1997]. Lansing's work in particular has its basis in anthropological fieldwork in Bali (Section 9.6.1). The assumptions of the Prisoners' Dilemma game theoretic matrix are:

$$DC > CC > DD > CD \quad \textbf{(EQ 3)}$$

$$2 * CC > CD + DC \quad \textbf{(EQ 4)}$$

	C	D
C	3,3	0,5
D	5,0	1,1

FIGURE 12. Prisoners' Dilemma Matrix [van der Veen, 2001]

Figure 12 shows that exploiting cooperation is the most rewarding, followed in order by mutual cooperation, mutual defection and being exploited for cooperating. However, alternating exploitation and being exploited leaves one less well off than repeated mutual cooperation. Nevertheless, defection is the dominant strategy since even though each player would prefer the payoff (3,3) to (1,1), without a guarantee that the other player will cooperate, the temptation is to go for the certain payoff of 1 and avoid the risk of being exploited. Thus, a dominant strategy exists when an individual player in a game, evaluates separately each of the strategy combinations he may face to provide the greatest payoff, and the same strategy is chosen for each of the different combinations. This is referred to as a 'dominant strategy' for that player in that game. However, when the Prisoners' Dilemma is iterated a number of times, it can lead to quite different results. It is well-known that individual pairs of players can achieve a stable cooperative relationship as long as the shadow of the future (the number of iterations of the game that are to be played) is sufficiently large [van der Veen, 2001]. Van der Veen writes that many studies using IPD concentrate on the effects of the variation of different parameters such as the number of iterations of the game, the selection of opponents, the search-space of possible strategies, and the mechanisms by which strategies spread through a population.

2.11.4. Conformist transmission

Anthropologists, such as Henrich [2002], have observed the spread of imitative strategic behaviour when influenced by peers in ethnographic contexts which cannot simply be reduced to rational economically motivated behaviour, but seems to be based on what is *perceived* to be successful. This appears to reduce the uncertainty and risk involved in choosing certain strategies with incomplete information, by removing the need for time-consuming 'trial and error' experimentation with various options. Such imitative behaviour does not seem to be the result of cost-benefit analysis, or the result of indigenous knowledge that is not apparent to agricultural extension workers, as anthropologists have sometimes found. Thus, Henrich argues that economic anthropologists should reduce their reliance on rational cost-benefit decision-making and incorporate a cognitively informed understanding of social learning, cultural transmission and information processing. He writes that by understanding how individuals acquire cultural information from the minds of other individuals in the form of ideas, behaviour and beliefs, we can provide both alternative and complimentary explanations for behavioural patterns, adaptation (and maladaptation), change, traditional and cultural evolution [Henrich, 2002].

Like Burton [1993] and Bennett [1976], Henrich emphasises the importance of the *process* of adaptation - *how* or *why* individual or groups alter their behaviours or strategies to adapt and sometimes maladapt to their circumstances - rather than whether they are already well-adapted to these circumstances. Henrich does not suggest that cost-benefit decision-making never takes place, but that non-strategic cognition mechanisms such as cultural learning *may* affect the evolution of behavioural patterns. He believes that human behavioural patterns are unlikely to be primarily a product of cost-benefit decision-making since human information processing is error prone and individuals often lack the data required by cost-benefit analysis. In effect, any evaluation about alternative behaviour can be classified as cost-benefit decision-making. However, simply copying the behaviour of successful individuals reduces the complexity of such situations since there is no evaluation necessary. Lansing has shown this to be the case in the decision-making of rice farmers in Bali (see Section 9.6.1).

Cost-benefit analysis is an attempt to identify the quality of an adaptive strategy and its match to a situation, based on the assumption that maximum benefits equals maximum satisfaction on the part of the people involved. However, few anthropologists claim that people are actually undergoing the cost-benefit model in their minds but that what they do is logically equivalent. That is, maximising benefits and minimising costs selects for and against different possible approaches by people in the long term, although they may at times try approaches that are sub-optimal (e.g. they are learning). There are a wide variety of approaches that have influenced economic anthropology and these can be divided into three categories. Firstly, *rational* models, which assume humans are motivated by narrow self-interest; secondly *social* models which assume that humans give importance to the well-being of others, their social group or society, and thirdly *moral* models which assume decisions are directed by a set of culturally learned principles distinguishing right from wrong [Henrich, 2002]. However, Henrich states that these are all actually sub-categories of the cost-benefit approach, since the assumption that individuals are goal-driven strategists who weight choices continues to underlie all of the models. In contrast, Henrich writes that cultural evolution may sometimes be driven by non-strategic cognitive processes such as selective imitation. He believes this is due, not only to the inability of humans to accurately calculate the large number of variables in most cost-benefit analyses but also due to associated 'memory bias', preventing accurate comparison of previous events and recurrent patterns (Section 7.7).

Henrich defines 'culture' as those ideas, beliefs, behaviours and values that *can* be transmitted from one individual to another via some form of direct social learning and thus may provide individuals with preferences, perspectives or context-specific heuristic rules. Specifically, he investigated why Mapuche farmers in Chile only planted wheat when barley was more drought resistant and suited to local environmental conditions. He shows how an understanding of the cognition of cultural transmission explains how ideas become widely shared and why they change over time.

While Henrich agrees that many economic anthropologists do see culture as part of the decision-making process, it usually seen as the *transmission* of cost-benefit decisions or behaviour that is indirectly based on cost-benefit decisions at some level. Therefore, culture has no dynamic role in the process but simply replicates the existing distribution of behaviours. Henrich refers to this type cultural learning as 'static transmission' and believes that from this perspective the driving force of change lies in the decision-making process and not in the transmission process. According to Henrich, *static* transmission will not maintain patterns of difference between groups, which are maintained through time under changes in economic and environmental circumstances and in the face of opposing individual-level cost-benefit analysis, even if small amounts of migration or interaction exist. Thus, the key to understanding differing behaviours lies in the *cultural processes that create and maintain variation in beliefs and ideas* [Henrich, 2002].

2.11.5. Simulation in anthropology

Fischer writes that simulation is not a new method to anthropologists who have long used it, mentally, or on paper before computers were available, to validate anthropological analyses against ethnographic data [Fischer, 2002a]. However, since computers also allow the exploration of situations which could not otherwise be easily analysed in anthropological fieldwork (recognised as early as 1965 by Hymes and later by Dyke, 1981, Hammel 1965 and Fischer, 1980 who investigated the impact of famines of different severity) this is a further advantage and indeed has been successfully employed by several anthropologists [for other examples, see Abel, 1998, Fischer, 1986, 2002 and Lansing, 1991 on ecological models, Fischer and Finkelstein, 2002 on prescriptive or preferential arranged marriage and Read, 1998 on kin-based demographic models, to name a few]. The earliest agent simulation by an anthropologist was probably by David Kronenfeld [1993]. While simulation has traditionally been a technique that is used for quantitative analysis, this has mainly been due to the historic development of computing and constraints on our ability to represent models and qualitative, symbolic data [Fischer, 2002a]. Anthropology often uses data which are difficult to quantify or sample (Section 7.1), though it is this qualitative information that is the foundation of ethnographic work. Thus most simulation techniques based on numerical and/or statistical criteria do not aid the analysis of rules of behaviour observed during ethnographic fieldwork and of interest to anthropologists, such as prescriptive marriage rules, for example [Fischer, 2002a].

Therefore, the use of agent-based simulation is valuable to anthropological research since structural relationships between individuals can be modelled using attributes which map directly to qualitative and quantitative empirical data, as opposed to the use of aggregated data used in other types of simulation. Furthermore, processes of individual and collective action can be analysed. Even when agents in multi-agent simulations are programmed with fairly simple rules, their collective behaviour can often become very complex (e.g. see Gilbert and Troitzch's [1999] discussion of multi-agent models and the Sugarscape model in particular [Epstein and Axtell, 1996]). One of the justifications for the development of 'social' simulations is that conventional statistical methods of analysis are generally based on the assumption that there is a direct relationship between the variables involved. The contribution of artificial intelligence to the development of agents allows this restriction to be relaxed, and thus there is the potential for more sophisticated types of *social simulation*.

The study of complex systems is an attempt to better understand non-linear systems which are difficult to grasp analytically. Often the best available way to investigate such systems is to simulate them although some non-linear systems will remain unpredictable even if an understanding of the influences of behaviour within the system is achieved. However, social science is less concerned with prediction than with *identifying how behaviour evolves and influences other processes* [Gilbert and Troitzsch, 1999].

'Emergence' is one of the most important ideas to originate from complexity theory. If interactions among a set of objects at one level cause the 'emergence' of objects at another level, they imply that a new set of categories are required to describe the phenomenon, other than that describing the behaviour of the underlying objects. Therefore, in an emergent model, higher order properties are 'expressed', based on the underlying phenomena and the contexts that emerge from the underlying phenomena. However, emergence can occur even in simple models and it is the emergence of these macro-phenomena as a result of simple local rules, which is of great interest in the analysis of complex systems. The additional complexity of human societies is that human beings also have the ability to reason about the features that emerge as a result of their action. That is, humans have the ability to dynamically 'alter the game'. This can give rise to the further emergence of complex structures such as social institutions and this is referred to as 'second-order emergence' [Gilbert, 1995, Gilbert and Troitzsch, 1999].

Sugarscape [Epstein and Axtell, 1996] is an example of a multi-agent model in which the *emergence* of social networks, trade and markets, cultural differentiation and evolution is the result of the use of quite simple agents. The ability to illustrate the dynamism of a system over time and the effects of simple but varying individual agent attributes has huge potential for a discipline such as anthropology. For example, Lansing simulated the unconscious cooperation of farmers in a village in Bali utilising a ritual irrigation system and religious cropping calendar [Lansing, 1991]. This resulted in observations which could be successfully applied back to the field empowering local farmers by *enabling recognition and an understanding* of their successful indigenous strategies among state and development agencies [Fischer, 2002a].

A further example of the complexity of emergent phenomena, which are produced from very simple rules is the Emergence of Organised Society (EOS) project [Gilbert, 1995]. The objective of the EOS project [Doran et al., 1994, Doran, 1995] was to investigate the growth of the complexity of social institutions during the Upper Paleolithic period in south-western France. Archaeologists believed that there was a transition from a relatively simple egalitarian hunter-gatherer society to a more complex one, involving status hierarchies and highly stratified roles. Simulation was used as a way of comparing competing theories about the transition to a more complex society, and whether the spatial distribution of resources and population concentration were in fact contributing factors to this social stratification [Gilbert, 1995]. The main objective of agents in the EOS model was to obtain a continuing supply of 'resources', some of which could only be acquired though cooperation with other agents. Agents which cooperated with the plans of other agents became *followers*, while the recruiters became the group *leaders*. Group membership was recorded in the members' social models while the groups continued to work together. Group membership was an *emergent* property of the behaviour of the agents, since agents had no awareness of the group as an entity to which they could belong. However, this also resulted in an inability of the agents to reason about this emergent property. The ability of human beings to reason about second-order emergence is the additional complexity which would be required to make models more representative of actual human behaviour [Gilbert and Troitzsch, 1999].

2.12. Summary

It is clearly unrealistic to expect multi-agent models to simulate all social and psychological processes, or even to be able to model any of them to a great level of detail. Rather the goal of the modeller should be to extract the most theoretically compelling features of the subject at hand. Furthermore, it could be argued that the elimination of the more fundamental aspects of human behaviour may provide the advantage of analysis of the phenomenon in complete isolation [Gilbert and Troitzsch, 1999, Fischer, 2002a, Dyke, 1981].

The symbolic paradigm is the traditional AI approach to building agents with cognitive abilities. However, the weakness of this method is that it is based on the 'physical-symbolic system hypothesis'. This proposes that intelligent action can be created by the manipulation of symbols according to symbolically coded sets of instructions. Its weakness is that it may result in fragile systems which may not withstand minor variations and difficulties in coding highly complex systems including representing the domain of 'tacit' or 'common-sense' knowledge [Gilbert and Troitzsch, 1999]. There are additional difficulties in validating models based on this type of qualitative data [Fischer, 2002a]. More recently, these obstacles have been overcome through the use of a variety of techniques, including the implementation of production systems, object orientation and machine learning (Chapter 3) [Gilbert and Troitzsch, 1999].

The aim of exploring the areas discussed in this chapter is to identify areas of anthropology which can usefully benefit from current computer modelling techniques to aid the analysis of qualitative ethnographic data. However, it must also be noted that the use of ethnographic data in building such models is crucial to their usefulness and potential in providing an understanding of target systems. In conclusion, the employment of a variety of paradigms documented here, which range from cultural ecology to multi-agent simulation have resulted in the reflexive methodology described in Chapter 3, which may result in an innovative research tool. However, the results of this process and the resulting model must be interpreted within the constraints of the assumptions on which they are based (Section 7.2).

The specific methodologies used in this research will be introduced in Chapter 3 based on some of the possibilities that have been reviewed in this chapter which reflects the pluralistic approach advocated by McGregor *et al.* [2001]. This includes details on the fieldwork process, including the way in which the choice of key informant/domain expert was made (Section 3.1.1), how the ethnographic data was collected, methods used to formalise this qualitative data using knowledge engineering techniques (Section 3.1.2) and how this data was validated (Section 3.1.3). Chapter 3 will also include a systematic review of software tools that were considered to build the model (Section 3.3) including an overview of the chosen software library (Section 3.4) and a discussion of the advantages of the expert system shell used (Section 3.5). The reasons that certain software tools were adopted or rejected will also be explained. Specific details on the techniques which are introduced in the following chapter, such as the use of the participatory knowledge elicitation tools, will be covered in more detail in later chapters (e.g. Chapter 6).

CHAPTER 3

Methodology

This chapter will provide an overview of the methodologies that have been used in this research, from the initial interview phase to the implementation of the (Learnt) Adaptive Dynamics Model (LADM). This will include a description of techniques used to choose the main informant (Section 3.1.1), validation of the knowledge elicited during interviews, including a discussion of survey methods (Section 3.1.3) and tools used for building the simulation (Section 3.2), including a review of software that was considered (Section 3.3). Initially it will address the importance of using ethnographic data for building a simulation which retains a qualitative framework, and conversely, the advantages that a modelling framework can provide to an understanding of ethnographic data, by illuminating the processes of interaction between qualitative social models and quantitative models from the physical sciences domain.

3.1. Use of ethnographic data for building a social simulation

Ethnographic interviews have been successful in steering the design of the model, the results of which, have in turn contributed to a greater understanding of the ethnographic data within the context of a theoretical framework, aiding the reflexive anthropological process. As mentioned in Chapter 1, the integration between quantitative and qualitative methodologies has been unsuccessful in the past due to the failure to address the differences between the domains of social science and natural science [Fischer, 1994]. Therefore, the methods underlying ethnographic data collection were fundamental to collating the type of data required for the qualitative multi-agent simulation proposed here, as opposed to the aggregated data summaries used in other types of simulation [Fischer, 1994]. This enhanced integration between the qualitative and quantitative data, has been aided by the use of the Bennett's theory of adaptive dynamics as a formalised abstraction of strategies in the target system, while retaining a qualitative framework, which helps to relate cultural knowledge to *context* and the behaviours that emerge in the model [Fischer, 1994] (Chapter 1).

3.1.1. Choosing an informant

The interdisciplinary nature of this research was labour- and time-intensive due to the variety of methods used, which required many new techniques and tools to be learnt in a short space of time (e.g. the design and development of innovative, participatory interview and analysis methods, familiarity with simulation toolkits, programming languages and expert system scripting languages and software). This required an efficient and systematic review of possible informants to identify a few key individuals who were knowledgeable, representative of farmers in the area and willing to contribute their time to this work.

Therefore, preliminary interviews were conducted at the case-study location in East Kent with several farmers and a representative from the National Farmers' Union. These were mainly large-scale commercial farmers of similar sizes growing similar crops i.e. wheat, beans, oilseed rape and potatoes. Discussions with the Kent representative of the National Farmers' Union provided contact information of those farmers who might be willing and receptive to the interview process and the subject of this study. These interviews provided some introduction to the agricultural domain in Kent and the opportunity to 'tune in' to local discourse, as recommended by Ellen [1984].

After these initial interviews, two farmers were then targeted for further semi-structured interviews and eventually one was chosen as the main informant due to a combination of factors. Most importantly, he seemed to be broadly representative of the opinions of other farmers who had been spoken to, and he was also very willing to contribute his time and efforts to this study and had a genuine interest in the research. However, both of these farmers had farms of a similar size, a similar cropping history since 1970 (both provided their cropping records) and similar views on various aspects of the farming industry.

In-depth interviews were then conducted with the key informant over the course of 3 years, using a range of techniques. His knowledge was consistently verified and validated using the input received from other farmers, published data, articles in the press and via a survey that was distributed to a separate sample of farmers, later in the interview process. With permission from the informant, the structured and semi-structured interviews were recorded using a tape-recorder and transcribed after each session. The initial interviews conducted with other farmers prior to this, were not recorded, to enable free and informal exploration of the agricultural domain.

3.1.2. Innovative interview techniques

Traditional interview techniques used in ethnography were used throughout the research process following Ellen [1984] and Spradley [1979]. However, this was also complemented by innovative participatory techniques for eliciting knowledge, which were the result of a combination of ethnographic and knowledge engineering methods, as suggested by Wooten and Rowley [1995] (Section 2.9). The motivation for this was that it allowed continued engagement with the key informant to refine and update knowledge as it was elicited, while also aiding the formalisation of the data for use in an agent-based model. The 4-stage participatory knowledge elicitation process initially involved interviews which identified salient aspects of adaptive decision-making in the agricultural domain (Section 6.1). This was validated and explored further using a computer-aided interactive questionnaire (Section 6.3.1) that was developed as a tool with which to identify the specific variables required for the decision-making process to proceed in differing scenarios. The results from the computer-aided questionnaire prompted a traditional survey to be distributed to 20 other farmers in the local area (Section 6.4.1), to once again verify the representativeness of the chosen informant, as consistent 'checks' were performed on the knowledge elicited (Section 2.9) [Wooten and Rowley, 1995]. Data collected from the computer-aided questionnaire (which was supported by the survey) was subjected to machine learning/rule-induction techniques to produce general rules of decision-making behaviour as a result of recurrent patterns in the data (Section 6.4.2). Analysis of this output allowed the creation of decision trees which could be used as rules in an agent-based model. These prototypical rules were validated using an interactive 'learning' program during later interviews, in an iterative process which allowed the main informant to correct, update and fill gaps in the knowledge that had been elicited (Section 6.4.3). Hence, this participatory, iterative 4-stage knowledge engineering process, from knowledge elicitation to knowledge representation, including verification and validation aided the transition from the qualitative ethnographic data to formalised data for use in a simulation. The process will be described in greater detail in Chapter 6.

3.1.3. Using a survey to 'check' the data

As mentioned, the way in which a traditional survey was used in this research was very specific since it restated the content of scenarios presented by the participatory knowledge elicitation tool (Section 6.3.1) as a method of 'checking' the representativeness of the data collected from the key informant (Section 3.1.1). Thus, the survey was systematic and necessarily restricted in scope (see Section 6.4.1 for more detail on the survey, its results and "Appendix A" on page 322 for a copy of the survey).

Some important aspects of survey techniques will be described for reference when a survey is required as a more conventional method of gathering initial data about the domain, the case-study area and possible informants. A survey 'sample' should reflect the characteristics of the population from which it is drawn and although the population is usually too large to survey all of its members a small and carefully chosen sample can be used to represent the population and may in fact have better *internal validity* than data from the whole population [Bernard, 1988].

Sampling methods are classified as either *probability* or *non probability* sampling methods. In probability samples, each member of the population has a known probability of being selected. These include **random**, **systematic** and **stratified** sampling. In non probability sampling, members are selected from the population in some non-random manner. These include **convenience**, **judgement**, **quota** and **snowball** sampling. The advantage of probability sampling is that sampling error can be calculated which is the degree to which the sample might differ from the population. When inferring to the population, results are reported plus or minus the sampling error. In non probability sampling, the degree to which the sample differs from the population remains unknown.

Probability methods

Random sampling. This is the purest form of probability sampling, if with replacement. Each member of the population has an equal and known chance of being selected. When there are very large populations, it is often difficult or impossible to identify every member of the population, so the pool of available subjects becomes biased.

Systematic sampling. Often used instead of random sampling this is also called an Nth name selection technique. After the required sample size has been calculated, every Nth record is selected from a list of population members. As long as the list does not contain any hidden order, this sampling method is as good as the random sampling method. Its only advantage over the random sampling technique is simplicity. Systematic sampling is frequently used to select a specified number of records from a computer file.

Stratified sampling. This is a commonly used probability method that is superior to random sampling because it reduces sampling error. A stratum is a subset of the population that share at least one common characteristic e.g. males and females, or farmers and non-farmers. The researcher first identifies the relevant stratums and their actual representation in the population. Random sampling is then used to select a sufficient number (a sample size large enough for us to be reasonably confident that the stratum represents the population) of subjects from each stratum. Stratified sampling is often used when one or more of the stratums in the population have a low incidence relative to the other stratums [Bernard, 1988: 82].

Non-probability methods

Convenience sampling. Usually used in exploratory research, this method is suitable where the researcher is interested in getting an inexpensive approximation of the truth. As the name implies, the sample is selected because they are convenient. This non-probability method is often used during preliminary research efforts to get a gross estimate of the results, without incurring the cost or time required to select a random sample.

Judgement sampling. This is a common non-probability method. The researcher selects the sample based on judgement. This is usually an extension of convenience sampling. For example, a researcher may decide to draw the entire sample from one 'representative' city, even though the population includes all cities. When using this method, the researcher must be confident that the chosen sample is truly representative of the entire population.

Quota sampling. A non-probability equivalent of stratified sampling, the researcher first identifies the stratums and their proportions as they are represented in the population. Then convenience or judgment sampling is used to select the required number of subjects from each stratum. This differs from stratified sampling, where the stratums are filled by random sampling.

Snowball sampling. This is a special non-probability method used when the desired sample characteristic is rare. It may be extremely difficult or cost prohibitive to locate respondents in these situations. Snowball sampling relies on referrals from initial subjects to generate additional subjects. While this technique can dramatically lower search costs, it comes at the expense of introducing bias because the technique itself reduces the likelihood that the sample will represent a good cross section from the population [Bernard, 1988: 98].

Based on the techniques described above, the survey which is described in more detail in Section 6.4.1 used a combination of *convenience* and *judgment* sampling as it was not meant to represent farmers in general, but conversely to assess the representativeness of the key informant's knowledge of local farmers in the area of East Kent. Though the sample was small and the number of respondents even smaller the survey did not rely on the snowball method of sampling at all, which would have introduced unnecessary bias, and therefore the results of the survey *in addition* to the farmers that were spoken to initially were valuable in supporting the choice of the main informant.

3.2. Model design

The purpose of the (Learnt) Adaptive Dynamics Model (LADM) was to illustrate the effects of opting for a particular adaptive strategy at both an individual and a group level within the context of an anthropological theory of adaptive consequences. Individual agents possessed knowledge regarding adaptation strategies and perceptual information about the environment including soil, weather and economic conditions based upon ethnographic data. The micro-level effects of adaptation resulted in macro-level strategic designs using Bennett's framework [1976] and this aided an analysis of strategies and their effects on the individual and the group.

Referred to as the Adaptive Dynamics Model (ADM), the original model abstracted a system of farmer agents with strategies which were adaptive and non-adaptive (sceptical agents) with respect to changes in temperature and rainfall to investigate past and present successful strategies, at an individual and group level, resulting behavioural and processual dynamics. The parts of the target system which were represented were empirical data on adaptive strategies, production data at an abstract level, income, investment, cost and hours of labour, climatic information and data on crop water requirements. The slightly modified Learnt Adaptive Dynamics Model (LADM) introduced a method for the spread of successful strategies within the system to emulate 'copying' from successful neighbours and has a slightly different name for ease of reference when discussing both models together. In the following chapters, reference to the (Learnt) Adaptive Dynamics Model refers to both models.

The use of Bennett's classification [1976] of strategies as an abstraction of empirical behaviour means that any results must be considered within the context of this framework. Though this provides limits to the appropriate uses of this abstraction in other situations, Bennett's framework is a useful vehicle for aiding the transition to a more formalised type of ethnographic data which may provide an enhancement of its subtleties if not allow it to be incorporated into a computer-based model. Furthermore, the use of a knowledge-based agent-based simulation allows the preservation of qualitative categories and less loss of the information which is critical for anthropological analyses which describe and explain regularities and variation in social behaviour [Spradley, 1979] (Section 2.9).

The use of artificial intelligence techniques in this field is essential since human behaviour, knowledge, experience and perceptions of risk are all factors which influence the decision making process, and thus need to be considered in the design of a model of human adaptation (Chapter 6 and Chapter 7). The simulation framework provides an environmental specification for the expert module, and uses an object-oriented representation of the relationships between multiple expert agents. Although models which incorporate AI techniques do exist, they are usually driven by soil, crop or climate models. The intention here was to provide a fully embedded feedback mechanism between the socio-economic knowledge base and the environmental simulation as explained in Section 1.1 and Figures 1 and 2. The combination of these modelling methods aims to address the concerns stated by Fischer [1994] that the integration of qualitative social models and quantitative physical science models has been difficult to achieve due to the implicit differences in each domain (Section 3.1).

Therefore, the use of an expert system for this model was significant in the design as behavioural processes were not to be ignored in the analysis. Since the domain contains rules with similar conditions and multiple outcomes using Bennett's framework, a forward-chaining rule-based approach (i.e. rule-based, rather than having many 'if-then' statements) was the most efficient method of implementation and a more flexible way of predicting outcomes. Additionally, a rule-based system easily allows categorisations of the qualitative ethnographic data into Bennett's framework, to emerge freely. And, by categorising observed empirical strategic designs according to their primitive effects as defined by Bennett, unexpected variations can arise within a multi-agent environment. Furthermore, since logical inferences over time were to be measured, and as truth-values vary temporally, and relative to different observers, process and perspective needed to be considered. A comprehensive reporting mechanism for the modeller and end-user allowed an analysis of the *process* of decision-making over time. The use of a simulation to complement the analysis was justified by the need to model the two knowledge domains. Both the quantitative, formally complete, logically consistent models based upon the physical sciences domain and the qualitative, formally incomplete, logically inconsistent models driven from the anthropological domain needed to be reconciled. Thus, the integration of a simulation and expert system allowed the best architectural solution to prevail to include both the qualitative and quantitative domains.

The socio-economic knowledge-based module was embedded using the Java Expert System Shell (Jess) [Friedman-Hill, 2001] (Section 3.5) within a multi-agent environmental simulation using the Recursive Porous Agent Simulation Toolkit (RePast) [Collier, 2001] (Section 3.4) developed at the University of Chicago. RePast is an open-source Java based library based on the Swarm modelling environment [Langton et al., 1999]. The simulation parameterised the scenario which was used as input for each expert (Jess) agent. Behaviour based on these parameters was retrieved by the simulation each time step which allowed information to be shared between agents. As agents continued to evolve in the system with continuing variation in environmental variables, they invoked strategies which were classified according to Bennett's framework. In the Adaptive Dynamics Model (ADM) agents attempted to be competitive while in the Learnt Adaptive Dynamics Model (LADM) they simultaneously mimicked their neighbours' strategies.

As mentioned, the domains of knowledge concerned were represented in a *forward chaining* (data driven) production system. This approach works well when it is natural to gather multiple facts before trying to draw any conclusions and when, as is the case in this domain, there are many possible conclusions which could be drawn from the facts e.g. farm-based adaptive options as well as Bennett's framework of adaptive dynamics will be outcomes that need to be derived on the basis of the facts. Forward chaining models begin with a set of known facts or attribute values and applies these values to rules that use them. Any rules that are proven true fire and produce additional facts that are again applied to relevant rules. The process continues until no new facts are produced or a value for the goal is obtained.

In contrast, *backward chaining* is an alternative (hypothesis driven) approach which begins with a rule that could conclude the goal for the consultation (e.g. 'what adaptive strategies do you recommend to allow me to grow warmer climate crops successfully?'). It then tries to obtain values for the attributes used in the rule's premise, and backtracks through additional rules if necessary to determine a value of the goal attribute. When there are many attributes employed in many rules, the backward chaining mechanism produces a more efficient mechanism than forward chaining because it will not be necessary to ask the user to input values of all of the facts. Some rule-based systems, such as Prolog and its derivatives, support backward chaining where the engine seeks steps to activate rules, whose preconditions are not met, also referred to as *goal seeking*. Jess (version 5 onwards) supports both forward and backward chaining.

Data for the model was derived from various sources of expertise. Climate data-sets were used to provide inputs of temperature and rainfall and thus also allowed crop water requirements to be calculated. The simulation functioned as a 'scenario/constraint generator' providing percepts that individual agents reacted to depending on their knowledge (based on the rules in Jess) and adaptive capacity (dependent on constraints). New instances of the simulation could be defined using a general simulation template (provided by RePast) which performed a model configuration. Consequently, it was possible to formally relate and analytically compare one scenario to another, since only the specification of the simulation was variable.

In the model, farmers agents were modelled on empirical data based on interviews with farmers in East Kent (Chapter 4). Acquiring heuristic data describing the way in which extreme conditions in the past have been dealt with was one basis for the construction of the expert system. The main constraints under which adaptive and non-adaptive (sceptical) farmer agents made decisions were those of limited access to irrigation and capital resources as well as productive choice which was dependent on the actions of others. Table 4 lists the inputs and outputs for the model.

TABLE 4. Inputs and outputs for the model

Farmer Agent Attributes	Input Data	Output Data
Adaptiveness (adaptive/sceptic)	Overseas Production	Income
Adaptation strategies depending on *adaptive capacity*[a]	Local production	Investment
Irrigation available	Price	Crop water requirements
Capital available	Cost of labour	Strategy choice
	Hours of labour	Type of high level strategies
	Crop water requirements	Type of low level strategies
	Seasonal Rainfall	Crop choices which depend on:
	Annual Temperature	1. order of crop choices
	Annual Rainfall	2. specialisation by other agents
	Irrigation required	3. adaptive capacity (irrigation and capital)
	Empirical strategies	4. adaptiveness

a. irrigation, capital and 'adaptiveness'.

The model architecture is illustrated in Figure 13 using a combination of the RePast and Jess software. Each box in the diagram represents an *object* in the model with its name and attributes listed, whether created in Jess or RePast. The arrows indicate the flow of information through the model, between the agent (represented using Jess) and its environment (represented using RePast).

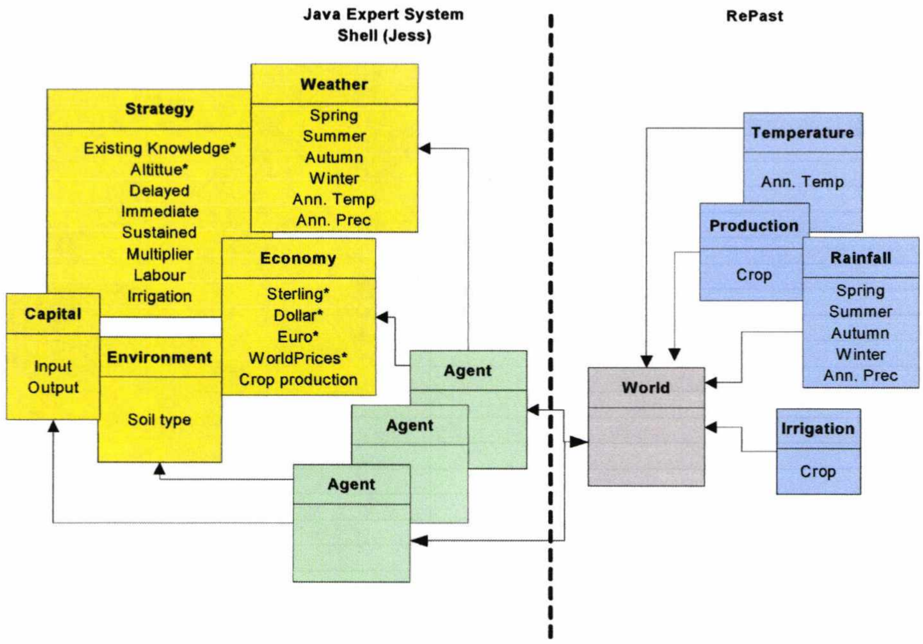

FIGURE 13. Model requirements (*These attributes were partially explored in the Knowledge Engineering phase of the research using Elimination by Aspects methodology (Section 2.10 and Section 6.5)). Each box represents an object in the model and its attributes which are listed. The arrows represent the flows of data between agents (Jess) and their environment (RePast).

A proposed understanding of agent behaviour from the Adaptive Dynamics Model (ADM) will be investigated using the Learnt Adaptive Dynamics Model (LADM) which operated under greater constraints of adaptive capacity with varying levels of capital and irrigation. However, the architecture of the LADM is identical, except that agents are simultaneously copying the 'adaptive' status of their peers (Section 7.5).

3.3. Survey of agent-based modelling tools

The use of agent-based simulation libraries can relieve social scientists of some of the burden of programming the parts of a simulation which are not content-specific, while also increasing the reliability and efficiency of programs, since the most complex parts of the program have been created [Tobias and Hofmann, 2004]. While reducing the amount of programming knowledge required, this also means that social scientists can focus more on theoretical and content modelling [Tobias and Hofmann, 2004]. Of course, there remain obstacles to opting for such tools, such as the learning curve that is required to become proficient in using them with confidence and the possible constraints in what can be achieved. Therefore, when considering the tools to use for this research, a number of agent-based modelling toolkits were researched. These are described in the following sections and the reasons for the chosen options are explained.

3.3.1. Criteria for the choice of toolkit

The main factors which need to be considered when deciding on simulation software from a non-programmer or a social scientist's perspective are ease of use, flexibility, compatibility, platform dependence, background support and potential for dissemination [Dugdale, 2004]. Furthermore, in the case of this research an added selection criterion was that Java should be the implementation language of the simulation framework. This is not only because Java is widely used and provides cross-platform independence but because the expert system shell, Jess (Section 3.5), that was being considered as a potential tool is also developed in Java and a seamless integration between the two libraries was required so that they could be interfaced as easily as possible. As Tobias and Hofmann [2004] have stated, Java also appears to have a guaranteed future meaning that further development of simulation toolkits can be incorporated into existing models which are created with them.

In addition to these factors, from a social scientist's perspective, it is very important that the simulation framework

> *...must allow agent based computer simulation that is* <u>*based on social scientific theories and empirical data*</u>*; better still, there should exist such models programmed in this framework. This means that agents can be modelled as 'free' and complex objects that represent real human beings, institutions, etc. as social scientific models do [Tobias and Hofmann, 3: 2004].*

Furthermore, the more theoretically compelling aspects of social phenomena require careful consideration when abstracted for analysis in a model and thus it is also important to understand the potential capabilities and future directions of available tools.

The three open-source toolkits which fulfilled many of the initial criteria described above and thus were considered when deciding on the best tool for this research were Swarm [Langton et al., 1999], Ascape [Parker, 1998] and RePast [Collier, 2001].

Swarm is a well-known open-source agent-based modelling toolkit which was developed at the Sante Fe Institute by the Swarm Development Group (SDG), founded in September 1999. Swarm is a software package for multi-agent simulation of complex systems and is intended to be a useful tool for researchers in a variety of disciplines. The basic architecture of Swarm is the simulation of collections of concurrently interacting agents allowing the implementation of a large variety of agent based models. Though it was originally written in Objective-C, a Java Swarm clone has also been developed allowing Java-based models to be created using the underlying Swarm architecture.

Ascape [Parker, 1998] is also a Java open-source library for simulating multi-agent systems particularly suitable for simulations in the social sciences. Ascape was developed by Miles Parker of the Brookings Institute in Washington, D.C. and the origins of Ascape also lie in the Swarm research project. From the beginning, Ascape has been developed with the long-term goal of enabling the design of complete Ascape models without writing any code and thus strong composability features are planned [Parker, 2001].

Similarly, the Recursive Porous Simulation Toolkit (RePast) [Collier, 2001] builds upon a Swarm-like framework and is written in Java. RePast is open-source software for agent-based simulation development. It has been developed at the Social Science Research Computing department by Nick Collier [2001] at the University of Chicago since January 2000. In similarity to the other libraries it provides utilities such as interaction spaces, random number generation capabilities, a GUI using control panels, agent-probing mechanisms and data collection features.

In order to assess the suitability of each toolkit for this research, Dugdale's criteria [2004] for choosing simulation software from a social scientist or non-programmer's perspective will be considered with respect to the three simulation toolkits mentioned.

Ease of use. One of the insights of this research is that social scientists with limited programming experience can in fact develop very simple models quite quickly to better understand their data. Therefore, the number of new skills that have to be learnt and the consequent 'ease of use' must be a key consideration. Repast is written in Java but follows a Swarm-like framework whereby each model has a similar structure as a result of a general scheduling engine and is very easy to understand with the availability of demonstration programs.

While Ascape is also very powerful and may be easier to learn than Swarm some Java programming experience is still necessary (at its current stage of development). However, Repast provides the Rapid Application Development tool, *SimBuilder* which provides an additional layer over the simulation code, enabling models to be developed with little programming knowledge. The intention is that the user can visually construct a simulation out of component pieces and specify the behaviour of that simulation using Not Quite Python (NQPY), a subset of the Python computer language. This is a scripting language which is much easier to learn than Java and thus SimBuilder removes the need to learn Java at all. However, when one begins to use tools which are designed to ease our use of them (which sometimes incorporate 'English-like' programming commands), there are also inevitably constraints upon what can be achieved and 'expressed', as there is usually a limited set of commands that can be used. This can inhibit what the user is able to implement [Dugdale, 2004]. And thus, while Swarm and Ascape do not provide such an interface, there are theoretically no constraints on what can be modelled, depending on programming and computing capabilities [Tobias and Hofmann, 2004].

Ascape and Repast have been less useful in the past for simulations which have no spatial aspects or for models that require a geographical information system (GIS) to simulate an actual terrain [Gilbert *et al.*, 1999]. However, developments in current versions of Repast, for example, include a new GIS plug-in. Thus, as mentioned, the direction of the future development of the tool that is chosen is important. Furthermore, in the case of Repast it is specifically geared towards simulating social phenomena and therefore network capabilities have also recently been added to the toolkit. In contrast, Tobias and Hofmann note that Ascape has mostly been used to create economic models where agents exist within 'scapes', which is therefore not suitable for applications-oriented social theory and social simulation that is grounded in empirical data [2004].

Flexibility. As mentioned above, a related point is that there exists an inevitable trade-off between ease of use and the flexibility of the tool. Another example of this is the ability of the chosen tool to display data generated by simulation models in a graphical format. This is useful since such components can be time-consuming to code, especially for a non-programmer.

Compatibility and maintenance. The ability to share code is an obvious advantage and this is easier to achieve with a common set of generic software libraries, such as those offered by Swarm, Repast and Ascape. At a minimum, approaches used in model development should be easily explained, adopted and re-coded, if desired using another tool. Converting an object-oriented model to another object-oriented programming language for example, would be easier than converting it into a procedural programming language. Therefore, the features of other tools in the field should be taken into consideration when opting for a piece of software, to allow possible further work to be easily undertaken.

Platform dependence. A point related to compatibility is the platform independence of models built using various tools. It is easier to share models and code if they can run in most environments. Java is currently the most flexible programming language which fulfils this requirement since it is completely platform independent.

Background support. The amount of support (such as manuals, demonstration programs, newsgroups and mailing lists) that is available with new software is crucial and was in fact one of the most important factors influencing the choice of tools for this research. Documents on how to get started with new software are extremely helpful. Mailing lists allow users to discuss problems they face when building models, and receive advice and solutions from developers and other users. Clearly, such advantages of certain modelling environments are important to know *before* the choice of tool is made. Therefore, it is often helpful to subscribe to several support lists for different pieces of software, before deciding on the tool to use, to assess how much they are used and how often people receive advice from developers and other users in the community.

Potential for dissemination. The flexibility to be able to put example models on the Internet for others to experiment with, by changing parameters, via graphical interfaces is now quite common and the ability to create QuickTime movies as another method of dissemination is also quite popular. The development of different tools will be concentrated in different areas and if the method of dissemination is important and specialised techniques are required (such as using QuickTime movies), the potential for dissemination should be a higher priority criteria in determining the choice of software.

3.4. Why Repast?

Considering all of the criteria described in the previous sections, using RePast *without* the SimBuilder interface provided a good balance between the RePast, Ascape and Swarm toolkits. Not only is Repast specifically geared towards simulating social mechanisms, by providing built-in tools, such as networks and a GIS component but it also includes useful 'How To' documentation that enables one to become easily acquainted with the software. Importantly, it includes ready-made model templates that can be used for social scientific modelling, to get started with building models very quickly. Publications by other RePast users on the website are also useful as is the community mailing list where support is accessible from developers and the wider user community (http://lists.sourcefourge.net/lists/listinfo/repast-interest) [Tobias and Hofmann, 2004]. It must be noted that Swarm (and to a lesser extent, Ascape, due to its relatively earlier stage of development) also provides extensive and useful documentation and support via a mailing list and this is confirmed in Tobias and Hofmann's [2004] evaluation of 3 simulation toolkits. According to this evaluation, Swam scores only a little less than Repast in 'general criteria', which include licensing, documentation, support, user base and future viability [2004][1].

However, RePast was chosen due to a combination of factors. The excellent documentation, model templates and support, via the mailing list, met the needs of a researcher with a social science background, without the undue constraints of a limited set of programming commands which SimBuilder might enforce. It was clear that Swarm and Ascape are very powerful and flexible tools for simulating social mechanisms, but personal experience was that there was steeper learning curve with Swarm and Ascape than with Repast. And while this may simply be the result of the lack of personal experience with this type of software, Tobias and Hofmann [2004] also found that Repast rated higher than Swarm in the criteria of *ease of use* and *ease of installation* in their evaluation of different agent-based simulation tools. In fact, '*except for the criterion "user base" ... Repast equals or surpasses Swarm on every criterion'* [Tobias and Hofmann, 17: 2004]. (Swarm scored higher in the criterion 'user base' since it has a long and widespread use by the scientific community particularly in the field of Artificial Intelligence).

It is hoped that anthropologists with little or no programming experience might consider complementing traditional fieldwork methods, by taking a computer-based approach to analysing ethnographic or anthropological data and might be encouraged to do so due to the availability of tools such as SimBuilder, which can be used to access much of the functionality of RePast. Therefore, many of the approaches used here can be followed and even simplified using the SimBuilder package. In summary, the RePast library was chosen mainly due to its ease of use when experimented with, and because it also satisfied many of the other valuable criteria described by

1. Ascape is not included in Tobias and Hofmann's evaluation.

Dugdale [2004]. In addition to this, Tobias and Hofmann confirm that as a result of a comparison of the 19 criteria in their evaluation,

> *RePast, is at the moment the most suitable simulation framework for the applied modelling of social interventions based on theories and data [Tobias and Hofmann, 21: 2004].*

3.5. Java Expert System Shell (Jess)

The *Java Expert System Shell* (Jess) developed by Ernest Friedman-Hill [2001] at Sandia National Laboratories, USA, is a rule engine and scripting environment written in Sun's Java language. It was an ideal tool for modelling the decision-making rules of agents in the system, using a forward chaining production system. Jess was a much better alternative than Prolog or Lisp simply because it is a scripting language developed in Java and has capabilities for communicating easily with a Java-based framework. Thus, as a possible 'plug-in' to the RePast simulation, it has little of the overhead costs which might be incurred if Prolog or Lisp were used. However, Jess was originally developed as a clone of CLIPS, and thus the syntax is very similar to LISP. It was foreseen that Jess would allow flexibility when integrated in a Java-based environment and would provide a seamless incorporation of data and *feedback* between the reasoning module, which incorporated the qualitative social sciences domain of ethnographic data including Bennett's framework, and the RePast simulation containing data from the physical sciences domain (e.g. climate, crop and irrigation data).

As mentioned in Chapter 1, there has been discussion in the field of agent-based modelling (see social simulation discussion list SimSoc at http://www.jiscmail.ac.uk/lists/simsoc.html) regarding the need for a declarative modelling language to represent qualitative features in our models. And although one of the values of RePast is its potential to model social mechanisms (Section 3.4), Jess serves as an ideal addition to it, particularly in the domain that this research addresses, since the qualitative categorisations of Bennett's framework can be easily represented. This approach is also useful for informants to understand model outputs and to provide feedback on the results of models (Section 3.1.2). Such involvement by informants will not be necessary in all model development but it is an added advantage in the construction of models representing social phenomena where a clearer understanding between observation and theory is required as mentioned in Section 1.1.

3.6. Summary

The choice of using Repast as the simulation toolkit for model development was influenced by the emphasis placed on the modelling of social phenomena in Repast's future development and its potential in terms of the use of networks, which are issues of great importance when dealing with ethnographic data. Jess became the ideal tool to complement the simulation due to its Java based framework and the power it provides for the categorisation of qualitative categories (e.g. Bennett's framework, which encapsulates the ethnographic data) which are crucial in the analysis of the *behavioural process* within the model.

In conclusion, the combination of qualitative and quantitative methods used in this research aims to facilitate an enhanced understanding of the ethnographic data by integrating rules which drive social models with those from the environmental domain. The use of the best placed modelling toolkit for simulations based on social theories and data, combined with an expert system shell which allows the retention and categorisation of qualitative data results in a model which may illuminate the nature of the interaction between social and physical models and an analysis of their effects.

Since one of the primary aims of using simulation in anthropology is to understand how different models interact (Section 1.3) one objective of this research was to link the socio-economic and physical systems involved, together to reveal their relationship and their interdependencies. The proposed abstraction of qualitative empirical strategies in the target system using Bennett's theory of adaptive dynamics will be described in further detail in Chapter 5. Chapter 9 explores the results of the model and whether it did in fact provide new insights about the target system within the context of Bennett's framework. The following chapter documents the ethnographic data that has driven the design of the model and informed the choice of Bennett's theory of adaptive dynamics to formalise the data.

CHAPTER 4 Ethnography

This chapter is an ethnographic account of the area of study in East Kent in the south east of England. It includes excerpts from interviews with a domain expert - a farm manager - who was the primary informant. These interviews directed the design of the (Learnt) Adaptive Dynamics Model (LADM) that was developed, which in turn aided a more refined understanding of the data that was collected during the interviews (Section 3.1). The positive results of this reflexive process will help to advance interactive methods for ethnographic research combining approaches used in traditional ethnographic practice with a more formal component, complementing existing methods rather than claiming to replace any specific methodology. The ethnographic data was not only the basis of the general approach used in the research. The methods underlying ethnographic data collection were fundamental to collating the necessary information for the agent-based simulation. As highlighted in Section 1.4 and Section 3.1, one of the aims of this research is to relate cultural knowledge to context and the behaviours that emerge, and this requires a better integration between qualitative and quantitative data and the analysis of these. This primarily involved a combination of the ethnographic data with Bennett's theory of adaptive dynamics (Chapter 5) and its incorporation in the simulation framework (Chapter 7), using knowledge engineering techniques to formalise the data (Chapter 6).

The goals of anthropology include describing and explaining regularities and variation in social behaviour as mentioned in Section 2.9 [Spradley, 1979]. Understanding this variation requires careful analysis and cultural description which is the basis of ethnographic work and is a first step to achieving this understanding (Section 6.1). However, accounting for cultural differences is aided by cross-cultural comparisons which in turn depends on good ethnographic studies which can reveal similarities as well as differences. The use of Bennett's theory has served as a vehicle to aid the generalisation of the rich ethnographic detail of this particular case-study, which would help its comparative application in other geographic contexts.

Understanding processes of strategic action and the basis of changes in ecological relations requires an analysis of conditions humans are willing to accept before the search for alternative paths will begin (Section 2.3.1). As stated by Bennett [1976], responses therefore vary by 'culture' but the process of adjusting behaviour to contextual habituated tolerances is cross-cultural (Section 2.3, Section 2.8). However, for a contextual socio-cultural understanding of that which is acceptable, and that which will prompt an alternative course of action, empirical data must be collected and analysed.

As mentioned in Section 2.3.2, opportunity costs are assessments made by people of the emotional, social and economic costs of shifting to a new strategy when existing ones are threatened [Bennett, 1976]. In order to measure these as influences on behavioural change Bennett [1976] has semi-formalised adaptive processes in a way that they can be used as a basis for analysis. The empirical examples that Bennett [1976] requires to ground this abstract formalisation are achieved in the data collected during interviews with farmers, the domain experts.

Ethnographic data collection began in mid-1998 when I was introduced to several farmers in the East Kent area (Section 3.1.1). Discussions revealed one farmer in particular who seemed willing and interested in dispensing his knowledge and discussing his work. The information provided by this informant was frequently corroborated using published evidence, discussions with other informants and a survey to assess the representativeness of this farmer, as the long-term domain expert. For details on the survey, which was used to validate the information given by the main informant, please refer to Section 6.4.1.

4.1. Kent case-study

The county of Kent in the southeast of England, UK, has been known as the 'Garden of England' for generations. As this implies the area is heavily dependent on agricultural activities. Kent has a population of over 1,500,000 and in addition to its traditional agrarian pursuits has included coal mining, cement manufacturing and paper manufacturing as industrial activities. Kent covers an area of 1,440 square miles and is close to the continent, with Calais approximately 23 miles across the English Channel from the port of Dover [Camelot Village, 2001].

With over 300 villages, the local landscape in Kent has many orchards, fruit plantations, fields of vegetables and market gardens. It was once famous for growing hops and fruit, vegetables and barley are also now grown for both the domestic and international market. Vines have been reintroduced, from which comes Kentish wine [Camelot Village, 2001]. In the past a village's greatest asset was its family run businesses and although this is still the case, changing trends in shopping habits, directed towards large Superstores, are having an irreversible effect forcing many such small businesses to close down.

Overall, there are only 0.25 million people in working in agriculture in the United Kingdom today, which represents approximately 100,000 holdings and these are mainly family farms [BBC 2, 1999]. Clearly farming has recently experienced some very difficult years in the United Kingdom with the BSE crisis [Krebs, 2000], the Foot and Mouth epidemic [Thompson, 2001] and extreme weather conditions such as heavy autumnal rainfall which has caused flooding in many areas [Environment Agency, 2004]. The strong pound has also had a detrimental effect on the entire export industry, and in farming particularly the prices of crops have been affected [MAFF, 2001, 2001a]. The price of wheat has halved in 3 years, and the collapse of Eastern economies has resulted in a loss of potential demand. In the UK, 80% of food is produced by only 20% of British farmers - the 'big farmers' - and it is one of these farmers whom I interviewed.

4.2. Interview material

As mentioned in Section 3.1.1, after going through a process of meeting and interviewing some farmers in the local area, a key informant was chosen. The interviews with the main informant were conducted over the course of 3 years between 1998 and 2001 during which time the farming industry suffered several devastating events. Before the outbreak of the foot-and-mouth crisis in 2001, British farmers were already facing one of the worst economic crises on record. In 2000, official figures showed that farm incomes had dropped for the fifth successive year with cereal farming dropping by 25% between 2000 and 2001 [MAFF, 2001]. The NFU estimated that 51,000 farmers and farm workers lost their livelihoods in the two years to June 2000, which has been described as the biggest exodus in living memory. Aside from the foot-and-mouth crisis the overwhelming cause of the problems faced by agriculture has been the strength of the pound and the influx of cheaper imports to the UK [MAFF, 2001, 2001a]. The situation has been accentuated by the EU ban on British beef after the BSE crisis, a collapse in world commodity prices, higher oil prices and environmental factors such as floods [Environment Agency, 2004a]. The onset of the foot-and-mouth crisis contributed to the industry slowdown which experienced many businesses folding [Mercer, 2002]. Foot-and-mouth has particularly affected the tourism industry since access to large areas of the countryside became prohibited. The knock-on effect to local economies particularly reliant on tourism in the south west of England which was an area badly affected by the epidemic [Mercer, 2002] was that 46% of firms were going out of business [BBC, 2001d]. Though my informant did not own any livestock, the whole farming industry has been adversely affected by the combination of these events, since the flooding occurred after the BSE crisis had already had a significant negative impact on the farming industry and all of these events took place during the 5 years prior to interviews with the informant [MAFF, 2001]

My main informant or domain expert, who will be referred to as Peter, is a farmer as was his father. He belongs to a small and scattered East Kent farming community of about 800 people (where much of the land is very low lying and includes a large area of marshland), which is a sparsely populated rural parish located half way between Canterbury and Margate. He is a tenant on a farm that is a 1000-acre arable and potato farm on sandy-clay loam which was formerly a tithe farm in the 1600s. A tithe farm was a central farm with off-lying farms which were let to tenants whereby rent was paid to the central farm in the form of one tenth of the crop - the 'tithe'. The farmer that rented the land at that time would then sell the remaining produce and amass his income through this method. By the early 1800s, the land was farmed in the normal landlord and tenant way through the Church. Much of the surrounding farm land is still owned by the Church Commissioners of England and is rented out to individual tenants at an agreed rent. In 1960, my informant came to the current farm as a child from the north of England with his family. His father sold his half of the family farm in the north of England, to his brother with whom he had been farming, and then used this capital to invest in a new farm in Kent.

Peter, has lived at the farm in Kent for almost 40 years, since his early teens, originally with his parents, and now with his wife and children. Peter took over the farm from his father in 1975. However, this is not a family farm, in any traditional sense. It is a very modern household with each member pursuing independent activities. The farm is solely Peter's responsibility. Indeed, there is a desire not to depend on family support to run the farm, but to make it as self-sufficient as possible. Peter was 51 years old in 1998 while the average age of farmers in the UK, at the time, was 57.

Peter farms one thousand acres of land (approx. 400 hectares) on his farm and manages two additional farms which amount to 1500 acres in total. In the mid 1980s there was a major change in the farms' cropping strategies from vegetable to arable farming. This allowed a significant reduction in the labour on the farm, which continues today. Vegetable farming was very profitable prior to the early 1980s but due to an economic down-turn between 1983-4 and new storage regulations, a decision to drastically change cropping patterns was taken in 1985. A new pack house, used for storage was required to meet the new regulations and although this was planned out and ready to be built, a simultaneous fall in the price of vegetables over 2-3 years resulted in a decision to change cropping strategies altogether. The new regulations coincided with a time during the early 1980s when European countries became big competitors to the UK market, since they had lower costs of production and thus their produce could be sold cheaper than that of British producers. At the same time, British supermarkets also developed the flexibility to buy produce from any source [BBC, 1998, Kirby, 1999b]. Although vegetable production can be very profitable, it is also very expensive since not only is it a labour intensive enterprise, but it also requires irrigation. Both potatoes and vegetables are irrigation intensive crops though the amount required for vegetables can vary and is totally dependent on summer rainfall. If access to irrigation is available the licenses required to use it are relatively inexpensive but may increase in the future as demand increases (Section 4.5.3) and there can be costs involved in applying it to the necessary crops (Section 4.5.3). Thus in 1985 the farm changed from a business employing 40-50 staff, in-season, to just three people with larger machinery and less irrigation requirements cutting unit costs. Peter then started growing wheat, oilseed rape, beans, peas and potatoes and continues to do so at present.

The financial situation did improve but due to the recent downturn in arable farming industry, mainly due to the effects of the strength of Sterling [MAFF, 2001, 2001a], which has affected all export industries, farmers now face a similar dilemma regarding a change in productive strategies or industry altogether and many farmers are re-assessing the viability of their enterprises, with some resorting to alternative employment [O'Brien, 2000, BBC, 2001c, Kirby, 1999b].

In 1998, farmers were only earning £50 per acre and it was estimated that more than four in five would be making a loss without subsidies from the EU [BBC, 1998]. While large arable farmers were still making a profit, it was much smaller than that of 1994 and 1995 and severe losses were expected to push smaller hill farmers into bankruptcy. The 54% drop in profits during the year ending in June 1999 meant that farmers were averaging a profit of £24 an acre (£57 a hectare). In real terms an average family farm of 300 hectares would have seen profits fall from £37,000 to £17,000. At this point the industry was reportedly facing its worst crisis for at least half a century, with predictions that losses would fall further to £34 a hectare. Many family farms that had been running successfully for generations were showing their first losses and were it not for the personal nature of the farming enterprise, many would have been closed down [Kirby, 1999a]. In February 2000, there were further reports that there was no sign of any easing of the worst crisis to hit UK farming since the 1930s. By December 2000 the NFU reported that farm incomes had fallen by 72% since 1995 and stood at £7,500 per farmer to cover both salary and the return on business investment naming the primary cause of the problem the strong pound which encouraged food produce to be sourced from abroad. Even the largest and most efficient farms were very negatively affected [Kirby, 2000b].

In addition to the economic aspects described above affecting farming, there are also extreme weather events to deal with. However, my experience through talking to farmers about their perceptions of climate change, is that there is a real scepticism towards any particular prediction of actual weather trends. There is an acceptance that climate change is occurring, but that this is not necessarily any different from the climate change that farmers have experienced during their lifetime or indeed over the last century. There is a feeling that there may be more climatic extremes, but not that the climate is necessarily shifting one way rather than another. For example, Peter told me:

I liken climate change to a pendulum in a clock, that for years, decades, centuries it moves one way and then the other. I mean if you believe some people there is another Ice Age coming! If you believe other people we are going to be desperately hot soon.

And yet, the extreme weather events of recent years have had a terrible impact on the entire farming industry, especially after it had already suffered the effects of the BSE crisis.

Well if I tell you now that farming is in such a bad way that this particular weather pattern we have got now could be the last straw on the camel's back for many farmers - it is going to have a terrific impact on the whole business it really is, particularly in southern England funnily enough, but throughout the U.K. We are all seriously considering our viability.

And, after this interview the Foot and Mouth epidemic struck the United Kingdom on 19th February 2001. By the time of the last recorded case on 30th September 2001, 6,094,139 animals had been slaughtered and the disease had cost the United Kingdom an estimated £2.4-£4.1bn [Thompson, 2001. See BBC, 2002a for a timeline of the crisis].

Such crises have been described as a 'time of change' whereby farmers are rethinking their strategies and whether to scale down their enterprises, diversify if possible, or quit altogether. Prior to the foot-and-mouth outbreak, there had been some cautious optimism among farming leaders. However, though less prominent than the crisis in Britain's livestock sector, the concurrent downturn for cereal growers resulted in an income drop of 61%, partly as a result of poor commodity prices. Storms and heavy rains at the time also disrupted planting and destroyed crops, leaving them rotting in the ground [Environment Agency, 2004].

4.3. Heuristics

In general, my experience of farmers in the local area was that they do not feel at risk of gradual climate change or even a random extreme climate even, since they have been adapting to small changes in climate all their farming lives and this is the very nature of successful farming. Furthermore, presumably, since they have survived they are successful. Discussions with the key informant revealed some general 'rules of thumb' or heuristics which farmers might invoke given particular conditions. These heuristics will be highlighted for discussion regarding what has been implemented in the (Learnt) Adaptive Dynamics Model (LADM) and for reference in Chapter 6 to aid an understanding of rules which have influenced the model's development.

4.3.1. Weather

It is predicted that temperatures will continue to rise between one and possibly three degrees over the next 50 years, with drier summers and possible droughts and wetter winters [IPCC, 2001].

> *I, as a farmer would imagine that **if the summers were warmer and the autumns were wetter you would have an earlier harvest**, and therefore all that would happen is that **the harvest would come early and your drilling*** [cultivation of ground for sowing seeds] ***would come early** so that you would still be able to establish your winter crops before the rain really started. **If the rains were really early then we would have to resort to spring sown varieties**... The net effect would be that you would be **drilling as soon as you possibly could which may be later than normal, but because the weather is warmer that would make up for lost time, so harvest would still be about the same time I would suspect.... If the autumn was continuously wet, wet, wet and we were under water, I mean that is a serious change - that is like this year, every year. If it was like this year every year, then yes there could be a problem**.*

This interview took place in the autumn of 1999 and similar conditions ensued in September and October 2000 and 2001. Flood alerts were issued in January 2001, when there was a record breaking wet autumn causing flooding which cost farmers millions of pounds. The NFU estimated that farmers had lost £500m in uninsured losses of crops and property, at a time when farm incomes were at their lowest in half a century [BBC, 2001f] (see Section 4.5 for a discussion of possible alternative strategies).

Peter told me that conversely in 1997, his oilseed rape seeds sat in soil for the whole of September because rain did not come till 4 October. Then frosts came early to kill off any shoots. Wheat was planted in as a last resort but as a result yields were half of what they should have been.

4.3.2. Economics

As mentioned, a prominent feature of our discussions was the severe decline in the price of crops, particularly since 1995, due to the strength of Sterling. Furthermore, while the currency effect accounted for a reduction in prices (an 18% cut over the previous 18 months from 2000), farmers had also been receiving a smaller proportion of the amount consumers spent on food [O'Brien, 2000].

> ***Historically yields over the years are gradually increasing, and world prices of course, gradually decrease**, because we are able to produce more tonnes at the same prices, because the yields are bigger from the newer varieties, and careful selection is doing that for us. Prices are tending to go down because we can get more tonnes and there are more acres being sown.*

This effect will increase as more countries with productive land joined the European Union, e.g. Poland and Hungary [BBC, 2001b]. There have been a number of additional economic factors that have negatively affected the farming industry in recent years. The decline of economies in Eastern Europe and the Far East has been a contributing factor since these were potentially new markets that could be supplied to. Press articles confirm that farmers are the latest victims of the high pound and the crisis in emerging markets. Farm prices are set globally and since agricultural products are traded around the world, the collapse in demand in emerging markets has lowered prices and hit exports dramatically [MAFF, 2001, 2001a].

> ***The one conundrum here is that there are more people in the East who want to get away from rice and gradually upgrade to more wheat allied products, that may alter the value of the end product to us.** You see the worst thing that has happened to us worldwide is the collapse of the Eastern economy... over the past 4 or 5 years, but it is coming back again now and that actually may help us again. It is a great shame because we were getting into the Eastern markets and it was beginning to grow and suddenly it collapsed.*

This also applies to the livestock market. Russia, for example, until 1998 took 45% of Europe's beef exports and 32% of pig exports - but now does not have the hard currency to pay for them [BBC, 1998]. In 1999, it was reported that the markets for sheep in Russia and the Far East had also collapsed [Kirby, 1999a].

Cropping patterns are market driven, as far as climatic conditions allow. As an arable farmer who grows wheat as a main source of income, Peter also has to rotate crops on the farm known as break crops in between each main crop of wheat. That is, the cereal crop must be alternated every year with a non-cereal crop to prevent the occurrence of disease and to maintain the quality of the main wheat crop, as far as possible. However, a frequent complaint by my informant was that there are not enough break-crop options in the United Kingdom, and this is something that would be a great help to farmers. Current break crops are oilseed rape, peas, beans and potatoes which are rotated with wheat which is the main crop. The current cropping strategy is really quite restrictive and does not allow for a great degree of diversity. Because wheat is the best priced commodity and the price of break crops is very poor, my domain expert is resorting to growing second wheats, on heavier land which is more resistant to disease. Though break crops are designed to be built into the rotation to prevent disease, they are not as valuable as main crops such as wheat and potatoes.

> ***Well it [my cropping philosophy] is actually very simple, it is finance driven, i.e. it is price driven, market driven. Now all the time we can produce a good wheat crop we can make money ... no the most important thing is to have a better price****...we are at the moment suffering right across the board. Currently, I am getting £73 for my wheat, I am getting £90 for my peas, this is per ton, and rape is about £110. Now they should be, wheat should instead of being £70 should be well above £100, peas should be well about £100, £110, £115, and oilseed rape should be I don't know up near the £200 mark, so we are quite a long way adrift at the moment.* ***But the ratio of what I plant on the farm and what crops I plant are purely market/price driven.*** *And so at the moment for example, peas aren't quite so good and rape isn't quite so good, so what I am doing, is I am growing as much wheat as I possibly can, in some cases second wheats, that means I am growing wheat in a part of the rotation which I haven't been growing lately.* ***Normally one would grow first wheats and get the biggest yield, from the very first wheat on that land. If you grow wheat after wheat there is already some inherent disease and the second crop of wheat doesn't do quite so well as the first.*** *There is a particular disease which eats away at the roots and therefore you don't produce so much yield.* ***So then you grow as much wheat as you can because that is still the best money earner, still the one with the biggest gross margin, but you still need a break crop at some time. So what you do is you choose your best break crop.*** *Well at the moment in terms of gross margins, there is probably not a lot to choose between rape and peas.* ***So I am going, roughly a 50-50 split. Half rape half peas for my break crops. So roughly 65% of the farm is wheat, the other 35% is shared roughly between rape and peas. What we are all looking for is another break crop - like Soya, like navy beans or baked beans as you would know them. Little things that we are looking for, they are not there at the moment[1].***

The issue of new crops and new varieties will be discussed in Section 4.5.5.

1. This order of decision-making has influenced the order of 'phases' of decision-making in the knowledge base and groups of potential crop rules which are invoked (Section 8.2).

4.3.3. European monetary system

Our conversations were naturally very finance oriented because of Peter's perceptions and use of economic issues, and inevitably included discussion of British membership of the European Union and its effects upon the agricultural sector. The loss of the Russian market after their economy's collapse and the continued strength of Sterling have long been known to be just two contributing factors to the crisis already facing agricultural incomes [MAFF, 2001]. In 1990, when the pound stood at 2.80 Deutschemarks, farm incomes were £2.5bn. By 1995, the pound was DM2.20 and farmers were earning £5.5bn. But in mid-1999, the pound was back at more than DM2.80, and farm incomes were down to approximately £2.25bn. In February, 2000 the pound was well over DM3.10 [Kirby, 2000a].

> *Once the pound is stable, once we join the EU for example, the European monetary system, we would then erase that [the strength of Sterling] from questions of the future. The only one thing that would come up is the strength or the weakness of the Euro which would then affect us in the rest of the world. You see at the moment our market is mainly Europe, and the world price is sometimes affected by the dollar, well it is affected by the dollar... the difficulty is, at what point do we join the Euro? If we join the Euro at current rates we will then be fenced in at this high level – we couldn't, we'd be stuck – you know we'd be at a definite disadvantage. Now ideally, if we had gone in when our pound was about, currently it is about 3.2 Deutschemarks to the pound, it was at one point 2.30-something, so that is almost a Deutschemark cheaper, weaker, so that would have been wonderful if we could have gone in then - we would be competing like mad now - we would be doing very well thank-you very much, but we are not – we are suffering because of the reverse process...so...* ***if the Euro weakened and we were part of it... it would help us export to the rest of the world.***

Thus, farmers are the biggest supporters of the single currency [BBC, 1998], since the Sterling-Euro price relationship is still a dominant factor determining the profitability of UK agriculture [Kirby, 2000b]. As far as farmers, manufacturers or anyone in the export industry are concerned there is no question that joining the single currency will improve their situation but the big question is *when* to join [BBC, 2002b]. The strength and weakness of international currencies has an effect on the prices of various crops and thus on the decision making process[1].

> ***If the pound is weak, that means that our buyers, our potential market can pay us more money, for the crops that we grow.*** *Now you will know that the pound is strong at the moment and therefore what we are getting is very low money for our produce because the*

> *exchange rate is so against us.* ***Any of us that are exporting, it is like any manufacturing at the moment – they are all finding it tough to export because our pound is so strong****... As far as farming in this country or any exporter,* ***the weaker the pound the more money we will make.***

In 2000, it was reported that the primary cause of this crisis in agriculture at the time was the strong pound, which affected exports and encouraged imports of food produced abroad. In 2000, very few markets were anything more than halfway to satisfactory, and many were poor. Even the largest and most efficient farms were in real trouble because the Sterling-Euro price relationship is still the dominant factor determining the profitability of UK agriculture [Kirby, 2000b].

4.3.4. Subsidies

The Common Agricultural Policy (CAP) was originally created in the midst of food shortages and rations in the aftermath of World War II and was based on three principles: (i) a single market in farm products (ii) with common prices and (iii) with free movement of agricultural goods within the community. However, by the early 1980s, intervention buying under CAP led to Europe's now renowned food mountains and thus CAP is now being reformed but it must also account for the inclusion of new countries in Europe such as Poland which has large expanses of rural areas and thus their potential productivity and the resulting effects on other producers [MAFF, 1999, BBC, 2001b].

Farmers are affected by the strong pound in two ways. Primarily, because agricultural support prices and direct payment made under the EU's Common Agricultural Policy are made in Euros (and approximately 40% of total farm income [MAFF, 2001, 2001a, BBC, 2001c]), which are then worth less because of the weakness of the Euro. And, secondly because much of the UK's farming output goes to European markets, where Sterling's strength makes it less competitive [Kirby, 2000a]. Therefore, subsidies can often influence what a farmer decides to grow, but these are being phased out via the Common Agricultural Policy Reform directed by the European Union [MAFF, 1999]. A component of this policy is what is commonly referred to as 'Agenda 2000' and Peter described it as

1. Though clearly important factors, the strength of individual currencies or other detailed economic market components have not been included in the LADM. However, an abstraction of production indices which seemed to be more of a deciding factor in the informant's decision-making process (Section 4.3.6), has been included. Bennett's framework also provides certain macro-level categorisations such as 'specialisation' (Section 5.6.5) which are indicators of economic processes.

> *...the way they [EU] are going to direct cash...they are going to try and get us on to world prices...it is really farming without subsidies in the long-term. But in the meantime we are going to be given subsidies which will be less on some crops. On other crops they will be maintained.* ***So no doubt we will swing towards those crops because we have got to survive so we have to take the ones we can make the biggest gross margin on****... they are talking about reducing area aid in Agenda 2000, on linseed particularly which will mean not many people will be growing linseed and people will also be growing less oilseed rape possibly. Now what effect that will have on the price we don't know yet...* ***of course if there is less being grown presumably the price will be more exciting.*** *We shall see – watch this space... they are asking us to look more at wildlife and the environment. They are encouraging us to go that route and there will be grants for that also. So things are on the change.*

However my informant explained that by the time subsidies are phased out, the cost of inputs will also decline, so that farmers will be able to farm successfully and in a sustainable way without subsidies (see Figure 27 on page 200 for an example of how subsidies can influence the decision making process).

> *I mean already we are seeing that happening. Now today our wheat prices are down to £68/tonne. Two and a half, maybe three years ago, we were £120, maybe £125/tonne. That is how much it has gone down - it has almost halved. Just to give you some idea - it hurts... So where can we claw back money? We are clawing back money from our inputs. We are getting cheaper fertiliser, sprays, seed – everything is cheapening because they realise that we cannot afford to pay these high prices.* ***It is the old business of charging what the market can stand.*** *And we are going to see that change too on the machinery front. It is a long way to go for machinery in my view, doubtless, and at the moment it is not moving very quickly. I think it has got to go down fairly quickly but we will see. Farmers are just not buying tractors...* ***The short answer is that we do depend on the subsidies, but we also have a crop that is not dependent on subsidies – potatoes... But the answer is that if you took subsidies away from our farm at the moment, we would be losing money.***

At the moment farmers are subsidised to grow nothing at all on a part of their land. This has proved useful in the aftermath of the floods in the year 2000 and 2001 since some of my informants land remained water-logged, and receiving payment to 'set-aside' this land was one way to claim some money back from it. According to Peter, however, it is not an income since the subsidy solely breaks even on the loss of the crop that cannot be grown. This is interesting indigenous logic since it would seem that subsidising loss of profit would lead to income, though admittedly not fortune. It seems that Peter does not consider it as an income since he cannot maximise the potential opportunities, using his own experience and knowledge, that his particular land provides when it is not water-logged.

4.3.5. Trading status

A distinction between types of trading became during our discussions, which warranted further exploration in the questionnaire ("Appendix A") distributed to farmers other than my main informant. There are two main types of trading status - independent, individual trading and marketing as part of a farming cooperative.

Farming cooperatives enable farmers to buy inputs as a group and therefore buy them at a cheaper rate. However, they also enable farmers to market their crops in a pool type system where they are guaranteed to receive an average price for their crop. Cooperatives are usually crop specific and my domain expert is a member of a potato cooperative and used to belong to a vegetable cooperative when the farm produced various vegetable crops in the 1980s. The alternative is to trade independently, or to do a mixture of both depending on the crops being grown. There are advantages and disadvantages to both types of trade.

> *There are several cereal coops around the countryside - actually I am not a member of those, I tend to do it myself. In that [cooperative] case of course, you just tell the marketing department what you have to sell and when you want to sell it. They find the markets... or as most commonly occurs, you might have a harvest pool [cooperative sub-group], a spring pool or a winter pool or a long pool, in which case all grain sold during that pools lifetime is divided up pro rata to each grower and they all get the same price, no matter when and where it is sold. There is sometimes an allowance for storage, if you store your grain until July for example, there is a cost incurred and you would get a refund to cover that storage so the only extra monies you would receive is if you actually keep it on your farm longer, but the whole idea, is to get an average price. You don't get the tops, but you don't get the bottoms. You get a middle-of-the-road price. Coops can be weak, if in a low price year for example you have got many thousands of tonnes to sell you then feel a lot of pressure, that you have to market so much a month, or so much a week and you can be a weaker seller, than perhaps an individual seller.* ***That is why I stay away from it on the grain front. And on the vegetable front I think it is a necessity in order to deal with the big supermarkets.***

This is due to the fact that supermarkets can buy from the cheapest source, and since demand for certain products is year-round they can potentially be supplied from southern European countries [BBC, 1998, Kirby, 1999b]. If supermarkets can source stocks cheaply from abroad they will do so. Farmers are deeply suspicious of supermarkets since retail prices for British food has not changed in recent years though farmers are earning less than half of what they were two years ago. The slight advantage of a cooperative liaising with a supermarket, is that crops are programmed to reach the market at specific times during the year so there is a guaranteed market for them. As other European countries tend to have lower costs of production overall, vegetable cooperatives are a necessity for the economic welfare of British farmers to allow them to compete more effectively with the lower prices of their European competitors.

4.3.6. Production and price

Crop choice is influenced by the price each commodity can attract in the market, more than any other factor. Clearly this is tied to supply and demand issues, since the greater the demand, often the more the price. However, crop choice is also contingent on the ability to be able to produce a particular yield per hectare to a particular standard of quality for it to be saleable.

> *The way things are going at the moment, we need to get 10 tonnes/hectare [wheat] which is a jolly good yield and anything less than that starts to deteriorate the margin.* ***Now at the moment, I would say I wouldn't want to farm if it got less than 8.5 tonnes/hectare as a round figure. At that level one is breaking even anyway****...we are farming in total 1200 acres at the moment at 10.5 tonnes/hectare which is an increase from previous years.*

Financial constraints (which refer mainly to the low price of crops which are overproduced by other countries) are the only reason that my informant cannot return to vegetable farming, since the climatic factors have been suitable since the 1980's.

> ***You see vegetables are always an option on this farm, but the reason that we don't grow them is because they are not viable financially. But if the price was to go up 10% it would make all the difference... So what we are looking at is an instance where the southern European countries have a problem because they can't send us the vegetables, then our doors are open again.***

Since price is governed by supply and demand, it is important for an agricultural producer to try and be a *unique* producer and do something different to one's competitors, as prices on such commodities are likely to be high, if demand is high. This aspect of producing something different to ones' competitors has been included in the LADM.

> *We used to grow onions here years ago and I have been wondering whether we should go back into onions,* ***but so is every other Tom, Dick and Harry, and I think that will be the next thing that is over done... So, got to be careful there.***

Overseas production, commodity prices and the value of world currencies were often mentioned in binary terms, as high or low, in similarity to the Australian wool producers studied by Murray-Prior [Murray-Prior, 1994] (Section 2.10). The strength of international currencies, which are also linked to the prices of crops were also classified the same way, as higher or lower than the value of Sterling by my informant (e.g. oilseed rape is dependent on the value of the US Dollar).

> *Oh, [prices] they are going down all the time... At the moment, since this time last year I'm guessing without looking, I'm guessing we are going to be £5 or £10 down on wheat, we're going to be £20 down on rape, maybe more.... peas, probably peas will be about the same, maybe £5 or £10 down. And that's coming down from you know big chunks of money, that have been carved off these prices. For example wheat was £130 a tonne, wheat today is probably under, oh, I don't know probably about £70, £75.* ***The price of oilseed rape has dropped because of the strength of our pound****, really. I mean that is what has been against us all the way along, is the strength of our pound.* ***If our pound crashed out for every percentage it went down we would get a percentage more on our income.*** *And that is what happened if you remember, when Black Wednesday came along and* ***the pound devalued 20 percent and our income went up 20 percent****, so we were doing very well for a few years but then of course it has turned the other way... and added to that* ***our costs have increased and we're getting nearer to world market prices*** *so it has sort of doubly kicked us in the back side really.*

However, there was more reference to production than to currency fluctuation as this reduced the complexity of factors that had to be considered. In contrast to Table 3 on page 29, my informant told me that many farmers remember 1975/1976 and 1983/1984 as 'good years' despite the droughts, as crop prices were very high due to demand created by the drought conditions - 'We'll never see days like that again' Peter said, with regret.

4.3.7. Intervention

The mechanism that is used as a safety net when marketing of crops is unsuccessful is referred to as 'intervention'. However, this is used as a last resort. When discussing the marketing of crops one particular year, my informant told me,

> *[the marketing of] potatoes is going well. We've sold half of the crop and rest will be going in May. Oilseed has all gone and that was quite poor, and wheat, I still have 1/3 of the crop to go and now the price has gone down so I am considering intervention. When you have a supply of wheat that is greater than the market requires we are given a minimum price of about £80/tonne which we can command providing the wheat is of a certain quality, and this is quite stringent, but we have good quality wheat on the farm, so we may well try to go that route. And if you meet the criteria they require you send it off to your local store which is a special store called an intervention store then you get paid eventually. Takes a little time.* ***And that is at the intervention rate at that time which depends on how strong the pound is versus the Euro. Intervention is a stopgap – it is the last possible thing you can do, it is a real stopgap. Don't like doing it at all,*** *and then of course this is where you see all those great big piles of wheat which haven't sold – they are in what is called an intervention store - and they come out when the price is right to bring it out. That is when there is a shortage – that is the theory – but there is too much wheat swilling around the world at the moment.*

The obvious disadvantage of these stores is that they can sometimes cause a lack of demand from the market in following years as mentioned in Section 4.3.4. When asked whether such a situation of market saturation could arise, my informant's response was:

> *Yes, there could be heaven forbid... it is frightening.* ***There will come a time when there is a world shortage and the price will get quite high, and then once it gets high you see all this stuff released and that will backfire on us because it will hold the price down artificially low, so there is always a pay back...I mean you know it helps you in the short term but in the long term it kicks you in the backside.***

In fact, in interviews the following year, my informant told me that having considered intervention the previous year, it had not been necessary because

> *in fact prices did get a little better there for a while, and we actually sold on a high. So ...in fact we equalled intervention prices but intervention is getting less and less and less - the prices are going down on that, so it is not going to be a consideration next year.*

4.3.8. Genetically modified organisms (GMOs)

During the course of our interviews, the issue of whether genetically modified crops should be grown in the United Kingdom received a large press, especially in the year 2000 when a 5-year ban on the introduction of GM crops was being considered. Some farmers who had allowed GM trials to be conducted on their farms had their crops damaged by activists opposed to what they perceived to be GM contamination [BBC, 2000]. Although not directly related to this research, the issue of GM crops is an interesting one, because it pertains to how competitive UK farmers can be if they do not follow the example of countries like the United States. On the issue of the possibility of growing GM crops my informant told me:

> *As a farmer, how do I feel? It excites me on the one hand, but it worries me when Joe Public i.e. you, and everyone else who is going to buy our produce is worried about it, so I am not sure that I would go ahead on GMOs yet until I got the 'OK' from the whole of the UK public* ***because what I wouldn't want to do is have my land marked as being in with GMOs. But I do see it as a terrific threat because here is America, South America, and Africa or wherever these GMOs are appearing - they are all getting their produce to the market cheaper than we can do it in Europe.*** *This is part of the reason why our produce prices are so bad in the UK at the moment, and that is going to get a lot worse quickly. So a 5-year ban on the introduction of GM crops is a huge threat and a terrific disadvantage [BBC, 2000].* ***In that case, there may be an opportunity for us to take advantage because so many crops are soiled with GM crops. Nationally we might gain because our crops will not be GM contaminated but internationally we would lose out. Big competition factor.***

4.3.9. Fixed costs

The greatest overheads on the farm are labour and machinery costs. However, expansion by taking on more land, requires more powerful, more expensive machinery, yet

> ***the whole idea of going outside your own farm is to spread your fixed costs.*** *The fixed costs are the things like the labour, rent, finance charges, machinery charges.* ***All these fixed costs are judged on an acreage basis. Therefore, the more you can spread those fixed costs, over more acres, the more likely you are to make a profit...*** *We try desperately not to have more machinery because that actually defeats the object, but* ***what we are trying to do is to spread our working staff and our machinery over more acres and therefore our establishment costs per acre are cheaper. And therefore our cost of production is cheaper and we are***

> ***more likely to make a profit... that is the theory. And in these tighter times, that is what we are trying to do. We are trying to farm more acres, we are trying to get our rents down, and we are trying to keep our yields up - that way hopefully we will survive.***

Peter was managing 500 extra acres of land when we met in 1998 in addition to his own land of 1000 acres and contracted 500 acres of additional land during the course of our interviews, resulting in an overlap between the two 5-year contracts.

4.3.10. Influences of peers, other producers and sources of information

An important area for our discussions were the forces that influenced farm management decision making processes. Although global production and consumption patterns inform local decision-making processes, other drivers ranged from instinct and experience, both one's own and that of other farmers (copying the experiences of peers is incorporated in the design of the LADM (Section 7.7)) as well as advice from the representatives of seed companies who encourage farmers to experiment with new varieties, which are specially bred for the British climate.

> *There is a NIAB (National Institute Of Agricultural Botany) handbook that we are given...NIAB has been the bible for the last 20 or 30 years, probably more...NIAB have been trialling varieties and they have a list of the best varieties and what those varieties are doing...* ***If you produce a variety of wheat and it is on the NIAB list then that is the best you could do ...if it is on the list and it looks good people will buy it. We use all the tools that we can. We get advice from people who have grown it before... from people that are selling it, from NIAB, and other organisations like NIAB. We then sit down and try some usually...we will try out a couple of fields or just one field even and see how we get on and if it is good we will save some seed and produce some for next year.*** *So we are allowed to save our own seed but we have to pay the royalties for that. That really is the same for every crop, including potatoes...*

While some may believe that industrialised agriculture in the Western world is not tied into cultural processes and values as it might be in developing countries others would disagree. Anthropologists may argue that these economic constraints are themselves cross-cultural, but that there will be local variants of these, meaning that they are interpreted differently in different places. Work by Ellen [1982] and Ingold [1991] (ecology) and Leaf [1983] and Pospisil [1965, 1972] (agricultural economics) for example, has demonstrated that while people adapt to fixed ecological, economic and climatic constraints, the manner in which they do so is not deterministic. However, there is enough similarity in many of the variables specific to these constraints to classify them for cross-cultural comparison (Section 2.3, Section 2.8 and Section 5.4). It is the *structure* and *organisation* of the variables and *how they relate to one another* that make them cultural, not the existence of them alone (Section 1.4).

Peter may express many of his constraints in economic terms, but as in the GM discussion, he is worried both by the financial outcomes of using GM crops, as well as the social consequences. Thus he is sensitive to the current context and the needs of the consumer. This might be argued to be economic in nature, but requires a high level of cultural awareness to make the different kinds of judgements he has expressed. His decisions are based on a sense of 'safety' and 'security', more than based on economics in the case of GM crops. Indeed, dealing with issues internationally appears to have made him aware of a range of issues in different parts of the world, including developing countries some of which receive food aid, and these feature in his thinking and planning for the future. This is not to say that because he operates in British markets with rules and regulations specific to the British context that he is culturally sensitive, but rather that he is aware of the cultural codes he must address to make a living and to live out the life of a British farmer.

Furthermore, in terms of the way in which people adapt and the types of decisions that have to be made, the decision making process and its high level effects are very similar in different parts of the world (see Section 5.1.3 on types of adaptive options and Section 5.6 on the high level effects of various strategies). For instance, the effects of any particular crop decision made by a farm manger often have very delayed effects due to the marketing of the crop and therefore farming is a long-term enterprise (see Section 5.5.2). Though this may be less so in developing countries due to a lesser emphasis on the marketing of crops the effects of decision making are nevertheless comparable (especially using a framework such as Bennett's (Chapter 5)). As in other parts of the world, Peter and his peers are influenced by what is going on around them, particularly the decisions of their peers. The way in which generic processes of adaptation can be viewed cross-culturally though contextual values may be different as in the East Kent case, is discussed in more detail in Section 5.4.

> *I would say we are not dissimilar to the way that farmers interact in developing countries - we do interact quite a lot - we talk to each other and have regular meetings to see what we are all doing.* ***There is an element of copy cat, in that if a system is working well, it will spread like wildfire.***

Our discussions revealed that farmers utilise *'copy cat'* strategies at a local (micro) level and the reverse (do the opposite of their competitors) at a national/global (macro) level in order to try and be a 'unique' producer. As mentioned, the inclusion of this dynamic in the LADM, which was developed to enhance the subtleties of the ethnographic data, is described in Chapter 7. However, interaction among the informant and other farmers is limited to 'copying' each other. It does not extend to sharing resources or utilities to any significant extent, as might be the case in developing countries.

4.3.11. Levels of risk and willingness to adapt

In the United Kingdom, crop choice is severely restricted by the range of crops that can successfully be grown in current climatic conditions. Introduction of new crops and new varieties can only take place when they are bred by seed companies and introduced through successful farm trials, so that farmers can be convinced to try growing them.

> *We can't grow grain maize at the moment in this country. But it is something we are looking at. If the scientists can* ***shorten the sunlight hours*** *that are required then we are in with a chance. One that is currently being looked at is Soya bean. Now this is one of the* ***biggest crops in the world for protein*** *and in fact right this minute* ***Brazil has just unloaded a load of Soya bean on to the world market and of course protein has just taken a dive*** *and with it has gone rape seed and that is not helping our business at all... If I tell you rapeseed has dropped £24 I think in the last three weeks...just staggering ...I mean per tonne that is a lot of money... In fact I was approached by a company to see if I would grow Soya bean this coming year because they have bred one that is suitable for our climate, but only in southern England, particularly the south-east, here and they are targeting Kent. I actually decided not grow it in the end because* ***I had my own pea seed from last year, so I have got some very cheap seed and the Soya bean (not GM, I hasten to add!) seed was going to be £190 per acre which is colossal, that is about £1000 / tonne just to give you an idea.*** *So there was that and it is also* ***a crop that nobody knows much about*** *so the* ***risk level was quite high*** *so we decided not to do it in the end.*

As a result, opting for new 'warmer climate crops' such as soya incurs 'uncertain costs' in the LADM and this is reflected by a relevant dynamic in Bennett's framework (Section 5.5.4). In reality, crop trials can help farmers assess a new crop's vulnerability to pests and disease. My informant did visit a crop trial of the new Soya variety, aptly named 'Northern Soya', before making a decision about whether to include it in his rotation for the next year. However, he was disappointed by the results that he saw.

> *What happens is that actually you* ***don't get a very good yield, because they are harvested so late into September, October, and the weather conditions can really spoil the quality of the grain****, so what we are finding at the moment is that the* ***yields aren't that great****, and at the end of the day the* ***gross margin is no better than peas or rape****.* ***And until that happens, we won't switch to it****.*

4.3.12. Scepticism to the climate change scenario

As previously mentioned, farmers are generally very sceptical about predictions of climate change:

> *Well I think that climate change has been going on since I was a kiddie, but it is so slow that* ***the actual change that we make is marginal, microscopic almost****....and......the only thing I can think that may change is* ***time of drilling****.....I would like to be warm here provided that we are going to be getting the same sort of rainfall that we have been getting.* ***I think there are going to be more extremes of wet and dry periods****.*

While it is true that predictions of climate change include the predicted increased frequency of extreme weather events, it is also predicted that weather will be wetter and warmer on average, with drier summers, and thus relevant measures will gradually need to be taken.

Peter's historical cropping records confirm that there was a change in cropping from vegetable to arable farming in the mid-1980s. This change was financially driven stemming from the increasing cost of labour and increasing competition from European markets. However, over the coming years a similar big change in cropping could occur, but more related to climatic change than to price, although these two factors are of course linked by productive potential.

4.3.13. Investment

Farming can be a very expensive enterprise and while those farming on the scale of my domain expert can make a very comfortable income in some years, as the price of crop commodities continues to decline overall, their gross margin decreases. An obvious expense is the purchase of seed which can be reduced if it can be saved from the previous year. However, there are disadvantages in doing this also.

> *If I give you an example: we produced about 3500 tonnes of wheat last year and we saved, just...off the top of my head...about 40 tonnes for our own seed. So that is a relatively cheap way of getting new seed. But if I can press upon you that the quality of your seed gradually goes down so you have to keep introducing new seed, so what we are doing this year again is, we're buying grain in small lots of a very good germination - an early generation - you go back to the basic seed and then you get what is called c1, c2, c3 and so on... and I am going back to basic seed on the farm, from which I save my own seed for the next two years from that crop. It is expensive, but it seems to work okay. Good investment.* ***You can save as long you like but in general terms the quality will decrease year on year.***

4.3.14. Goals of the farmer

Although many of our discussions revolved around the financial motivation of farming, it was necessary to question whether the goal of the Western agriculturalist is always to maximise profit.

> *Well* ***not necessarily*** *some people would say, now you see we have often had this conversation around this table.* ***Some people don't want to maximize profit.... They are happier to take a slightly easier, lower level approach and have an easier life, and not make quite so much money....*** *And I can relate to that...* ***But because I'm a tenant I don't own my own land... Everything we farm is rented and therefore we have an immediate cost, the first cost we meet is to our landlord and that tends to go up.***

In terms of methods of adaptation the ultimate goal of the farmer is an important consideration since less intensive forms of agriculture may require less extensive and more gradual adaptive strategies.

This is a factor which has been considered in the design of the expert system, since the decision making process will vary with the goal of the actor (see Section 7.2). Future work may require a variation of socio-cultural variables and this could be achieved using Gladwin's methodology (Section 2.10). This possibility has been considered in the current design of the LADM (Section 6.5) and thus it could be extended to accommodate these requirements.

4.4. Crop options

The lack of break crop options (such as peas, beans, oilseed rape or any other non-cereal crop) in the United Kingdom was often mentioned in our discussions. When questioned about possible alternatives to current crops my informant told me that current options are,

> *linseed, spring or winter beans, and this is becoming an option the Soya bean but I wouldn't say it's an option because it hasn't been seen to produce a yield of good quality yet. Really that's it - you could consider flax. So it's the pulses, which are peas, beans, both winter and spring, linseed, flax, oilseed that's spring and winter - those really are the bread and butter break crops. Outside that of course you can go into crops like potatoes, onions and then vegetables - that's when you start to get into complications.*
>
> *Now, there are other crops that don't depend on subsides, like sugar beet, like onions, so there are crops that we could go into, but it is not quite that straightforward.* ***You have to gear up for it*** *– in the case of sugar beet, you actually have to have a* ***contract with the British Sugar Corporation****, which is not easy to come by. And also we don't have a* ***sugar beet factory anywhere nearby****, in fact I think the nearest one is in Calais. So we can't really go into sugar beet. Certainly we could go into something like* ***onions****, but then that is a very* ***risky crop. Because a) It is difficult to get quality, b) It is difficult to get a yield and c) It very often is over supplied.***

4.4.1. Financially driven crop mix

When Peter was asked whether he would grow a new break crop if there was demand for it, his response was:

> *Oh yes definitely, especially if it was worth more money. It would have to be worth going for money-wise, and* ***it would want to be worth more money than peas and rape. Because we know how to grow rape and peas, we are reasonably good at it.*** *I mean if it was valued at similar sort of gross margins as peas and rape it would just be another one to discuss almost...* ***You see I try and make decisions on what I know I can grow on the soil types with or without irrigation to maximize our income from the farm. I think that it is as simple as that.***

4.4.2. Climate driven crop mix

Other crop options are new crops which are warmer climate crops that have been bred to be more suited to the British climate. Northern Soya is a new crop which Peter had been approached to grow by seed companies and had tentatively considered over the years of our interviews.

> *Now this particular company are importing some and they are trying to breed up for this country – and they see this as a big opportunity... I mean so do I – I am getting quite excited about it. I mean I would like to grow some next year and perhaps will. But that will not be weather-related. That will be finance-related whereby I would like a slice of the action of this high protein bean.*

> *It may be that because we are getting slightly warmer, we may be able to grow Soya in this country but if we do it's on a really marginal basis...anywhere south of here, sort of the Paris basin, and that way, I think they're okay and anywhere north of here, I don't think they will entertain it... but having said that there is a crop in East Anglia or several crops in East Anglia where they are trying it... and which I gather are reasonably successful... but we don't know until it's been harvested. I'd actually like to go and see it harvested to be honest, so that I know from my own point of view.*

Warmer climate crops such as soya, sorghum and maize require a shorter sunshine requirement to be successfully grown in the United Kingdom.

> *It is being talked about in the agricultural press at the moment as to whether we can do it here. What we want is sorghum with a shorter harvesting requirement i.e. less sunshine requirement...**various crops have crept northwards over the years as we have warmed up and as they have needed less sunshine to ripen them** (Section 2.7.1).*

But, for a farmer to switch from current crops to new ones, there would obviously have to be a financial incentive greater than that which is being achieved by the current rotation of crops, due to the risks involved. Factors which are considered are

> ***first and foremost the ability for it to produce the biggest gross margin**. Now that may not be the crop, for example, wheat, that produces the biggest yield...sometimes you can get a good quality wheat that will produce a medium yield but that will be worth more to you per tonne and therefore will give you a bigger gross margin. Some crops succumb to diseases easier, quicker than others, and some are resistant to disease...Looking at cost of getting that crop to fruition, to harvest and its ability to return you the biggest figure, the biggest net*

> *figure, the biggest gross margin. So, yes that's what we are looking at. We are looking at yield, but we are looking at quality, we are looking at resistance to disease, its standing power. That is it really.*

4.4.3. Insurance crops

It became clear during the course of our interviews that potatoes were included in the farm rotation every year as a type of safety mechanism as well as a break crop. Potatoes are a specialist crop because they are expensive to produce, and hence very few people grow them. However, they can generate a very high income, and conversely they can also cause huge losses if they do not command a good price in the market. However, on Peter's farm, on a year to year basis, the same acreage of potatoes are chosen every year, as a safety mechanism, if on average over five to ten years they produce a profit.

> *Last year potatoes were good, this year they were bad.* ***Potatoes will always come into the rotation as long as they return something over a ten year period. Because potatoes are the biggest potential money earner, that is decided first in the rotation. Then wheat, then break crops.*** *50% of 65% wheat is first wheats and 15% is second wheats. 35% includes potatoes. Potatoes is only 40 hectares, and peas are going to be gosh, 100 hectares each roughly. Because potatoes can earn us a lot of money...but problem is they* ***tend to be a bit boom and bust, and if you grow too many, you could lose too much money.*** *If you grow a lot you can make a lot of money, but you can also lose it quickly. So what we have been doing over the years is taking the middle of the road philosophy on that.* ***We grow the same acreage every year****......and in a five year period it tends, or it has tended to in the past work out in your favour better than other crops, but* ***equally it is also the most expensive crop to grow because you have to pay a lot of money for your seed potatoes, for your machinery and you carry an extra man at least... Because machinery and labour is so expensive less people get into it and nation-wide there are very few potato growers.***

Several consecutive years of bad prices on potatoes would lead to a much swifter reaction against including them in the rotation now, than in the past because of the low prices of other commodities. However, because there are relatively few producers there are few nation-wide competitors. Since potatoes are used as a type of safety mechanism I enquired as to whether they would continue to be grown in a warmer climate scenario.

Yes, providing you had the water... I mean looking further south for example in France they grow potatoes in France, not so much in the really hot areas down South, although having said that they grow potatoes in Spain. [However] they tend to get them in earlier and out earlier and they go for that niche market, the earlier market.

4.5. Strategies

As mentioned, apart from recent events that are specific to the British farming industry such as the BSE crisis [Krebs, 2000] and the outbreak of Foot and Mouth disease [Thompson, 2001], the effect of the strong British pound has also affected all export industries in recent years, and the farming industry is no exception [MAFF, 2001, 2001a].

I mean one has to be relatively optimistic otherwise we wouldn't be farming, but all we can do is farm the best way we can, as ***efficiently*** *as we can and hopefully get the* ***cropping right, percentage wise*** *and get the* ***best yield with the least input****. That's what we are trying to do all the time.*

Despite additional difficulties with recent severe flooding events [Environment Agency, 2004, 2004a], each autumn over several years, the motivation to continue to farm often stems from the desire to maintain family tradition, to be able to pass land on to children or purely for the enjoyment of farming. Therefore, the goal of all British farmers is not necessarily to maximise profit (Section 4.3.14).

However, the main assertion of farmers in this study was that crop choice decisions were greatly influenced by financial factors, and while climate and environment were important to consider and crucial to the decision making process, they played a lesser role than financial motivation (Section 4.4.1).

Sometimes a market will ask to grow a certain thing. I mean in the vegetable days we would be growing particular vegetables or we would spot a ***niche in the market*** *and we would go for it. Usually it is* ***financially driven****... I still come back to saying that as a rule it is first and foremost* ***financially driven****, depending on your* ***staff levels****, your* ***soil types*** *and, okay,* ***irrigation*** *in the case of* ***potatoes*** *definitely..... Really that is it, it is* ***market led*** *really.*

Many of the discussions with my informant revealed day-to-day and year-to-year adaptations that are already made on the farm, which will serve as a valuable range of experience to draw from in the future. Some of these adaptation options are discussed in the interview excerpts below. Again, key concepts and heuristics that were identified as potential rules are highlighted.

4.5.1. Improving soil type

Due to the nature of the research, much of our discussion revolved around strategies taken to alleviate any negative effects of past and present weather events, to address past criticisms that cultural ecology does not take historical processes into account (Section 2.2). My domain experts' vast experience of farming meant that he already possessed a repertoire of strategies which he would implement in particular circumstances. To summarise a discussion on suitable soil types for particular crops:

> ***Heavy soils can be superb at giving you good yields because they hold water longer*** *and therefore* ***in a drier year, a heavier soil will, provide more water for your plants than a medium or a light soil****...so...* ***the worst scenario for drying out is a sand or gravel which doesn't hold water.*** *And medium soil would be a mixture of the two really ...* ***what you really want is a medium soil, or slightly heavier than medium soil really.*** *They're as good as any.*

Soil requirements are also affected by climatic conditions and generally soil type and capability were referred to in our discussions, with or without the application of fertiliser and nutrients since these need to be added to even the best soil after a time.

> ***If it [soil] is light, the one thing you can do is to add nutrients, and turn it into good cropping land, provided there is enough moisture.*** *If it is droughty then it is very difficult to get a decent crop from.* ***Heavier soil has its inherent moisture in it so at least you get a reasonable crop even in dry year.***

Since nutrients are also a general requirement of all soil types, their inclusion in the definition of a 'good soil type' was largely taken for granted, suffice it to say that

> ***wheat needs Nitrogen, potatoes need NPK [Nitrogen, Phosphorous, Potassium]. Well all farm crops need good nutrients in the soil to grow successfully and have a good pH, pretty near the middle of the pH scale around 6.5 or 7.0.... Those are the major criteria... Rape doesn't need so much as the wheat. Potatoes need good nutrients across the board.... These assumptions are made when you decided it is a good soil ... precursor......make sure lime is on to de-acidify the soil, add P and K as base fertilisers and then you add nitrogen to the requirements of the crop. Quite simple really.***

As Peter related to me on many occasions, the main driving feature of this and similar farming decisions is economics. It is significant that this factor even permeates as far as the nutrient requirements of each crop and affects the price of the end product.

> ***Things like peas of course are a legume and produce their own nitrogen so they will be cheaper to grow, but that is very often reflected in the price you get at the end of the day.***

However, it became apparent that there are other important factors apart from economics which affect such decisions and these will be discussed in Section 4.3.11. While soil type cannot be altered, it can be improved and made better to work with.

> *What you can do is you can make it more friable* (easily crumbled). *By that I mean more friendly when you come to cultivation, by not over-working the soil, by ploughing back in humus, ploughing back in organic matter, being careful when you do your cultivation's i.e. no compaction, none of this squashing down of the soil, that's the worst thing... to work on a soil when it's really wet and squash it down, it knocks the life out of it. What you need is a friable soil with air in it, lots of big aggregates, so that you have got this lovely soil that warms up quickly. Organic matter will hold moisture for you in wet times... so that sort of thing - you have to look after the soil. I was going to say it is it is like a marriage, you have to work at it.* ***You have got to make sure you're putting back at least what you're taking out.*** *And as I say the better you treat it to the better it treats you I think.* ***And you get better drainage too if you've got friable soil... Drainage is crucial... You cannot really change your soil type, but you can make it more user-friendly.***

Throughout the interview process there was an emphasis on the recognition to take care of the environment, and the acknowledgement that European Union guidelines and policies such as Agenda 2000, which will reduce subsidy payments to farmers, will also aim to add to the responsibilities of the farmer, the role of 'steward of the countryside'.

4.5.2. Changing planting dates

Many of the decisions made by farmers have a combination of delayed, immediate and sustained effects. According to Rosenzweig and Parry they are of two types. Type I decisions are day-to-day farm-level decisions, such as the change of sowing date, and Type II are more significant changes which require significant commitment, such as changing to a new crop altogether [Rosenzweig and Parry, 1994] (Section 5.1).

Naturally farmers are adapting to the climate all the time and make day-to-day as well as year-to-year decisions based on the weather. For example, Peter told me:

> ***Golden rule – in autumn when planting and ploughing seeds, plough up close and drill up tight as if it is going to deluge that night, up to plough furrow so that is weather tight, because we expect rain in September, October. In spring work in reverse as if it is never going to rain again – drill and roll in straight behind to conserve moisture.***

As Peter repeated in a later conversation the same strategy would also apply to future situations if annual rainfall increased.

While a dry July is needed for the harvest period, the ground should ideally be moist at the end of harvest, in preparation for the planting season. If this is not the case, irrigation may be required to give the crop a start, or alternative cropping strategies may be invoked. During our interview period, the domain expert tried growing potatoes on his heavy marsh land for the first time, after a dry autumn, due to the lower irrigation requirements, as heavy land holds water better than other soil types. This strategy did not prove very successful as the marsh land was too hard to work with potato machinery to get the crop out as it retained so much water.

However, heavy soils can also be exploited in other ways, by repeating crop growth two years in a row, without as much risk of disease as compared to lighter soils. However, this does result in a decrease in the quality of the crop and thus in price.

> ***Wheat is still our best priced commodity and the break crops are going through such a poor stage we are all looking at growing some second wheats**, which means **wheat after wheat**. Now you can do that on certain types of soil, usually the **heavier land**. Now on the soil at [contract farm] for example, it is a disaster, it tends to be **lighter, stonier, drier** and you just **cannot grow a second wheat on that**. There's a lot of second wheat through there right now and it is not good, frankly.*

Winter sowing would occur when increasing dry seasons are evident, as this allows the establishment of a better root system, before the dry periods set in. Spring sowing would be chosen if the weather is getting too wet, forcing farmers to choose spring rather than a wet autumn to plant (Section 4.5.2).

> *If we knew we were going to get **wetter climates we would drill earlier** to beat the rush, which is what we're trying to do now, because we always expect it to be.... you see in the **autumn you drill, and you do your cultivation as if it is going to rain hard tomorrow**.... So*

> *you don't work your land too much ahead.... In the spring time it's the other way around... You* ***plough and get your seed bed ready as if it is never going to rain again, so you conserve moisture*** *whereas it's the way around in the autumn....* ***Planting dates*** *really is all about the* ***time*** *you want that* ***crop to come to market****, and that really is down to* ***vulnerable crops like potatoes****, so we try and plant our potatoes* ***early*** *as we can to* ***get them out as early as we can****.... But there are certain crops in the old* ***vegetable*** *days for example when we were literally* ***planting to a program*** *in order to bring to produce to market in a programmed fashion.... Other than that the times at which we drill our current crops which are mostly* ***arable crops*** *really is, we* ***drill as early as possible when the conditions are right****, so you get the* ***best length of season*** *and the* ***earliest harvesting*** *so you can get on with the* ***next crop***

4.5.3. Irrigation and drainage

Many years earlier, Peter had collaborated with neighbouring farmers to buy a pump to access water from a local water source. This pump is now managed by the Internal Drainage Board who issue water licenses to farmers at a charge. Peter has a 12 million gallon water license and is charged at a rate of £11.20 per megalitre - 1,000,000 litres (220,000 gallons) from the ditch system which, according to Peter, is very reasonable.

> *All the land is irrigable so in theory everything could be given a start now. The ground is as dry as a bone in this part of Kent, but opposite north of The Wash the soil is so wet. Same in Scotland – too wet. Will irrigate rape seed that is going in now...* ***We concentrate our irrigation on potatoes because that is where we get our value for money.*** *Having said that there are times when we want to put a crop in during a dry time - now if that doesn't get irrigation or rain of course it doesn't germinate and therefore it doesn't grow therefore you don't get it away properly, so there are times when we irrigate then and* ***particularly oilseed rape has to be in and up quickly, it has to be established well before winter, so there is a cost there on oilseed rape.***

Furthermore, if Peter were to switch to vegetable production and continue with potatoes, there would a problem of water supply, since the 12 million gallon water license that he currently uses is mainly required for the potato crop, but vegetables also require irrigation.

> *Well the option there is fairly straightforward.* ***You would then apply and hopefully get a license to fill a reservoir during the winter.*** *There is a lot of water that goes out to sea in the*

winter time that is just wasted and ***it is just a question of harnessing some of that for a reservoir.***

However, Peter anticipates conflicts in the future regarding water conservation and increasing crop water requirements (see page 142 for discussion on increasing irrigation).

This is going to get worse. By that I mean, now ***they are talking about irrigation licenses having a finite time and that you have to re-apply for a license, and I can see that the cost will gradually creep up - I really can see this as being a problem.***

4.5.4. Coping with flooding

One of our interviews took place shortly after the floods in the autumn of 2000. This had been a particularly wet autumn with record levels of rainfall [White, 2002].

Well, just to fill you in we have had something like 8 inches in October and we are now in the middle of November, we have had a further 2, 2.5 inches. So we have had something like 10 inches in six weeks and our drainage system has suffered quite badly. And down on our marsh land, our flat land which is actually below high tide level, so it is actually fairly low lying, some of that is currently under water, we have got ponding there and I doubt that the crop that is under the pond will now grow because it has been under water for too long. We have still got 20 acres of potatoes in the ground, which represents about 400 tonnes, and we have got somewhere between 70 and 80 hectares of wheat to still drill, which represents about 15% of our drilling, so we have only done 85% of our drilling, because of the rain - we just haven't been able to get on. I think really that sums it up.

Crop which are under water for a prolonged period of time die.

Wheat will stand water logging for several days as long as it dries out after that, but once it has been under water for a long time, it is not like rice, it won't survive indefinitely.

Farmers' indebtedness fluctuates in line with the weather since as well as borrowing to increase their efficiency, farmers borrow to improve environmental standards [Kirby, 1999b]. After the record-breaking autumn of 2000, BBC Environment Correspondent, Alex Kirby, wrote, "I know a farmer in Kent, in the dry south-east of England, who in the three months since mid-September has had close to his entire annual rainfall" [Kirby, 2000b].

Opinion was that even with weeks of sunshine and drying winds there would still be real problems. The record-breaking floods also led to an increase in pest problems.

It has been the worst slug year that we have had on record, so the slugs have really enjoyed the weather and they are nibbling away at our crops as we speak so we have been using a lot of slug pellets - I don't think I've ordered slug pellets ***by tonnes*** *ever in my life, but we are now. You only put 15 kg of slug pellets per hectare - it's an expensive little time - so not a lot of fun really - it has been a tough year.*

4.5.5. Introducing new crops

It was important during interviews to assess the receptivity of farmers to new 'warmer climate crops' if they could be grown successfully in the United Kingdom. Indeed, regardless of any scepticism towards climate change it was clear that if there was a market demand for a crop, it would certainly become a consideration in order to remain competitive.

Without doubt, I mean ***we are all looking for new crops. We are fed up with the old crops, because they are all becoming overproduced.*** *At least we don't get the money for them that we used to. That is world pricing. Europe is gradually moving to world pricing.*

Other options would be to go back to vegetable production and originally in our interviews, my informant believed that this may be the only group of crops with any financial potential. He considered growing potatoes on smaller acreage approach than currently being undertaken. However vegetable production would require many more staff, which are difficult to employ during the harvesting season since they are in great demand by all farmers. Vegetables are also overproduced by other European countries at the moment as mentioned by Peter in Section 4.3.6.

Changing weather patterns are having an effect on what is grown in the U.K. and in particular in the south-east. As mentioned in Section 4.3.11, seed companies have bred a new variety of Soya bean which requires less sunlight than normal, hence its name *Northern Soya*. Farmers in the south-east of England are being encouraged to try this growing this crop, but convincing them to do so is difficult because of the risks involved and the possible consequences and uncertainties of switching to a new crop.

The ability to be able to supply such a crop to the domestic market would provide a desirable competitive edge to British producers. However, the decision to grow a new crop would only be taken if it could command a high enough price at market to adequately cover the cost of its production. Importantly it would also need to be worth more than the crops that are currently being grown (see Section 4.3.2).

> ***Instead of having to buy it in from warmer climates**, we grow it ourselves. And I know what'll happen – **the price of the beans will come down** because we can grow it here, it will be cheaper in the end for the market.*

With new crops emerging such as *Northern Soya* there are possibilities for introducing new break crops into the crop rotation. Each year at the time of consideration of the following year's crop rotation we discussed my informant's views on the new crop.

> *What is going to persuade me is that:*
>
> *a) we can grow the **quality***
>
> *b) we get the **money**, and*
>
> *c) we can get the **seed** at a **sensible price**.*
>
> *Because at the moment the seed price is high, and will be until it becomes a commodity. 170 millions tonnes of Soya beans are eaten around the world every year – that's a lot. Now we can grow a million tonnes here if we put our minds to it, I am sure....But yes it is a late harvest, this is the problem, and I would like to go and see them harvesting that [in a crop trial] in East Anglia .... I suspect it is going to be in September, rather than in August...I want to decide this now so that I can put it into my rotation. I would like to decide this autumn, if I can see it is being grown, so that I know exactly what has been going in. You see I did my farm rotations ages ago. Okay I have been playing with them ever since, but I mean I knew what I was going to put in what fields months ago. You see that is what I do – it is very simple.*

When approached by seed companies such as the developers of Northern Soya, the factors which had the most influence on the crop choice decision and assessments about the possible quality of the yield of the new crop were experience and the results of experimental crop trials. However, most importantly it depends on

> ***gut feeling ... you have to see it and try it yourself really. You can't beat growing it on your own farm and experiencing it first hand.** The next best thing we can do is **go and see it growing,** isn't it? ... I did actually put my name to acreage this year, but I backed out in the end, because I was **frightened** that it was going to get too **complicated**.*

Crop trials are important because they also provide an insight into the diseases and pests that a new crop is susceptible to.

4.5.6. Growing an 'insurance crop'

As mentioned in Section 4.4.3, potatoes were grown as an insurance crop, as they are considered a 'boom and bust' crop in terms of their financial return, but their performance is monitored over a five year period, and if on average the crop returns a profit, it is kept in the crop rotation.

> ***We look upon wheat as being our major form of income through the combine and in order to get good crop of wheat you need to be on first wheats... In other words you try and get a wheat - break crop - wheat - break crop and so on.*** *And we also introduce potatoes into that which helps give us a bit of cash as well. That can be a very good cash winner, but it can also be a big loser, like this year it is going to be a loser. So we have got everything pointing against us this year, you know it is all pretty dismal, but we'll see. You have to look at* ***potatoes over five-year period, ten-year period***... *What we do is we would* ***look at the break crop options and forecast the sort of finance we expect from each crop*** *and if for example oilseed rape looks particularly bad we might grow peas or vice versa it could apply as well. So in fact what we tend to do is we tend to is... our break crops -* ***tend to be a third peas and two thirds rape****.... but you can change that any way you like.*

Other possible risk reduction mechanisms were identified during interviews:

4.5.7. Use of fertilisers and herbicides

Interviews revealed that the experience of the informant observing his neighbours was that the more fertiliser that was used with winter sown varieties of crops, the greater the yield of the crop, although fertiliser is expensive. Though, spring sown crops are less expensive to maintain requiring less application of herbicides, this is also usually reflected in the price. Under normal conditions, crops compete with weeds, which also respond to climate change and enriched CO_2. Depending on the circumstances, the effect of climate change may be for weeds to grow faster than field crops. This would have a negative impact on crop yields, and would in all likelihood require greater application of herbicides, a high-cost input [Rosenzweig and Iglesias, 1998].

4.5.8. Membership of cooperatives

One method of improving the situation of farmers is to increase cooperation between individuals since the independent spirit is much stronger in Britain than in Europe and the US where trading cooperatives are very strong and provide some sort of safety net [Kirby, 1999b].

4.5.9. Remaining competitive

Membership of the European Union has greatly increased the risks of belonging to the agricultural sector, since when yields are low, losses can be compensated for by another country, and crops can be exported to wherever they are needed. In the past, national governments compensated for monetary losses in cases of shortfalls in national consumption. Today, British supermarkets buy from the cheapest source, and do not have to support British producers. The feelings of some farmers are that supermarkets hold a great deal of responsibility for the difficulties they currently face in this regard [BBC, 1998]. The competitiveness between producing nations means that each crop choice is important as it has to have a high probability of benefiting the farmer financially, given all the variables and constraints mentioned. When my domain expert was asked whether prolonged poor crop prices would affect current crop choices, he responded, using the potato crop as an example.

> *Oh, definitely, oh yes you couldn't survive. You know you just couldn't survive. Especially now when **the margins on other crops will not rescue you**. Once upon a time, you know 5 or 6 years ago when we were doing reasonably well and world prices were good... EEC prices were good we could actually bounce back, from a loss on potatoes because of course it would cover that. But **nowadays you know the potatoes have got to stack up on their own.***

4.5.10. Balancing the costs of labour and machinery

Farmers report that medium-term developments such as the strength of Sterling and the fall in world commodity prices have affected the long-term viability of agriculture and the countryside. For example, the UK labour force has been falling while farm sizes have been increasing [BBC, 2001c]. This is not only changing the demographic shape of the country side but also its character. Furthermore, the younger generation are no longer taking up the occupation of their parents and many are leaving the countryside. An NFU survey in 2000 suggested that nearly half of hill farmers believed that their children would leave agriculture due to the low incomes and instability. Farmers say that this in turn affects the wider rural economy, including the sustainability of village life and the relative power of small producers against supermarket chains [BBC, 2001c].

Confirming this the informant had contracted additional land and planned to alleviate the economic strain on the farm by reducing staff even further and buying in bigger equipment to cut unit costs. However, machinery is expensive, depreciates with time and has overhead costs so it can be counter-productive to some extent. With his machinery, Peter estimated that two people could work 1000 acres of the right type of land. Therefore, if feasible, it is seen as advantageous to buy bigger and more powerful equipment, in order to decrease labour and increase the acreage that can be farmed, possibly including contracted land. In general the larger the farm, the more machinery and less labour it employs [Nix, 1998]. The way in which risk is assessed is whether enough income can be accrued to cover labour and machinery costs since...

> *...our **biggest annual overhead** is labour and machinery, usually, **labour** actually. Labour and **depreciation** and the two ones that really hurt and depreciation comes from the depreciation of your **new machinery**. **On a five year rolling average you are losing 20% a year and that goes against you as a loss**.*

The costs described here are categorised in the LADM as resulting in 'uncertain costs' based on Bennett's framework [1976] (Section 5.5.4), due to the expense and depreciation involved of labour- and machinery-intensive crops (as mentioned, opting for new crops altogether also incurs 'uncertain costs' in the LADM (Section 7.5)).

Contract farming helps to spread the costs (including labour and machinery) of the farming enterprise over more acres.

> *We are in a very tight financial situation as I was saying and what we all looking at is trying to grow our business, **increase the size of our business**, and in fact we have done that this year, we have taken on another 110, 112 hectares, we are taking on this Autumn. So that is going to **stretch our staff and our machinery even more**.*
>
> *[But] you can only do that as far is your machines stretch. **What I'm trying to do is not to invest any more money in capital items like machinery**... We just keep ticking over as if it was a small farm - we're not a small farm. We're actually we're about 1000 acres, normally, but we've taken on all the land which totals about 500 acres now. So we are about 1500 acres. So we have increased our farm size by another 500 acres.....with the same machinery... You see what I don't want happen is to get to the stage where suddenly these outside*

> *farms say "okay thanks..., we've enjoyed having you for five years, I think we'll go back and do it ourselves now". **And suddenly I'm left with a great big overhead that I can't support, that is my biggest concern. So I think we have got to be careful.***

The methods used by farmers to buy machinery depend on government incentives.

> *... it depends what your cash situation is and what benefits you get to from renting, hiring, leasing. **Now what we do is we try and buy, all the time we have available cash we will buy... unless the government changes the rules on the leasing and it is tax advantageous to lease because you can get tax relief on leasing payments, and that's been quite useful in the past.** Although that's all changing at the moment, it's all in a state of flux... **But as things get tighter I guess that we will all be moving gradually back to hire purchase and leasing.***

Decreasing machinery would mean increasing labour and this is problematic, because there is often too great a demand for seasonal staff and not a large enough pool of casual labour available. Certain specialist crops such vegetables and potatoes are labour-intensive and thus different crops have varying levels of labour requirements. During harvesting, labour often needs to be increased for all crops.

> *You see we're harvesting today for example rapeseed and then we shall go onto **wheat in the first week in August** and then we shall be **turning around and drilling some of that wheat straight back into oilseed rape**. So you know it is a **continuous process** and the **quicker** we can get it done the **better**. You see in **other countries** of the world you have got to more time, you know you might have a **couple of months between harvesting and drilling**. But in the **UK and the further North** you get the worse that gap gets, the **tighter that time gets - the turnaround time**. You see that is why we have a lot of pressure of coming up. I have just **doubled our staff** this week as of Monday. We have gone from three to 6 in order to get things done **quickly, efficiently and so that we can get the next crop in**. So as I speak to you there's just **myself and six others. That will last until the end of October now.***

4.5.11. Building a reservoir

Increasing irrigation by building a reservoir would be costly, both in terms of actual cost, and in terms of loss of land area to grow crops for income. However, irrigation could also be extracted from natural resources (Section 4.5.3).

We have actually ***increased irrigation this year****, at least we have made it easier by burying some more underground main, so we are taking the underground water supply another quarter of a mile, I know that doesn't sound much but it is quite distance, underground giving us another area of land, and that is for potatoes, and we're* ***actually using that this year****. Yeah, so we are looking at* ***irrigation, it is so important for potatoes****, less so for other crops, but in a* ***dry year other crops could benefit****. But what usually happens is that we are peddling so hard on our potatoes, that we don't actually get time to put water on anything other anything else but potatoes.*

Crop yields are limited by irrigation and

....in some years one might actually decrease the fertiliser because you know that your ultimate yield is going to be limited by water for e.g., because you can't irrigate all your crops. Decreasing irrigation[1] saves money because you are buying less water and there is less overtime going into moving pipes about and that sort thing – it doesn't save an awful lot of money, I have to say.

4.5.12. Contract farming

With hindsight, Peter noted the drawback that renting the farm brings:

[My father] moved from ownership to being a tenant and that is something that I have always felt that I would have loved to have been is a landowner, rather than a tenant. You see anybody sitting pretty now with their land purchased and no rent being paid and let us say no mortgage can weather the sort of [financial] storm we are in at the moment.....

However, contract farming is one method that farmers are using to increase their incomes, and many smaller farmers are in need of tenants as they are going out of business due to the various disasters which have struck the industry [O'Brien, 2000]. This is a very good way for farmers who have the spare capacity to increase their incomes, to try and counter-act the effect of falling crop prices to some extent, and for struggling farmers to rent their land out and look for off-farm sources of income (Section 4.5.13). While many farmers are looking for alternative sources of on-farm income (in the form of alternative crops), the size or location of many farms can also result in limited opportunities and thus the only alternative may be other/additional off-farm

1. The strategy to decrease irrigation was included in the interactive questionnaire described in Section 6.3.1.

employment [O'Brien, 2000]. Peter explains that by taking on contract farms both parties actually benefit.

> *To give you an example, I'm in the middle of a five-year contract with one farmer and the one that I have just been talking about, that will be a five-year contract as well. So there will be an overlap there, so if one goes at least the other will keep going. But the idea is to farm well enough and hopefully do a good job for them as well.* ***You see both these two farms are smaller farms where it is hard to generate enough income to support the families concerned.*** *So what is going to happen is, they are saying to me* ***if you contract manage this farm, as long as you give me a certain figure and we agree that that is a profitable figure for them and for us then they will be better off than they were before. And they can then also go and get a job. In both cases that is what's happening ... So it's a bit like renting it, and this maybe a way forward and a way to expand.***

Peter includes his contract farms in his rotation in a broad sense.

> *Now, in practice what will happen... I will tend to block the land so that the farm number one for example might be all wheat, where as a once upon a time they would have had their own little rotation going.* ***What I'm going to try and do is I'm going to try and get each farm to be blocked so that they are all wheat one-year then all a break crop, all wheat, all a break crop and so on. That's the plan... So my philosophy is to farm as hard as I possibly can, but looking after the land... You have to look after the land and keep putting back into the land what you're taking out otherwise it will creep up on you and that is another problem.***

However, as mentioned before, while the aim of increasing acreage is the spread one's fixed costs, there are still costs involved and thus the potential financial return has to be carefully assessed:

> *That is another problem we find in taking on new land too. That it may not have been fed quite so well particularly from the pH point. You know we get acidity creeping in.* ***So there is a cost going into a farm initially****... [provides the example of his new contract farm]... I know we're going to have to put some lime on there to bring the pH up. We're also going to have to add quite a bit of fertiliser, it's quite a difficult farm actually....*

There is a trend in Britain and most developed countries towards fewer and bigger farms, since advances in technology mean that fewer people are needed for less land than even a few years ago to produce the same amount. Therefore, economics mean that only farmers who can afford to invest in modern machinery will survive and prosper [Kirby, 1999a]. In February 1999, it was predicted that 25,000 of Britain's 170,000 full-time farmers would be driven out of the industry by the crisis in agriculture, while some may merge their farms into bigger more profitable units working the land more intensively [Kirby, 1999b].

4.5.13. Generating alternative sources of income

Farmers are also diversifying their strategies and subsidising their incomes by selling directly to the public at farmers' markets. Since the first farmers' market opened in Bath in 1997, the movement has grown to include 375 sites which is one of the most dramatic expansions in retail history [Verdin, 2001]. If possible, farmers are interested in diversifying rather than downsizing, either in terms of making the most of their existing assets, such as converting a disused barn into a stable, or by exploiting markets for non-traditional crops [Verdin, 2001], and becoming 'unique' producers.

4.5.14. Trading in the Futures market

The Future's market is an alternative forum in which farmers can trade their grain in order to secure a guaranteed price based on its predicted yield. Peter has dabbled in the Futures Market[1] in the past, but is reluctant to try it again despite the economic downturn.

> *Trading in Futures is always an option but I think it is almost a different ball game that is not really farming as such, but... it's hedging your bets on* ***guaranteeing a price ahead****. So if you think you can make money on a particular price level and you can see that on a Future's price, say next April, next May, next June, and so on, you could hook on to that and guarantee you are going to get that price but* ***if the market goes up of course you lose out, course if the market goes down you've won****. So you know it's 50/50 one way or the other.* ***Not many farmers do it*** *- there was a period when a lot of us tried it and... it wasn't a vast success. I think I have tried it three times now. This is on Options - three times I've done it, and I think twice we have missed out and once we won out, so there's not much in it.*

1. The strategy to trade in the Future's market was included in the questionnaire knowledge engineering process (Section 6.3.1). It was used as a gauge for identifying a worst-case scenario, as trading in Futures is very risky and rarely attempted.

This is an interesting point since the choice of what is known and what is not, reflects cultural focus. Peter knows about these alternatives and could possibly benefit from them, but he has reasons for not pursuing them.

> ***I am a firm believer in sticking with what you know best.*** *But then if you can see a profit and guaranteed profit in these difficult times I can understand and I am tempted myself into thinking well lets take that profit. You see for the last couple of years I have been hanging on to my grain right to the end hoping for a better price which is what has happened since I have been involved in farming –* ***the price of grain has always gone up. The last two years it has gone down!*** *[laughs] Anyway, who knows this year I think it might do the opposite and go up again.*

This was in 1998, and farm incomes have gone down every year since. In 2002, it was reported that overall farm level incomes fell by 10% bringing the average farm income to £5,200. Total Income From Farming (TIFF) figures showed a fall in income of 27% in real terms to £1.88bn, down by *more than two-thirds* over the previous five years [MAFF, 2001].

4.6. Summary

This chapter has documented some of the salient aspects of the interviews that were conducted with the main informant. Our discussions revolved around the difficult financial situation facing UK farmers at the present time (including the effects of the BSE crisis [Krebs, 2000], the Foot and Mouth epidemic [Thompson, 2001], almost annual extreme weather conditions [Environment Agency, 2004, 2004a] and the effects of the strong pound [MAFF, 2001, 2001a]). Strategies which were being used to remain profitable under these circumstances were discussed. Importantly, this involved trying to be a *unique* producer by avoiding crop choices that are overproduced around the world since these were likely to be low in price. In addition to this there was a corresponding willingness to adopt any successful agricultural practises of neighbouring farmers. New crops such as *Northern Soya* were seriously considered as options due the lack of alternative break crops available in British farming. Decisions while financially-motivated to an extent, were also dependent on past experience, willingness to adapt, public perceptions and personal opinions and values.

These interviews have been successful in guiding the design of the LADM (Chapter 7) and the choice of the adaptive dynamics framework as a method for categorising the information (Chapter 5). The results of the LADM have in turn contributed to a greater understanding of the ethnographic data (Section 9.8). Traditional ethnographic methods used in the interview process have been complemented by participatory computer-based methods described in Chapter 6, which will illustrate techniques to relate cultural knowledge to context (e.g. Section 6.3.1) and the behaviours that emerge (Section 7.5). Integration between qualitative and quantitative data is achieved by combining the ethnographic data with Bennett's theory of adaptive dynamics (Chapter 5) and its incorporation in a knowledge-based simulation framework (Chapter 8). Furthermore, analysis of regularities and variation in adaptive behaviour [Spradley, 1979] (Section 2.9) is aided by the use of Bennett's framework which could support the process of generalisation and cross-cultural comparison, if used in future work as a standardised method. Chapter 5 explores some differing approaches in climate-related adaptation research and the dominant principal aspects of the anthropological theory of *adaptive dynamics* [Bennett, 1976]. This classification mechanism was chosen since it appears to *usefully* categorise some of the qualitative data described in this chapter. These linkages will be explored in greater depth in Chapter 5 and Chapter 6.

CHAPTER 5 Adaptive Dynamics

This chapter will describe various approaches to adaptation research in the field of climate impact analysis and describe in detail the anthropological theory of *adaptive dynamics* [Bennett, 1976] which has been used as a qualitative framework to formalise the observed ethnographic data (Chapter 4) for analysis using an agent-based simulation. Bennett describes this theoretical framework in his book *'The Ecological Transition'*, in a chapter called *'Adaptation as a Social Process'* [Bennett, 1976]. Ethnographic interviews (Chapter 4) have been successful in directing the design of the (Learnt) Adaptive Dynamics Model (LADM), through a process of formalisation that allowed the rich ethnographic detail to be retained. Relating cultural knowledge to context (using Bennett's theory of adaptation) and the behaviours that emerge (in the simulation) enhances integration between the qualitative and quantitative data (Section 1.4). In this way, this combination of methods can contribute to a greater understanding of the observed ethnographic data. The contribution of Bennett's framework to this process will be discussed in the remainder of this chapter.

The applicability of Bennett's framework above other models of strategic choice (e.g. Section 2.4) will also be explored as well parallels with models in the climate impacts field. Importantly, Bennett's theory of adaptation and decision-making is *agent/actor-oriented* and thus it provides a basis for a more analytical insight into the *process* of adaptation and its resulting consequences on the *individual and the group*, compared to other models of adaptation that have been researched (e.g. Section 2.4, Section 2.7, Section 2.11.2). However, it also relates closely to the empirical data described in Chapter 4. Thus, it appears to represent a sound theoretical abstraction of strategies in the observed target system [Edmonds, 2002], providing a reasonable vehicle to bridge observation and theory, in the domain of agricultural decision-making, under environmental and socio-cultural constraints. Of course, the use of such a theory invariably involves assumptions regarding behaviour and cognition and any results must be considered within the context of these assumptions (Chapter 7 and Section 8.4). However, Bennett was also interested in the *general* role that adaptive skills had to people in most societies over time and less concerned with particular causal factors such as climate (Section 2.3), which makes the generic nature of the adaptive dynamics framework quite flexible and amenable to other applications in anthropological research.

5.1. Climate-related research on adaptation

Although there is a vast literature on climate change, research on climate impacts analysis (CIA) and particularly on adaptation to climate change is fairly new (for some exceptions, see Parry and Carter, 1998, Smit et al., 1996, Smith, 1997, Smithers and Smit, 1997, Tol et al., 1998, Downing, 2000, 2002). Much work until recently focused upon mitigation of the effects of climate change, rather than adaptation to it. Indeed Parry and Carter [1998] recognise that relatively little analysis has been done on the efficacy of different adaptive strategies as distinct from mitigative strategies, which reduce greenhouse gas emissions and are deliberate policy initiatives which are treated separately in CIA. The reason for the lack of research on adaptation is that there are many different types of strategies that could be adopted and there are many therefore that need to be evaluated. Parry and Carter [1998] infer that since some adaptation is bound to take place at the local level, the separation of impact from adaptation assessment is artificial. However, analysis of adaptation in the way that Bennett formalised it during the 1960s and 1970s is still unavailable. Having said this, there is much valuable research in the field of climate impacts analysis that has contributed to an understanding of the *adaptive dynamics* framework, since the identification and evaluation of adaptive possibilities are essential components of CIA studies. Such additional identification and evaluation mechanisms will provide useful descriptive features within the LADM (Section 8.2.1).

In 1998, Parry and Carter identified three types of adaptation. Firstly they categorised *autonomous adaptations* as in-built adjustments or physiological changes. Secondly, *routine adjustments* which refer to everyday responses whereby a farmer may, for example, alter the sowing date of a crop due to a change in climate. And, finally, *tactical adjustments* which refer specifically to learning and adaptive behaviour. These categorisations are summarised in Table 5.

TABLE 5. Summary of categories of adjustment [Parry and Carter, 1998].

Type of adjustment	When it is invoked	Example
Autonomous	An in-built or physiological adjustment	When a plant reduces transpiration by closing its stomata as an automatic response to drought.
Routine	Everyday responses	When a farmer alters the sowing date of a crop due to a change in climate, such as the last frost or anticipation of the start of a rainy season, both of which affect the growing season and thus the performance of crops.
Tactical	Learning and adaptive behaviour	Adjustments which follow a sequence of anomalous climatic events indicating a shift in climate.

Parallels can be drawn between the frameworks that are mentioned above. For instance, Parry's descriptions of routine adjustments result in events which have various effects described by Bennett's framework, which are classified here as *primitive effects.*

Similarly, Rosenzweig and Parry [1994] distinguish between Type I and Type II adjustments whereby the former represent relatively simple farm level adjustments and the latter represent more significant changes in farm management strategies. Clearly, Type I adjustments are synonymous with Parry and Carter's definition of routine adjustments while tactical adjustments refer to Type II level intervention.

TABLE 6. Summary of categories of adjustment, [Rosenzweig and Parry, 1994].

Example of Type I strategy	Example of Type II strategy
Simple farm level adjustments such as changing sowing dates.	Significant changes such as the installation of an irrigation system.

Parry and Carter [1998] also identify seven steps for evaluating adaptation strategies.

5.1.1. Defining objectives

The objectives of the farmers in the area in which this study was conducted were derived from discussions with the informant. However, it has also been important to recognise that there are varying goals of other actors in the farming enterprise in the same and differing geographic locations, as mentioned in interviews with the main informant and other farmers (Section 4.3.14 and Question 10 in the survey).

5.1.2. Specifying important climatic impacts

When identifying an important climatic impact, the details which need to be considered are the magnitude and regional extent of the event, frequency, duration, speed of onset and seasonality (timing during the year). The general approach for identifying exposure units at risk from climatic variability is vulnerability assessment [Parry and Carter, 1998].

5.1.3. Identifying Adaptation Options

Parry and Carter identify six generic types of behavioural adaptation strategy for coping with the negative effects of climate change which were originally identified by Burton *et al.* [1993].

Prevention of loss. This refers to anticipatory action to reduce vulnerability developed from past experiences.

Tolerating loss. Involves accepting adverse impacts in the short term because they can be absorbed by the system without long-term damage (e.g. a crop mix designed to minimise maximum loss, to ensure a guaranteed minimum return under the most adverse conditions).

Spreading/sharing loss. These are actions which distribute the burden of impact over a larger region or population beyond those directly affected by the climatic event. (e.g. government disaster relief). Unrelated to climate, in the case of this field study this is analogous to historical government schemes to compensate farmers for any shortfall in their income due to an oversupply of produce and resulting lowered prices. However, this is no longer the case at present since supermarkets in the United Kingdom can buy from the cheapest source and therefore will import from other European countries, where costs of production are often lower [Kirby, 1999] much more readily than they used to.

Changing use or activity. This involves a switch of activity or resource use from one that is no longer viable, following a climatic event, in order to preserve a community.

Changing location. Where preservation of an activity is considered more important than its location and migration occurs to areas that are more suitable under the changed climate. This option is not usually considered an option within agriculture since changing the area of activity to an area with a better soil type is not usually possible. However, it could occur when a farm manager takes on other farms in addition to his own, which may contain different types of land. This would usually only be possible if the farmer was successful on his own land and had enough carryover capital to cover the time that it would take to create an income from new land, since this type of investment is a strategy with delayed return, or in Bennett's terms, 'delayed effects' (Section 5.5.2).

Restoration. This refers to the restoration of a system to its original conditions following damage or modification due to climate events. However this is not strictly classified as adaptation to climate change as the system remains susceptible to subsequent comparable climatic events [Parry and Carter, 1998].

5.1.4. Examining the constraints

Once identified, the effectiveness of differing management strategies could potentially be assessed with respect to stated objectives using Gladwin's 'Elimination by Aspects' methodology (Section 2.10) in the expert system part of the model in future work. This would allow the inclusion of differing goals (as step 1 of 'defining objectives' (Section 5.1.1) will also have taken place), such as income, technology and productivity requirements and a fairly simple customisation of the model to include the constraints of different geographic locations involving varying sets of socio-economic constraints (e.g. Section 6.5).

5.1.5. Weighting objectives and calculating trade-offs

Parry and Carter state that since the previous steps for evaluating adaptation strategies frequently yield conflicting results, this particular evaluation stage is crucially important since it is designed to resolve conflicts between strategy choices by attaching weights to different objectives according to assigned preferences and comparing the effectiveness of different strategies in meeting these revised objectives. Empirical data on decision-making used in the (Learnt) Adaptive

Dynamics Model (LADM) was validated in numerous ways with the informant to avoid possible conflicts between strategic choices (Section 6.4).

5.1.6. Recommending adaptation measures

Finally, Parry and Carter write that recommendations made to policy makers from evaluations should clarify any assumptions and uncertainties involved as well as rationale used.

5.2. Parallels with climate-related frameworks

As mentioned, Rosenzweig and Parry [1994] have developed a methodology that is used in assessments of climate change impacts by classifying adaptation into two types. A combination of Bennett's framework and Rosenzweig's typology will be incorporated in the (Learnt) Adaptive Dynamics Model (LADM) due to the benefits offered by both.

Connections can be made and parallels drawn between the general frameworks mentioned above and Bennett's framework [1976]. For instance, *routine adjustments* as defined by Parry and Carter [1998] result in the *primitive effects* described by Bennett's framework. In essence, Rosenzweig and Parry's [1994] typology abstracts further Bennett's idea of *primitive effects* and provides an alternative way of describing Bennett's *strategic designs*. Rosenzweig and Parry distinguish between Type I and Type II adjustment whereby the former represents relatively simple farm level adjustments such as changing sowing dates and the latter represents more significant changes such as the installation of an irrigation system. Although Bennett's framework is very useful, it cannot easily be translated into everyday events. In contrast, Rosenzweig and Parry's typology represents *degrees of scale* of adaptation and thereby allows for a more refined description of events. Parry and Carter's definition of routine adjustments are synonymous with Type I adaptation, while their definition of tactical adjustments allies with Rosenzweig and Parry's Type II level intervention. A further benefit of Rosenzweig's typology is its incorporation into a study to model the effects of climate change on crop production [Rosenzweig and Parry, 1994] which could be useful in further extensions of the model. This study modelled the effects of climate change on global food supply using a trade model which incorporated the effects of the two levels of farmer adaptation (Section 2.7.4).

5.3. Parallels with strategic choice models

As discussed in Section 2.4 strategic choice models are also used in the business and management field and these models will be a basis for comparison with the more descriptive adaptive dynamics framework used in this research. There are indeed many links between the two. For example, business models of strategic choice describe change in small enterprises as a result of limited resources and change in large enterprises as a result of past choices which constrain future ones, in similarity to Bennett's definition of *action constraint* (described in Section 5.6.4). Similarly, both consider context to be a determining issue in the choice process, as illustrated on pages 50 - 52.

However, the view of 'strategy' common in business management has been to devote attention to short-term cost cutting and to focus on *efficiency*, defined as the relationship between inputs and outputs, rather than on longer-term *effectiveness* [Wilson and Gilligan, 1997]. A focus on effectiveness would highlight the link between the organisation and its environment which is more aligned with the feedback effects between environmental and socio-cultural processes described by Bennett's framework. However, short-term *efficient* strategies (see Section 5.5.1 on strategies with *immediate effects*) as well as longer term *effective* strategies (see Section 5.5.3 on strategies with *sustained effects* and Section 5.6.6 on sustainable long-term strategies) are both captured by the *adaptive dynamics* framework [Wilson and Gilligan, 1997].

In a more dynamic interpretation, Wilson and Gilligan [1997] emphasise that 'strategy' is not synonymous with 'long-term plan' but is an enterprise's attempts to reach some preferred future state by adapting its competitive position as circumstances change (Section 2.4). Thus, while a series of strategic moves may be planned, competitors' actions will mean that the actual moves will have to be modified to take account of those actions, indicating a need to have the flexibility to react to unforeseen and uncertain situations or to anticipate the actions of others. For example, infeasible options (Figure 7) such as the growing of Genetically Modified crops in the agricultural domain (Section 4.3.8), may seem highly attractive to some actors and may have powerful supporters. Thus, the reasons why they are infeasible need to be supported with clear evidence as has been the case with some press coverage of GM crops. This has also led to protests to disrupt GM crop trials by opposition groups. As Macmillan and Tampoe [2001] have stated, the choice of what not to do may sometimes be as important as choosing what to do, in order to win support of various interest groups with differing goals e.g. those implementing the strategy - the farmers - and those who will be affected by it - in the case of GMOs, the wider public.

'Acceptability' is an aspect that is built into the use of Bennett's framework, since the experiences, perceptions and options that have the support of the informant are that which guide the exploration of *possible* strategic options. As mentioned in Section 2.4.1, the *process* of decision-making is also affected by political and cultural factors and their effects which Bennett's theory can help to illuminate, with the input of informants/domain experts.

Additionally, strategic choice models which provide obscure categorisations and little natural synergy with observed processes in the target system, will create further difficulties when trying to interpret their results in the context of the observed system. For example, descriptions of 'related' (backward, forward, and horizontal) and 'unrelated' diversification described in Section 2.4 are less useful in trying to achieve an understanding of social processes within the dynamic agricultural context in which they are observed.

Macmillan and Tampoe [2001] write that strategic options and methods of implementation have to be combined into a much smaller number of strategic options, linking what might be done into potential strategies and testing general ideas of future direction against detailed options. Similarly, Bennett's framework incorporates a combination of bottom-up and top-down approaches, allowing the identification and linkage of low-level options with larger scale strategic processes.

5.4. Bennett's theory of Adaptive Dynamics

Bennett's framework is more applicable to the research questions addressed here than other strategic choice models for several reasons. Primarily it serves as a good theoretical description of strategic behaviour in the target system since it provides a better 'fit' with the ethnographic data than those models described in Section 2.4. And, yet it does appear to cover the areas discussed in the strategic choice literature and illustrated in Figure 6 and Figure 7. This will become clearer in the comparison of Bennett's categorisation of various adaptive behaviours, referral to the ethnographic context and adaptive strategies documented during interviews with the informant (Section 5.4). Furthermore, Bennett's theory offers great scope for analysis within the architecture of a qualitative multi-agent model allowing the descriptive categories of micro-level primitive effects (Section 5.5) and macro-level strategic designs (Section 5.6) to be explored effectively. Not only is the framework generic and applicable to a wide variety of domains but the structure and classification of the rules is such that the results can potentially be complex and result in many combinations which may be better analysed in a simulated environment.

Bennett suggests that one avenue for research by anthropologists is the analysis of the process of adaptation selection over time. This refers to the forging of a strategy over a long period using experimentation and adaptation – he suggests a minimum of two generations at the least – to analyse how such a system actually emerges. Many monographs deal with the ethnographic present, though Bennett, claims that as anthropologists are beginning to study cultural ecology in more complex systems there is a recognition for the analysis of the larger system within which the micro study is taking place, in addition to an historical overview, to assess whether there is a recurrence of adaptation processes over time and through generations. This makes Bennett's theory of adaptive dynamics highly applicable to a simulation study since adaptation can be observed over time using many generations of agents, in a micro-laboratory setting. Furthermore, the basis for any emergent phenomena regarding adaptation, which is dependent on micro-level individual strategies, can be explored. However, from an anthropological perspective, we are concerned with how such strategies emerge over time *as a part of* cultural process and the structural *relationship* between adaptive knowledge and the cultural context.

Humans reflect on the consequences of their actions and adapt them accordingly when meaning is attached to those consequences. Such adaptive strategies refer to actions with a predictable degree of success which are selected by an individual or a group to achieve goals. However, the same environmental phenomenon may result in different reactions at different times in the same society and among different groups or in different societies. Thus, culture can be viewed as a set of precedents which consciously or unconsciously guide decisions, such as the (possibly subconscious) successful adaptive strategy of the New Guinea Maring, known as the Kaiko ritual, [Rappoport, 1968] or the 'transformation stories' of the Warao Indians [Wilbert, 1996] (Section 2.2). Furthermore, there is often a time lag between the perception of environmental degradation and action which is often a feature of culture. Culture is the source of rules built from past experiences of successes and failures. The rules may be cross-cultural but it is the way in which these rules and structures of knowledge relate to the cultural context that is important to understand. For example, Bennett claims that the 'modern', 'market' dimension of the North American setting he has studied [Bennett, 1966] echoes tribal cases at the level of social interaction and decision making, in competition for land, redresses of imbalance, renovation of resources and development of internal-external relationships (see Section 2.3.1 for a discussion of cross-cultural tolerance thresholds). The obvious differences in social structure and cultural influences are clear, but fundamentally

> *we are dealing with processes that undercut subsistence and even technological levels, and it is this domain of cultural ecology that needs development so that policy-relevant findings can emerge* [Bennett, 1976].

It is this level of analysis and understanding which one requires in order to further illuminate ethnographic data and thus a compelling reason for using Bennett's framework, not least because its roots are in cultural ecology and environmental anthropology. This also relates to the generic cross-cultural nature of adaptation decisions (Section 2.3) and the discussions that were conducted with the informant. Strategic choices may appear different on the surface, due to the variable meanings that people give to the constituents of the cross-cultural constraints which affect their decisions (Section 4.3.10) and how these relate to structures of choice. These will often be issues of finance, cost, profit, efficiency and effectiveness. These factors may be used to explain choices, but they are not necessarily the basis on which choices are made. While strategic choices may involve such rationalist criteria, politics and socio-cultural values underlie these choices once they make the minimum hurdle of being defensible. Therefore, the *processes* involved in decision-making are comparable cross-culturally, though the content and meaning attributed to the variables involved will be different in different contexts (Section 2.3). For example, the informant discussed many of his options in terms of economics and finance but eventually many of his decisions depended on how 'comfortable' he was with his choices and this was defined by his own 'values' (e.g. the discussion of GM crops and his view of the public's perception of GM 'contaminated' food (Section 4.3.8 and Section 4.3.10)). Arguments can be made for what is 'comfortable' and 'safe' on rationalist grounds, but this is sometimes post- not a-priori argumentation.

It became clear from our interviews that farmers do use a framework for adaptation on a short and long term basis, which corresponded to the theory of adaptive dynamics. However, it was necessary to question whether farmers used foresight and strategies which could be linked to the adaptive dynamics framework when planning for the future and whether strategies that were used were a part of cultural make-up or defined by links to cultural values as in the case of the New Guinea Maring [Rappoport, 1968] and the Warao of the Orinoco Delta [Wilbert, 1996], for example. Whether this was the case needed to be investigated through an analysis of the drivers of historical adaptations, as prescribed by Bennett, which was achieved through interviews (Chapter 4). The acceptability to the informant of the consequent adaptive suggestions made by the model determined whether it could provide an understanding of behaviour within the adaptive dynamics context.

Bennett's theoretical framework for adaptation processes and its relationship to observed data is explained in the following sections. Firstly the distinction between 'strategic designs' and the 'effects' of a strategy, which result in strategic designs is important to understand. 'Strategic designs' can be considered by the observer or analyst as a type of precedent or cognitive map, and thus can become a part of culture, through beliefs and practises relating to such beliefs. That is, a series of steps in which one action often leads to others depending on context and individual goals.

For example, in the case of the field site used in this study, a dramatic shift took place in the mid-80s from vegetable to arable farming. The informant claims that this was due to an economic downturn in the vegetable industry, but the decision to change was also encouraged by new storage regulations that were introduced at the same time, which meant new storage facilities had to be built (see Section 4.2). The decision to stop vegetable farming meant that an insurance crop had to be introduced to cover the immediate loss from the vegetables, hence a series of necessary steps ensued, which are referred to as types of adaptation with 'primitive effects', resulting over time in adaptive patterns - strategic designs. Strategic designs consist of one or more types of adaptation with primitive effects, for which the risks are variable. Strategic designs can also be referred to as macro-social or second-order concepts, while primitive effects occur at the micro-social level (see Section 2.3).

5.5. Adaptation with primitive effects

Bennett's framework of adaptive dynamics is shown in Figure 14. An important feature of the model is *time* and consequently a pattern of repeated strategies results in differing strategic designs which sometimes have negative outcomes i.e. they are maladaptive. A negative strategic design involves a series of strategies which, over time, become constraining or increase the vulnerability of the individual concerned. This can be the result of the unforeseen consequences of opting for a particular strategy or as a result of immediate, short-term planning without adequate consideration of future consequences.

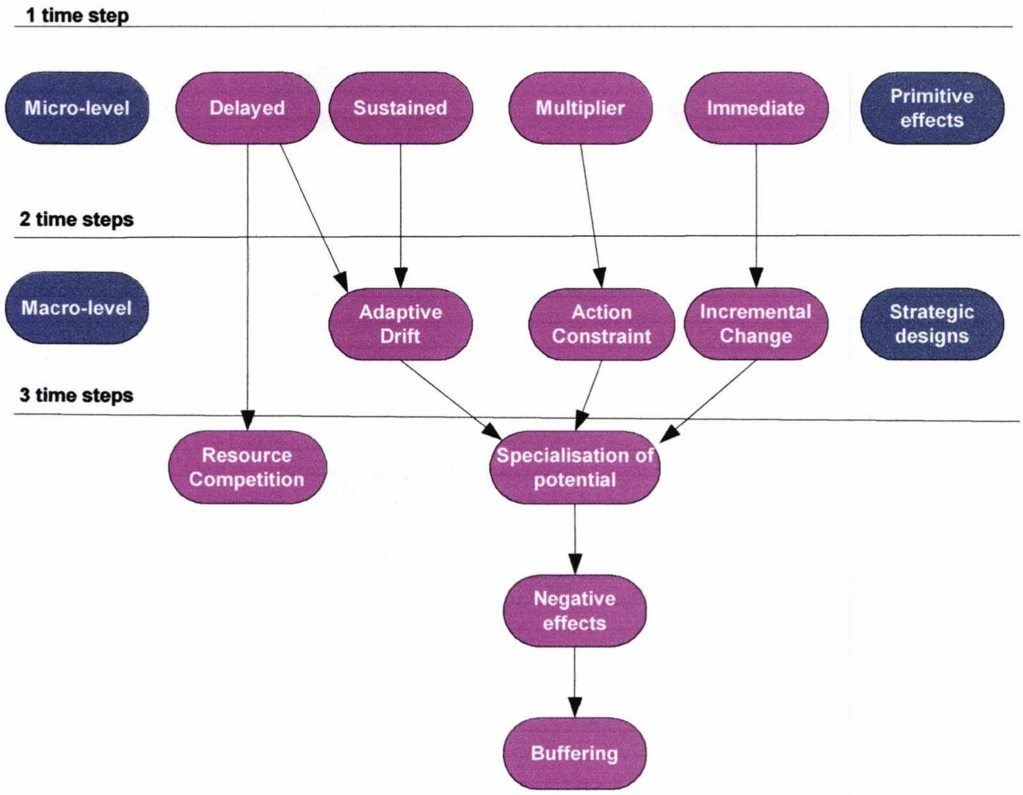

FIGURE 14. **Micro-level primitive effects and macro-level strategic designs in Bennett's framework of adaptive dynamics [1976]. The arrows show the direction that the primitive effects of various strategies take and the time involved in the evolution of the resulting strategic designs.**

Bennett's classification of the *effects* of various adaptive strategies is described in the following sections.

5.5.1. Strategies with immediate effects

The 'returns' of a strategy with immediate effects can be low-risk, if an achievement of some result is relatively certain to occur. Examples would be improving irrigation facilities or doing a favour in a social system where there is pressure to reciprocate and thus the favour will be relatively certain to be returned.

5.5.2. Strategies with delayed effects

These are also low-risk strategies, if they are relatively certain to produce results in time, such as a farmer planting a crop. However, because of the time lag involved when a farmer plants a crop, which will come to harvest the following year, stored, and possibly not be sold for up to one year more, he must have adequate carryover capital. This is even more crucial if a farmer is also managing other farms on a contract basis as the risk factor is probably increased, since initially the same amount of carryover capital must sustain the farmer until the next crop is harvested and marketed. This can take two years from when the crop was first planted, and longer from when the choice to grow the particular crop was made, as my informant told me:

> *It is often 2 years before you see the end result of a decision because you have to plan, you then plant the seed, you then harvest it, and it may be a year, or almost a year before you've sold that crop, so it is nearer two years or more.*

However, if the harvest is successful, the farmer will of course be better off, than had he been farming just one farm.

5.5.3. Strategies with sustained effects

Strategies with sustained effects will produce a continual flow of returns once initiated. The risk factor is variable. These strategies may require constant input of resources or capital but to be profitable, input must be lower than output, minus any additional costs of strategic operation [Bennett, 1976]. In the case of my field-site, a district wide farm co-operative has collectively bought a water pump, to channel water to each farm from the same water source. The Internal Drainage Board (IDB) now maintains the pump, and are paid drainage rates by the farmers for a guaranteed supply of water (Section 4.5.3). Thus the risk involved in the initial investment was fairly low due to the sustained supply of water over the years, though a minimal continued investment is still required.

5.5.4. Strategies with multiplier effects

Multiplier effects are of various kinds and can also be strategic processes. They generally refer to strategies which may have uncertain costs. For instance, my informant has approximately 1000 acres of land, and has taken on two contract farms amounting to 1500 acres in total. However, he does realise the *uncertain* and *delayed* cost incumbent on him to buy more expensive machinery.

I have to say that when we change tractors we do say, instead of getting one sort of middle to high horsepower, we tend to go for high horsepower. So we do spend a little bit on extra powerful machinery because we've got the extra land so there is an added cost.

The introduction of high yielding crop varieties or new crops altogether is another example of strategies with multiplier effects since problems created by one technological strategy - intensive agriculture - are attempted to be solved by introducing a new technological device which may have additional, and, as yet unknown costs. This escalation in technology and development which has a momentum of its own, is a common feature of growth oriented systems and leads to further effects described by Bennett (see Section 5.6.3).

The introduction of powered machinery in farming permitted production at lower labour costs, but also required a rise in prices. This process demands further mechanization in order to further reduce costs, and increasingly large and expensive machines are added to the system, until the costs of machines begin to exceed the savings, creating financial crises and permitting increased abuse of resources (although the latter consequence is not inevitable, since under some circumstances machine cultivation can protect soil and water resources) [Bennett, 1976: 285]

Thus crops which require machinery have uncertain costs (Section 4.5.10) and the same could apply to new crops about which little is known regarding pests and disease and the requirements of fertilizers and herbicides (Section 4.3.11). According to Bennett's framework, adopting such strategies would result in 'multiplier effects' (Section 5.5.4).

5.6. Strategic designs

The following adaptive *processes* can be identified over a certain period of time. They are the product of patterns of cumulative strategies which result in immediate, delayed, sustained or multiplier effects.

5.6.1. Incremental Change

This refers to the process of adapting to change on a 'reactive' basis rather than on a planned one. That is, reacting to each event one-by-one using short-term strategies which have *immediate* effects. Action that is taken to serve immediate needs in this way can result in an accumulation of errors since future costs are not considered and long-range planning for change in whole systems is not carried out. Thus, incremental change refers to a pattern of errors resulting from following short-term strategies without due regard for external costs or damage resulting in environmental degradation. When discussing the reasons that smaller contract farms often had to be managed by someone else, my informant explained,

> *... they do a jolly good job - for the size of the farm -* ***it is not easy to generate enough cash from those acres, and consequently, yes what happens is eventually, you decide not to buy that new tractor, because you can't afford it, so you end up with old equipment, small equipment, slower equipment and it is a slow process but it catches up on you. I think that is the best way to describe it.***

Bennett also uses machinery buying to illustrate the effect of unplanned, 'immediate effect' decisions.

> *To illustrate the effects of these concepts in strategic action analysis, we may consider the strategy of "machinery-buying" by farmers. For a given situation, this strategic action can have: (a) immediate financial effects in the form of lowered costs, (b) but with an escalating effect of increasing costs, and (c) delayed deteriorative effects on the natural resources* [Bennett, 1976: 285-6].

Bennett describes *incremental change* as a pattern of strategies which involves short term decisions made without long-term planning.

5.6.2. Adaptive Drift

Adaptive drift is a one-directional process whereby a movement of decisions are taken due to socio-cultural reasons, which are usually related to social stratification.

> *Other adaptational processes also become significant in 'drift' such as the 'vicious circle' of increasing efficiency in production, which demands ever-greater production at lower costs, until resources are depleted or abused. The striking thing about adaptational drift is that it is frequently accompanied by an aura of rationality. While a degree of awareness of the contradictions usually exists, it is surrounded with rationalisations; essentially, drift is a prolongation of the status quo disguised as planning* [Bennett, 1976: 288].

This is similar to the Wilson and Gilligan's discussion [1997] regarding the balance between efficiency and effectiveness, illustrated in Figure 5 (Section 2.4). However, adaptive drift more specifically is a strategy that refers to the movement of decisions in a *particular direction*. In the agricultural context, repeated choices of particular crops may be made due to previous investments and the narrow range of crop choices available in UK farming (Section 4.4.1).

5.6.3. Buffering and Step-Functioning

Also related to Wilson and Gilligan's discussion [1997] of efficiency versus effectiveness, the 'buffering effect' is visible when a detrimental strategy is followed due to other factors which encourage it to do so, despite the danger that is evident.

> *Vested interest are one kind of buffering mechanism of particular importance in all growth-oriented systems where gain is large and risk of loss is correspondingly felt to be severe* [Bennett, 1976: 286]

However, buffering can only persist for a finite period of time since its negative effects will overwhelm the system by either causing damage to resources, or triggering a controlling mechanism on the negative activity in question.

> *Step functions exist where, due to buffering, a considerable output or operation must proceed until enough has accumulated to trigger a demand for, or the imposition of, control* [Bennett, 1976: 286].

Bennett identifies an inherent danger in attitudes to environmental change which is that only a minority of the members of any large population are usually affected by natural disasters and consequently the majority do not feel the necessity to adopt protective strategies as they have never experienced any disaster contact. He writes,

> *this process is particularly evident in the contemporary scene, where a sense of urgency over environmental "crises" develops in one group in the population, whose protests have zero effect because the situation is not sufficiently dangerous overall for a change to be effected.* [Bennett, 1976: 286].

5.6.4. Action Constraint

Action constraint represents the tension and paradox created by the desire to change future direction and the inability to do so, due to underlying constraints, based on previous investments. It involves a particular type of decision which has 'uncertain costs' [Bennett, 1976] referred to as multiplier effects in Bennett's framework (Section 5.5.4). The resulting increased and uncertain number of variables in the decision-making process increases constraint by limiting future choices, due to the binding powers of decisions that have been taken [Bennett, 1976]. This can result in vulnerability which lowers future adaptive capacity. This is similar to the definition of change in business models where small enterprises are seen to be constrained by their limited resources, while change is restricted in large enterprises as a result of past choices which constrain future ones (Section 5.3).

> *This process refers to the effect of increasing the number of variables in a situation - a consequence of strategy design – and so limiting or controlling future decisions and changes. This may be another way of referring to drift but in 'constraint' one is concerned with the tension produced by a contradiction between the desire to alter the pattern and the impossibility of doing so due to the binding power of decisions produced by a very heavy investment* [Bennett, 1976].

This corresponds to the hesitancy of the informant to forego previous investments, and make new ones by switching to the new crop Northern Soya, despite his own admission of the need for new break crops in British farming (Section 4.5.5).

5.6.5. Specialization of Potential

Also referred to by Bennett as **adaptive specialisation** this process involves the increasingly specialised use of a resource over long periods of time, and thus can invoke the buffering mechanism (Section 5.6.3). If a larger regional unit is involved, the specialisation of resource use results in particular productive regimes carried on by subgroups in the regional population. It is clear from conversations with my informant that it is important to try and be a 'unique' producer. For example, he claims that there are very few potato growers nation-wide, because the machinery and extra labour required is so expensive. He has invested in this enterprise along with his arable cropping because potatoes act as an insurance mechanism providing a good return on average, over a five-year period, should the price of any other crop be lower than expected. However, part of the decision to specialise in a particular crop depends on what is already being overproduced, since this will affect the price that it can command in the market place.

> *...[vegetables are a] consideration should combinable crops get bad. I am not sure that I really want to go that route. My heart tells me that would be wrong because everyone is looking at doing the same.*

Although specialisation of potential may produce sustained yields, it simultaneously lowers the capacity for adaptation, due to the rigidity of the relationships that are forged with natural resources, and in this case, consumer markets. In developing countries particularly, this rigidity increases the vulnerability of producers to economic or environmental shocks. Indeed, the results of the model indicate that this vulnerability is also evident in developed economies where there is heavy dependency on a narrow range of crops (see Section 4.3.11 and Section 9.3.5).

5.6.6. Resource Competition

Bennett's definition of resource competition is one which involves the interaction of individuals over a long period of time, and can result in the emergence of new patterns of behaviour as a result of its effects (as with other strategic designs). Specialisation (Section 5.6.5) and action constraint (Section 5.6.4) are closely related to resource competition but this dynamic represents *sustainable* behaviour over time.

> *Competition for resources proceeds cyclically in many cases, and may approximate steady states or homeostatic rhythms when the competing groups move toward an accommodation pattern in which allocation of particular resources in a scarce or marginal set are made to particular groups... The competitive process in humans is always* ***dynamic****; arrival at a particular allocation always involves* ***time*** *and increasing populations or* ***external inputs****, conquests, and so on can upset the systems and lead to* ***renewed competition*** [Bennett, 1976: 286].

5.7. Linking theory and observation

Bennett's theory of adaptation has been used as a vehicle for formalising observed data for analysis in an agent-based model. This may inform the theoretical framework and thus provide an enhanced understanding of the target system. As mentioned in Chapter 3, the agents in the Learnt Adaptive Dynamics Model (LADM) represent adaptive and non-adaptive (sceptical) farmers who possess a corresponding repertoire of strategies. In the model, 'strategies' are any type of farm management option that can be taken, from choosing a particular crop to installing irrigation and changing planting dates, which result in Bennett's 'primitive effects' (Section 5.5). Adaptive agents possess more strategies than non-adaptive agents since they are willing to invest in new technology crops. Agents choose their options in response to changes in the environment, constraints on irrigation and capital, the choices of other agents and the resulting effects of these choices *over time*, resulting in macro-level, strategic designs. One of the main features to emerge from the interview data was the desire of farmers be productively different from their competitors. This dynamic is reflected in the model whereby if one agent persistently chooses a strategy and thereby specialises in it over time (a category represented in the adaptive dynamics framework as *specialisation of potential* (Section 5.6.5)) other agents would make alternative choices. Interviews also showed that certain strategies could entail costs which were uncertain (e.g. the depreciation and cost of machinery and labour) and similarly new strategies could incur costs which were unknown (e.g. growing a new and relatively unknown crop for a changing climate). Such 'uncertain costs' were reflected in the model using *multiplier effects* (Section 5.5.4) and the strategic design of *action constraint* (Section 5.6.4), over time. The goal of the agents was to meet the costs necessary for their crop choices, and the model allowed an analysis of the strategies that resulted from the interaction of adaptive and non-adaptive agents.

The status of cyclical resource competition or *homeostasis* as described by Bennett (Section 5.6.6), was used as a measure of sustainability or stability for the system and also therefore for the ultimate success of the agents. The dynamic represents sustainable behaviour by agents over time, since market saturation/specialisation and resource depletion (Section 8.3) were taken into account over several years as suggested by Bennett. If the same choice is made year after year, and the product of this repetitive strategy is a negative strategic design (a strategy which may increase future vulnerability), a warning is issued regarding market saturation or resource depletion/over-use. This would be an example of a mal-adaptive strategy (e.g. Section 5.6.3). Thus, resource competition represents the conflicting constraints (Section 9.6.1) of competition and sustainability since it is the result of sustainable, but opposing crop choices by agents over time, operating under differing constraints of irrigation availability and finance. This affects subsequent crop and strategy choices by the agents in the system. Thus, this illustrates the emergence of *sustainable interaction* and a *pattern* of adaptive dynamics that a group can follow, leading to a stable system overall, while *simultaneously* maintaining individual stability. Should such an integrated pattern of behaviour exist [e.g. Henrich, 2002] (Section 2.11.4), Bennett's qualitative categorisations allowed strategies to be identified, and whether these differed *individually* in order to maintain a sustainable, stable pattern overall, was a source of investigation.

Bennett's framework for understanding adaptation is useful not only in its classification of observed data, as described in previous sections, but also due to his general approach. In 1966, Bennett wrote about the interaction of agriculturalists with agencies within their respective environments using a game-based analogy (e.g. Section 2.11.3), referring to *opportunity costs* (Section 2.3.2) as the cost of following one particular course of action or activity as opposed to another. In writing about North American rural society Bennett wanted to move away from propositions regarding the linearity of change processes and modernization in favour of a *theory of adaptation.* This theory is *neutral* in terms of assumed directions of change which is in fact, in part, determined by the members of the society under study (possibly through such mechanisms as 'conformist transmission' [Henrich, 2002] (Section 2.11.4)). Therefore, the local situation must be viewed from the standpoint of the goal and strategies of local people as well as from an external theoretical viewpoint. The three groups that Bennett studied - farmers, ranchers and Hutterites - varied greatly in their involvement with external institutions. However, despite differences in the involvement of these groups with the wider economy, in similarity to Fischer's [1994] recommendation to focus on the *interaction* of different systems and subsystems of knowledge (Section 1.4), it was the *pattern of interaction* between the *microcosm* and *macrocosm* that also concerned Bennett [1966]. Bennett writes that this type of interaction is that which defines a 'complex society' since local units are subject to processes of readjustment in response to external (non-local) forces (Section 2.3). As mentioned, these processes of readjustment and response are comparable cross-culturally though the content and meaning attributed to the variables involved and the way that they relate to higher level structures of knowledge will be different in different contexts (Section 2.3), as this is what makes them *cultural.*

> *In more concrete terms, [the pattern of interaction between the microcosm and macrocosm] describes a system in which the local person cannot make decisions on local terms exclusively, but must consider the wishes and demands of people outside of his local system. In this sense, "complex societies" are not new, but have existed since the Bronze Age, and anthropologists have studied them all along without knowing it. One can visualize the irrigation farm in a Mesopotamian community, or a British farmer in the 18th century, alike coping with water masters, tax collectors, grain agents, landlords, and the politicians - and much as their descendants in 20-century North America cope with similar functionaries and agents* [Bennett, 1966: 443].

5.8. Summary

Bennett's recognition of the complexity of adaptation, strategy and response, as dependent on culture and context has resulted in the flexible *adaptive dynamics* framework. Thus it is ideal for the translation of ethnographic data to an agent-based model which focuses on adaptation. Frameworks such as those from business management literature (Section 2.4) or the use of evolutionary computational methods (Section 2.11.2) would be less useful approaches here. Most business models (and most modelling approaches) are not agent-focused, and thus are difficult to represent in an agent framework. That is, they do not capture the interactiveness of the situation (e.g. the *pattern of interaction* between the *microcosm* and *macrocosm*, and simultaneous local agent-to-agent interaction), and instead summarise this interaction in terms of a relatively macro-level effect. That is, they describe the emergent behaviour, and some of the inputs that are associated with the emergent behaviour, but cannot propose an adequate mechanism for the *relationship* or *interaction* between the inputs and the outputs other than resorting to various black boxes (e.g. social effects, culture, 'the market', 'competition'). The value of the agent-oriented approach is precisely where we cannot connect what we know to be true (or at least have evidence for) to the macro-phenomena before us. While we may have knowledge of primitive properties and behaviour, it is difficult to model this into macro-level phenomena solely on the basis of known primitive effects.

The value of ethnographic data is that it provides much of the information one needs to construct agent level models, and particularly where we have intelligent agents who need not deterministically follow given paths, this data is required. Traditional models and genetic algorithms can only operate on material patterns. They are less useful if we are concerned with the value-based patterns that are actually instantiated into behaviour, but where the action is for example, related to valuation, knowledge of alternatives and social goals.

Furthermore, the relevance of this particular theoretical framework to empirical observations is important for the results of the model to be easily understood and interpreted and for the number of assumptions to be minimised. The individual strategies which have primitive effects (delayed, immediate, sustained, multiplier), are constituents of larger processes known as strategic designs (incremental change, specialisation, action constraint, adaptive drift and resource competition) which bear some relationship to qualitative data on ecological and environmental adaptation. Since a strategic design is a series of steps composed of freely emerging, complex patterns of strategies which have primitive effects, the criteria by which Bennett describes observed empirical strategies according to their effects, means that unexpected variations may arise within a multi-agent environment.

As a result, Bennett's framework may provide a useful tool in aiding the transition from qualitative anthropological data to more formalised format, possibly for use in computer-based models such as multi-agent models. The ability it provides to *meaningfully* categorise qualitative data in a generic fashion makes it applicable in a range of situations assessing social change and its effects upon individuals and groups. Such a framework could illuminate important aspects of ethnographic data since it necessitates a sharp focus on the information that is collected. It potentially allows an analysis of historical change, lacking from some past studies on cultural ecology (Section 2.2) and thus the identification of transitional issues, which may usefully inform future adaptation. Indeed, by illustrating the comparative consequences of decisions taken, an assessment of whether new problems are generated by the use of old solutions is also possible. As a standardised framework it may also alleviate criticisms that micro-level studies cannot be generalised to larger areas or other geographic contexts (Section 2.2). However, in order to successfully translate the ethnographic data into Bennett's framework for use in a knowledge-based model, formalisation of the qualitative data was required. This was carried out using participatory knowledge engineering techniques which are described in detail in Chapter 6.

CHAPTER 6

Knowledge Engineering

One of the aims of this research was to evaluate the application of a variety of computer modelling techniques (Chapter 3), in order to better understand the interaction of social models (e.g. models of adaptive behaviour), with other, more well-understood models (e.g. crop or climate models) [Fischer, 1994] (Chapter 1). One such computer modelling technique incorporates methods used in ethnographic fieldwork with classical knowledge engineering techniques from computer science in order to alleviate weaknesses inherent in both methods. This provides a more participatory and robust process, from knowledge elicitation to knowledge representation, providing a greater clarity of the ethnographic data and thus possibly a greater understanding of social models of adaptive behaviour. The fusion of these techniques has resulted in a 4-stage process which incorporates consistent verification and validation on the data as it is collected. The application of this innovative methodology is successful precisely due to the mutual benefits that each technique provides by addressing current bottlenecks in both methods.

The dynamic representation of human intelligence is crucial since human behaviour, knowledge, experience and perceptions of risk are all factors which influence the decision-making process (Section 2.5). The techniques developed in the field of Artificial Intelligence (AI) have demonstrated capability as a modelling medium in this respect. The combination of a social model of formalised ethnographic data on adaptation, using AI techniques, with a model representing physical environmental processes, using a simulation may allow an analysis of the interaction of the models and a greater understanding of the processes involved (Section 1.4). The techniques described in the following sections allowed a greater understanding of empirical data through the computer-aided classification and formalisation of the knowledge elicited, with the potential to reveal new avenues for ethnographic investigation. Furthermore, the way in which the knowledge was elicited using ethnographic methods (Section 6.1) was crucial to the success with which the simulation functioned and the results it yielded (Chapter 9).

As discussed in Chapter 4, the knowledge acquisition phase of the research took the form of structured and semi-structured interviews with an expert in the agricultural field - a farm manager - tending between 1000 and 1500 acres of land (Section 6.1). Other farmers with businesses of a similar scale were interviewed to assess the representativeness of the chosen domain expert/ stakeholder and his ability as a key informant (Section 3.1.1). Further knowledge was elicited from the main expert using an interactive questionnaire (Section 6.3.1) and a survey (Section 6.4.1) was distributed to a sample of 20 farmers in the area, as a consistency check of the data that was being provided by the main informant. Relationships within the data produced from the computer-aided questionnaire, were identified through the use of a machine learning algorithm (Section 6.4.2). Analysis of output from the machine learning algorithm allowed the construction of decision trees which were used to create production rules for incorporation into an expert system using Jess [Friedman-Hill, 2001] (Section 3.5). These prototypical rules were further validated using an interactive learning program during interviews with the domain expert, to refine and prune the decision trees as necessary in an iterative process (Section). Hence, the knowledge engineering phase of the research lasted from 1998-2001 (Chapter 4) and the substages involved are depicted in Figure 15.

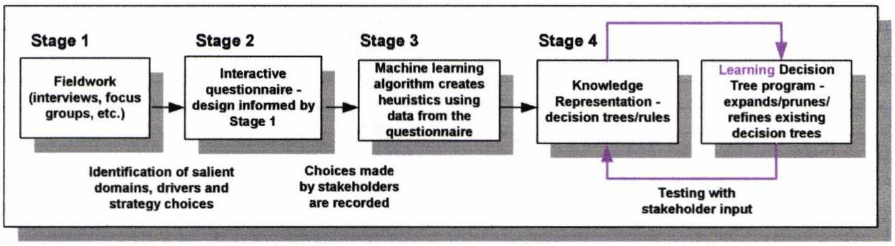

FIGURE 15. Stages within the knowledge engineering phase

6.1. Descriptive Elicitation

One of the key skills of anthropological enquiry is the ethnographic interview and the ability of the anthropologist to broach the realm of tacit knowledge, and make inferences based on what is said and observed without being influenced by his/her own cultural assumptions (Section 2.8 and Section 2.9). Furthermore, it is the role of the ethnographer/knowledge engineer to make generalisations and abstract statements based on these inferences, without distorting the terminology of the informant by expecting them do so. Part of the ethnographic process is knowing what questions to ask. However, formulating questions requires derivation from one's own cultural frame of reference, which may be different from the frame of reference the respondent uses to provide answers and thus distortion can emerge. Therefore, in ethnographic interviewing both questions and answers must be discovered *from* informants [Ellen, 1984, Spradley, 1979]. This is the significant difference between the interview that may be conducted by the journalist, and the ethnographic interview, where the former imposes a question based on a framework that is possibly very different from that of the domain expert [Ellen, 1984]. Furthermore the latter can often result in the discovery of new and unexpected areas as a basis for study as a result of 'tuning in' to local discourse in order to discover issues which enable the ethnographer to ask competent questions which will be meaningful to the informant [Ellen, 1984]. Recognising the value of anthropological approaches to knowledge elicitation and the implicit lack of assumptions about the expert's thought processes, Wooten and Rowley [1995] have utilised ethnographic methods, to facilitate the knowledge engineering process (Section 2.9). They undertook interviews with financial experts with the aim of creating an expert system emulating financial decision-making processes. Specifically they refer to methods used in the 'Wood and Ford interview model' [Wood and Ford, 1993] which is based on work by James Spradley [1979] (Section 2.9).

The first knowledge engineering phase in the Wood and Ford model [1993] (Section 2.9) is referred to as *descriptive elicitation* and should include the use of grand tour, case-focused and natural language questions in order to learn about the domain, language, cues and labels used by the expert [Spradley, 1979, Wooten and Rowley, 1995]. Grand tour questions are used to encourage the expert to talk about a usual sequence of events in the decision making process so that more about the domain can be learnt. Case-focused questions elicit specific examples from personal and second-hand experience, enabling the use of domain specific terminology. The aim of grand-tour and case focused questions is to learn key terms. However, often the expert may use simplified terms, for the benefit of the ethnographer/knowledge engineer, which is undesirable since this may not represent the terminology of the expert. Therefore, Wooten and Rowley used 'native-language questions' derived from Spradley [1979] to promote the use of terms that are relevant to the expert and his/her domain. This type of question encourages the informant to use terms most commonly used in the domain once domain relevant questions have been identified through descriptive questions [Spradley, 1979].

During the interview process, the combination of question types suggested by Wooten and Rowley during the unstructured interview phase meant that the knowledge engineer did not have to be very familiar with the domain, though enough to put the informant at ease. While familiarity with the domain could allow the knowledge engineer to broach the realm of *tacit knowledge*, that which experts usually find very difficult to put into words, too much knowledge of the domain can also introduce bias, and it is important that the informant always feels that he is the expert. Acquiring familiarity with the domain quickly is an obvious advantage, in developing key structured questions early in the development cycle, while at the same time not distracting the expert's train of thought by requiring explanations of terminology [Wooten and Rowley, 1995]. However, anthropological skill combined with the computer-aided tools described in the following sections are a powerful combination in attempting to acquire the tacit knowledge. This can then be formalised using traditional knowledge engineering techniques.

6.2. Structured Expansion

The aim of this phase was to try and expand one's understanding of the relationship between domain concepts and the organization of the expert's knowledge [Wooten and Rowley, 1995] or the cultural themes relevant to the domain [Spradley, 1979]. It required the expert to provide explanations for the grand tour answers given in the previous phase. Follow-up questions were asked to discover the decision network used by the expert. These structural questions were asked repeatedly in all the various possible contexts until the particular portion of the domain was exhausted. This involved relationship and contrast questions. Relationship questions are added to identify the cover terms (concepts) and the included terms (super-ordinate concepts) that make up the hierarchical relationships in the decision network. In addition, contrast questions are asked to elicit the relevant features and dimensions of these relationships. As in the experience of Wooten and Rowley, the understanding gained during the unstructured descriptive elicitation phase enabled one to know what contrasting questions to ask during the structured interviews.

6.3. Scripting

Process tracing and **protocol analysis** were implemented as part of the scripting phase to validate the knowledge that had been elicited during the previous interview phases. This involved an interactive problem-solving session whereby decision-making sequences were logged and could be subjected to protocol analysis, retrospective verbalization and used for follow-up interviews. According to McGraw and Harbison-Briggs [1989] the effectiveness of process tracing and protocol analysis depends on completion of the domain familiarization and conceptualization stages, as well as follow-up interviews to refine and clarify the analysis of the decision-making process. The processes suggested by Wooten and Rowley have been added as computer-aided elements during the knowledge engineering phase and will be explained in Section 6.3.1 to Section .

The unstructured and structured interviews that were conducted with the domain expert allowed familiarisation with the domain under investigation and enabled a modification of the **concurrent verbalization** method, where the expert 'thinks aloud'. This was achieved by carrying out a series of simulated scenario problem-solving tasks, using an 'interactive questionnaire', to identify important drivers in the decision-making process and possible recurrent cognitive principles, as advocated by Spradley [1979] (Section 2.9) (Figure 16) [McGraw and Harbison-

Briggs, 1989]. The data produced from the expert's responses to this task was then subjected to a machine learning/rule induction algorithm which created decision trees (Section 6.4.2) which were then independently evaluated against the data or by additional data collection (Section). This phase expands the declarative and structural knowledge found in the earlier stages and tries to discover the procedural knowledge used in solving the problem. Follow-up questions (aided recall), retrospective verbalization and cross-examination questions [McGraw and Harbison-Briggs, 1989], were asked after the task to find the reasoning behind the expert's decision structures.

6.3.1. Rapid prototyping with an interactive questionnaire

The aim of the interactive questionnaire (Figure 16) was to identify the dominant variables/principles which govern the expert's decision making process and to generate protocols, using a limited number of variables to simplify the domain. McGraw and Harbison-Briggs [1989] refer to this method as a type of **constrained information processing task** in which the expert's access to knowledge is restricted in order to determine what *specific* information is needed for their decision making.

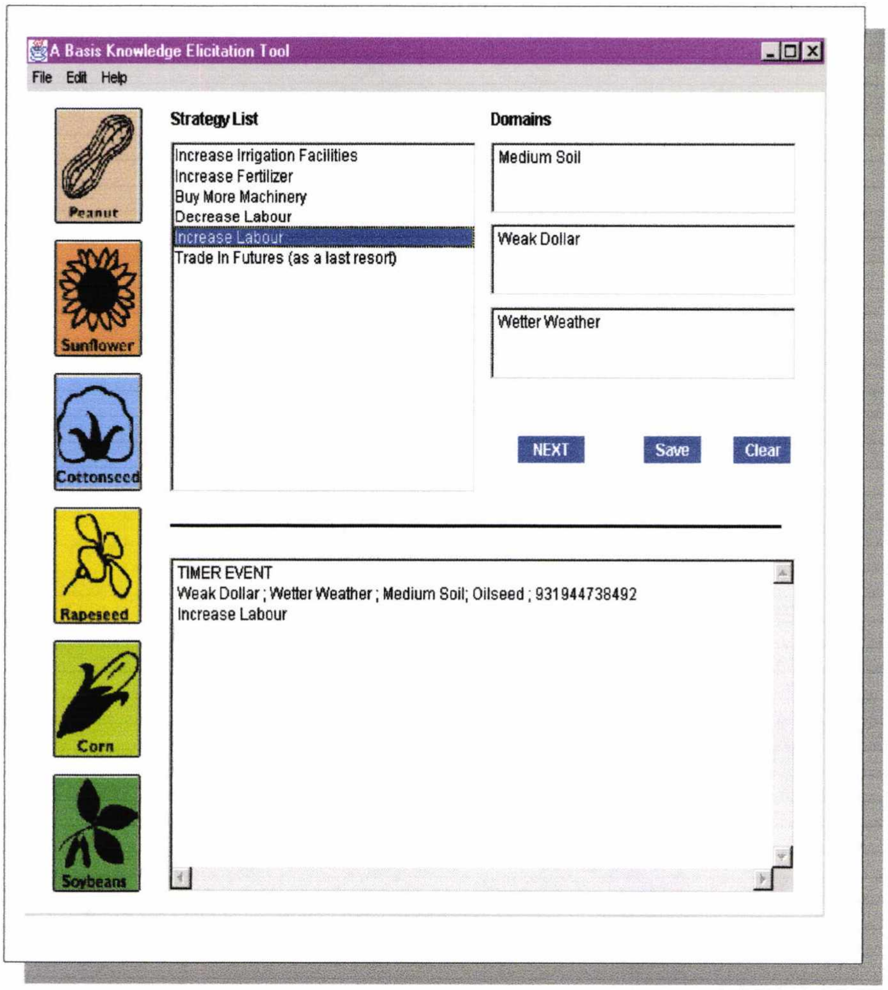

FIGURE 16. Screen shot of program used for process tracing.

The data produced (Figure 17) from the interactive questionnaire, enabled the identification of potential rules for the construction of a knowledge based system as shown in Table 11, after a process of rule induction (Section 6.4.2). The salient domains in the decision making process, which had been identified during interviews, were the environmental, economic, climatic and strategic domains. A *domain* is a range of possible enquiry space within which different variables used in the decision-making process can exist. The strategic domain contained expertise on adaptive options which was derived from discussions with the domain expert.

The program (Figure 16) represents various scenarios for the given domains each time it is prompted to do so by the expert, by clicking on the button for the next scenario at any point (this allows the expert to control the speed of the iterations allowing him as much time as required to consider his options and the given conditions). A crop choice (the goal) can then be made based on the given scenario, with an adaptive strategy, from the Strategy List, if this is necessary to grow the crop successfully in the stated conditions. The choices made under and each scenario are recorded in the log area shown in Figure 16. The program iterates the scenarios randomly and includes each domain incrementally. That is, in the first instance, only the variables in one domain are randomly iterated and the expert is prompted for his choice of crop. Subsequently, the other domains are individually explored. This is so that a base line of crop choices and strategic options for each set of conditions in each domain can be made. Eventually all domains are included in the scenario. This allows a fairly full and exhaustive exploration of the domains present, the possible crop and strategy choices and various decision pathways.

The crop categories that were included in the program were warmer climate crops (soya), main crops (wheat and vegetables), break crops (oilseed rape, peas and beans) and insurance crops (potatoes) since these crop options were considered by the domain expert in the area of interest in East Kent. The aforementioned domains of environment, economy and climate were chosen for representation in the interactive questionnaire due to their importance in the experts' decision making. Adaptive choices were made by the expert based on the constraints represented by each domain in random scenarios. Responses and time taken to respond were recorded during the constrained information processing task, both for future reference and for discussion. This data was translated into protocols using a machine learning algorithm to produce decision trees of the *possible* rules that exist within this domain (Section 6.4.2). This helped to identify propositional and decision-oriented knowledge that could then be analysed further during interviews.

It was necessary to confirm the configuration of circumstances which caused each adaptation strategy to be invoked. Thus this task provided a way to explore structural questions involving *verification* questions, such as domain, included term, semantic relationship and native-language verification questions [Spradley, 1979]. However, this did not replace the role of interviewing the informant since the interactive task allowed the identification of further structural questions for each domain and thus to discover any possible domain boundaries, since structural questions are specifically designed to test the ethnographic hypotheses that have emerged from domain analysis [Spradley, 1979]. **Retrospective verbalization** [McGraw and Harbison-Briggs, 1989] regarding the reasons certain choices were made, took place during further follow-up interviews.

Therefore, the computer-aided questionnaire was an automated method of exploring the relationship between domains and discovering the cultural themes which connect them, as described by Spradley [1979] (Section 2.9). Comparisons and contrasts among domains can help to reveal relationships which are often tacit and difficult to elicit otherwise. The fusion of the qualitative ethnographic and quantitative rule induction and refinement methodologies which are explained in Section 6.4.2 and Section further increase the probability of revealing this knowledge. However, before the process of rule induction could proceed, a further process of validation of the knowledge of the domain expert was undertaken.

6.4. Validation

Validation throughout the knowledge engineering process was important to ensure that the researcher's 'understanding' of the expert's knowledge was consistent and represented as accurately as possible. An attempt was made to validate the data from the computer-aided questionnaire using a survey that was distributed to other farmers (Section 3.1.3).

6.4.1. Survey data

The aim of this survey was to 'check' the data (as suggested by Wooten and Rowley's [1995] 'controls' and 'checks' (Section 2.9)), that was provided by the domain expert in the computer-aided questionnaire (Section 6.3.1) and during interviews (Chapter 4), to assess the representativeness of his knowledge as compared to that of local farmers [Ford and Wood, 1993]. The survey restated the structured information acquired from the computer-aided task and thus questions regarding crop choices were systematic and restricted in scope, since responses were required as a 'check' of the 'decision drivers' provided by the domain expert (see page 322 for a copy of the survey). A sample of 20 of the closest farms within the radius of the domain expert's farm were chosen as a result of a combination of *convenience* and *judgment* sampling. This was not necessarily a representative sample (see Section 3.1.3 for a discussion of survey methods), although it served the purpose of testing other farmers' knowledge in the same small geographical area, with similar and differing farming enterprises.

While 11 responses were returned, only 7 can be reliably documented here. Responses were from a variety of different farm types and farm sizes. Of these, 2 farms were above 1000 acres in size, in similarity to the domain expert, 2 farms were between 500 and 1000 acres (both

800 acres) and 3 farms were below 500 acres. All grew similar crops to the main informant such as cereals, oilseed, peas, beans and potatoes and some also grew sugarbeet, barley, linseed hops, fruit and vegetables.

The goal of most of the respondents in the survey was to maintain a reasonable living and not always to maximise profit (Table 7) as the domain expert had also indicated during interviews (Section 4.3.14). It was also clear that most were totally reliant on subsidies (Section 4.3.4) and several expanded on this by saying that they could not survive without them at present, and were looking for alternative sources of income (Section 4.5.13). An additional pressure for many of the respondents was their position as tenants on their land, in similarity to the domain expert, meaning that the rent they owed was an immediate cost and placed them at a disadvantage to other farmers who owned their own land (Section 4.5.12), particularly since the agricultural sector has been suffering such severe financial crises in recent years [MAFF, 2001, 2001a]. It was interesting to note that agricultural decisions were mostly influenced by family members but also by research stations, government policy and importantly the agricultural press (Section 4.3.10), possibly since this is also an indicator of public opinion e.g. in the case of GM crops (Section 4.3.8).

TABLE 7. General survey questions and responses

General questions	No. of positive responses
Inherited farm	3
Purchased farm	4
Rent farm	5
Always farmed	6
New to farming	1
Contract farm	1
Goal -maximize profit	3
Goal - maintain a reasonable living	6
Goal - keeper of the countryside	1
Goal - carrying on family tradition	3
Goal - develop farm for a successor	2
Motivation - enjoy farming	2
Motivation - be own boss	1
Motivation - pleasant living environment	1
Access to irrigation	5
Membership of farming cooperative	2
Membership of machinery ring	2
Reliant on subsidies	6
Influenced by family	4
Influenced by employees	3
Influenced by other farmers	2
Influenced by specialist adviser (research stations)	1
Influenced by government policy	1
Influenced by agricultural press concerning items of short- and long-term concern to decision-making	1

In terms of answers to the more systematic questions (Table 8) regarding the drivers of crop choices, there was agreement that a weak pound and a strong Euro were important for all export crops (as for any export product) (Section 4.3.3). There was some agreement with the domain expert that poor overseas production was also a good driver of crop choice, presumably due to higher prices because of increased demand (Section 4.3.6). However, the strength of the US Dollar was also considered a beneficial factor for oilseed rape while irrigation and labour were regarded as important for vegetables and potatoes.

TABLE 8. Factors beneficial to crop choices

Beneficial factors:	Potatoes	Wheat	Oilseed	Vegetables	Onions	Maize	Soya
Warmer weather		1	1		1	6	5
Cooler weather	1						
Wetter weather							
Drier weather	1						
Combination of all of the above at different growth stages		1	1	1	1		
Current climate	3	4	3	3	2	1	1
Must be bred with a shorter time to harvest						6	4
Strong pound							
Weak pound	2	6	4	4	3	4	3
Strong dollar		2	3	1	1	2	2
Weak dollar	1	1	1	1	1	2	1
Strong Euro		1	1	1	1		
Weak Euro							
Good overseas production	1						
Poor overseas production	3	5	5	4	3	4	3
Irrigation	3			4	2		
Extra labour	1			2		1	

Additional factors (Table 9) which respondents added themselves to the survey as important drivers for crop choices were the correct storage facilities for certain crops, the opportunity to learn about new crops before deciding to grow them (Section 4.5.5) and the recognition that more effective weed control would be required in a warmer climate (Section 2.7.3 and Section 4.3.5). Furthermore, the correct marketing of vegetables was reinforced as being crucial to providing a successful income from this crop choice (Section 4.3.5).

TABLE 9. Additional factors considered when choosing crops.

Additional considerations	Potatoes	Wheat	Oilseed	Vegetables	Onions	Maize	Soya
Correct soil type	3	2	1	3	1	1	
Cost of inputs	1						
Correct marketing	2	2	3	4	1	2	2
Correct harvest/ packhouse/storage system	1	3	1	1	3		
Drier autumns	1						
Crop rotation to avoid disease	1	1	1				
Machinery/financial return	1		1				1
Longer summer						1	1
Proximity to residential areas (could affect spraying and irrigating)	1						
Training and education on how to grow it						1	
Need to research the crop							1
Faster weed control						1	

Some of the comments in the survey (sometimes by multiple respondents) reflected discussions with the domain expert. These are listed in Table 10 and categorised according to the salient domains which were identified during the earlier interview phase.

TABLE 10. Factors considered important in each domain by respondents in the survey.

Market	Climate	Environment	Strategies
Emphasis of market forces changing agriculture rather than climate.	Winters are warmer and wetter than 20-30 years ago.	Soil type will become more important than at present for some crops with climate change, since fruits benefit from warmer springs, while some cereals and hops could be adversely affected by warmer winters.	The need for more powerful machinery for potatoes in a wetter climate.
Recognition of the costs involved in switching to warmer climate crops and the need for a market. Not just monetary cost, but risk, knowledge and market demand are required.	Change in crop direction will take at least one year (Section 5.5.2) and will only be considered if there were to be a consistent pattern of climate change.	Recognition of evolving role as 'keeper' or 'steward' of the countryside (Section 4.5.1) to provide naturally growing food in return for a reasonable living (Section 4.3.14).	Farmers are adaptive and reactive. They are used to change and always flexible.
Looking at other forms of income (Section 4.5.13) due to the loss of subsidies (Section 4.3.4).	Would consider moving from oilseed rape to sunflowers in warmer weather.		Fungicide is needed in wetter autumns.
Euro is as important as the US dollar in decision-making.	For shorter harvesting period in wet weather need more powerful machinery.		Storage and machinery are important factors in decision-making
Confirmation that money is being lost.			Research into crops is important
Motivation - love of farming and wanting to 'be your own boss'.			Decision-making is influenced by employees/ specialist advisers/ government policy/ family members and other farmers.

The survey reinforced many of the domain expert's responses to the computer-aided questionnaire (Section 6.3.1), and much of the discussion that took place during interviews with him (Section 4.2) and with other informants during initial interviews (Section 3.1.1). This supported the choice of the main informant as the domain expert, the general range of choices that he made during the computer-aided questionnaire (Section 6.3.1) and his reasons for doing so.

Once this process was complete the data from the constrained information processing task was subjected to a rule induction/machine learning algorithm. However, in order to continue to provide 'controls' and 'checks' on the data as a part of the validation and assessment phase advocated by the Wood and Ford [1993] interview model, a program to refine the data with the input of the domain expert was used in later interviews. This was to assess the completeness of the decision-trees generated by the rule-induction algorithm. This provided some validation of the understanding of the decision sequences and the relationships between key concepts [Spradley, 1979] gained during interviews. It allowed gaps in the knowledge space to be filled and it potentially enabled the realm of *tacit knowledge* to be probed.

6.4.2. Machine learning

The ID3 rule-induction/machine learning algorithm [Boden and Linåker, 1999] was chosen due to its ability to operate on non-numerical data. It is an algorithm which uses mathematical methods to identify recurrent relationships within large datasets by simplifying them. An important factor about the ID3 algorithm is that it implements exception based filtering. That is, it learns by forming rules and actively seeking instances that do not follow these rules. It then uses these exceptions to enhance its own understanding of the data set.

Data that was collected from the constrained information processing task session (Section 6.3.1), was re-formatted to represent a single goal attribute (Figure 17), in order for the ID3 rule induction algorithm to successfully build a decision tree for each goal. Consequently, the algorithm had to operate on several files of data, one for each crop type. As an initial stage in using the ID3 algorithm it was necessary to remove any 'noise' or conflicts from the data, since the algorithm fails to run otherwise. The ID3 program indicates where conflicts in the data reside, since data cannot be processed beyond a point where the same set of conditions produces two differing results. These conflicts were resolved by further consultation with the expert and adjusted accordingly, before implementation of the machine learning algorithm. In line with Wooten and Rowley's recommendations, this provided a further 'check' on the data collected and allowed further refinement with ongoing expert input.

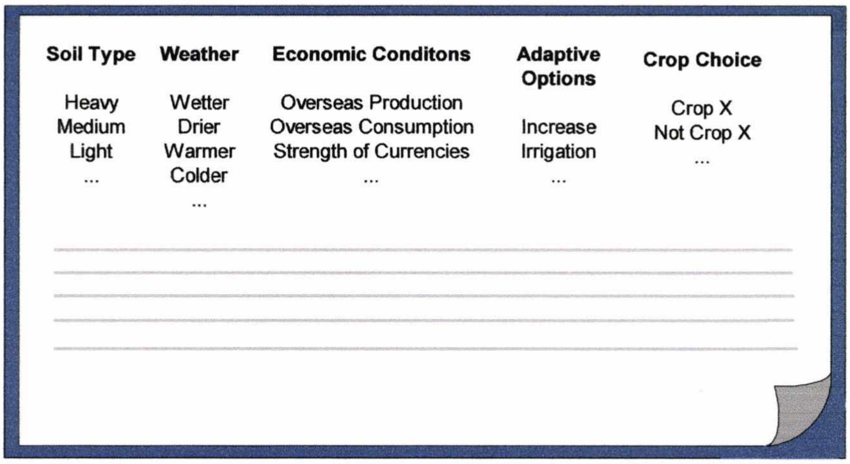

FIGURE 17. Questionnaire output formatted for input to the rule induction algorithm (one file representing one crop goal)

In order to process the data from the constrained information processing task into decision rules, a mapping file was created as guided by Boden and Linåker [1999] and shown in Figure 18. This creates values for each possible variable in each domain represented in the questionnaire output (Figure 17). A program written by Boden and Linåker [1999] uses the mapping file to perform an operation on the questionnaire output which converts all the data into values, which is then converted into a matrix for input to the ID3 algorithm.

```
% map file for cropChoice.dat

% skip the first line since it just contains header information
startline 2

% skip the first column since it just contains row numbering
1 skip

% column 2 is attribute Environment (soil type)
% referred to as attribute 0 (ATT0)
2 Heavy 2
2 Med 1
2 Light 0

% column 3 is attribute Weather (climatic trend)
% referred to as attribute 1 (ATT1)
3 Drier 4
3 Warmer 3
3 Wetter 2
3 Cooler 1
3 NoChange 0

% column 4 is attribute Economy (status of global economy)
% referred to as attribute 2 (ATT2)
4 PoorOSProd 8
4 NewConsumers 7
4 StrongDollar 6
4 WeakPound 5
4 WeakDollar 4
4 StrongPound 3
4 FewConsumers 2
4 GoodOSProd 1
4 MoveWorldPrices 0

% column 5 is attribute Strategy (required in order to grow the crop
successfully)
% referred to as attribute 3 (ATT3)
5 IncIrrigation 5
5 IncFertiliser 4
5 IncMachinery 3
5 IncLabour 2
5 DecLabour 1
5 TradeInFutures 0

% column 6 is the crop goal (which crop to opt for)
6 Veg 1
6 NoVeg 0
```

FIGURE 18. Mapping file

The output of the ID3 program creates decision trees of the form:

```
if ( ATT1 >=4.0 then
if ( ATT2 >=6.0 then ON )
ELSE OFF
```

FIGURE 19. Output of ID3 program.

This is then interpreted by referring back to the mapping file (Figure 18), and thus decision trees with the original qualitative domain values can be created. Figure 19 translates to:

```
If (weather = warm) then
if (economy = poor overseas production) then
Grow vegetables
```

FIGURE 20. Translation of ID3 output.

From the interviews and responses derived using the computer aided questionnaire and the subsequent decision trees created by the ID3 algorithm, the particular conditions under which individual categories of crops and strategies would be chosen became clear. These rules are summarised in Table 11, where some conditions are expanded to provide additional explanation.

TABLE 11. Rule conditions.

Crop Type	Weather	Economy	Overseas Production	Overseas Consumption	Strategy	Rule
Warmer climate crops	Warmer	A move towards world prices, so wheat, the staple cash crop, will be worth less.	If there are more overseas producers of wheat (e.g. Eastern Europe), wheat will also be worth less as a commodity, so it may be worth trying to grow more under-produced specialist crops.	Not a consideration as would be grown for the domestic market also. Less would have to be imported.		If **weather**=warmer and **economy**=lower wheat prices and **production**=high wheat production => **Grow warmer climate crops**
Cereals (Wheat)	Same or becomes warmer	-	Poor overseas production	More overseas consumers. E.g. Near Eastern countries may become big consumers, as they want to upgrade from a rice to a wheat diet. However, they may try to grow their own wheat initially.	Machinery	If **weather**=same or warmer and **production**=poor overseas production **consumption**=high overseas consumption and **machinery** is available => **Grow wheat**
Potatoes	Same/ warmer weather	Strong pound	Unimportant as this is a domestic crop, although poor European production of other crops would increase prices.	Domestic consumption	Irrigation, labour and specialist machinery	If **weather**=same or warmer and **economy**=strong pound **production**=poor European production of other crops and **specialist machinery** and **irrigation** and **labour** are available => **Grow potatoes**

Crop Type	Weather	Economy	Overseas Production	Overseas Consumption	Strategy	Rule
Vegetables	Warmer and milder winters	Weak British Pound lower costs of production allowing farmers to be more competitive with European producers	Poor European production	More overseas consumers.	Irrigation and labour	If **weather**=warmer or milder winters and **economy**=weak pound **production**=poor European production **consumption**=more overseas consumers and **irrigation** and **labour** are available => **Grow vegetables**
Break crops (Oilseed)	Same/ warmer/ wetter weather	High prices for oilseed require a strong US Dollar. Lowering grain prices.	Poor overseas production	More overseas consumers.		If **weather**=same or warmer or wetter and **economy**=strong dollar or low cereal prices **production**=poor overseas production **consumption**=more overseas consumers => **Grow oilseed**

The prototypical rules generated using the rule induction algorithm were validated using published evidence [e.g. Nix, 1998], expert judgments and further computer-based tools (Section 6.4.3) with the expert during follow-up interviews. In Wooten and Rowley's example, validation of the knowledge elicited was achieved by revisiting domain experts and running the financial expert system with them. When this process was repeated with independent experts there was agreement by all participants agreed with the recommendations of the program. In the process described here, further validation of the rules created using the ID3 algorithm, was achieved using a 'learning decision tree' program to refine the decision trees and fill gaps in existing knowledge.

6.4.3. Learning Decision Tree Program

A learning decision tree program, adapted from an example provided by the developer of Jess [Friedman-Hill, 2001, Russell and Norvig, 1995], helped to confirm a consistent understanding of the domain, and was chosen as a further method with which to validate the rules produced by the ID3 algorithm. This was due to the ability of the learning program to accept new information from the expert and refine incorrect rules.

The 'learning' program incorporated the existing decision trees produced by the machine learning algorithm (Section 6.4.2) as 'facts' using the Jess script. The program poses each decision tree as set of questions to the domain expert (Figure 23), to see if s/he agrees with the rules and the outcomes. Therefore, when run with the expert, if a decision was reached in the tree (a leaf node), it was validated by consultation with the expert. If the expert believed the answer to be correct, nothing more was done as shown in Figure 21.

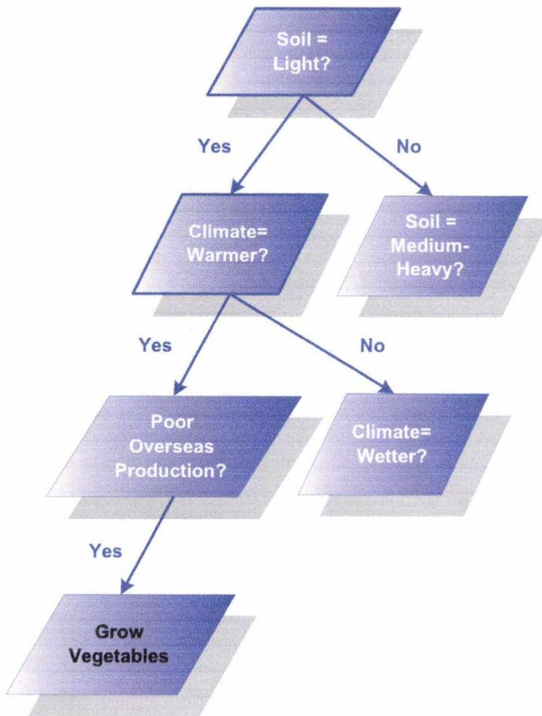

FIGURE 21. Crop choice identification decision tree

If, when running this scenario, the expert regarded the conclusion as incorrect, he was prompted for the correct response and the incorrect node was replaced with the correct answer. However, in certain instances, it was clear that gaps in the knowledge elicited remained and outstanding conditions were left out of some of the rules, which may be correct only to a certain point in the tree. Thus, the expert could be asked for a distinguishing question, which when answered 'yes' would separate the incorrect response from the correct one. The decision tree was then modified to accommodate both the additional condition to achieve this new inference, as well as the old answer. That is, the answer node was replaced with a decision node that contained a question that differentiated between the old answer and the right answer. Therefore, the old rule is refined and updated and a new rule is created. Figure 22 illustrates an example derived from one such successful consultation session with the domain expert.

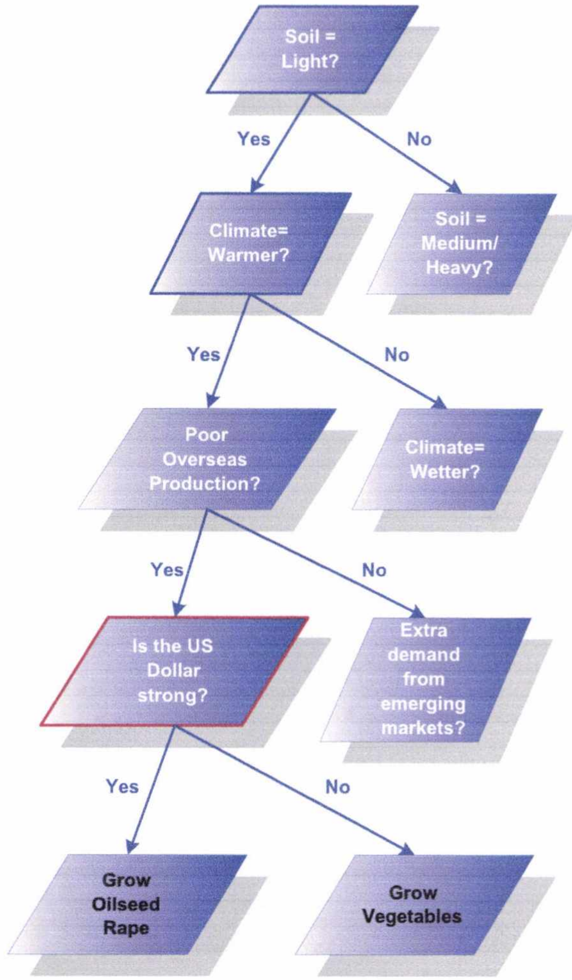

FIGURE 22. Crop choice identification decision tree after learning

This allows an opportunity for the domain expert to update and refine the rules, producing a new file of decision tree data. In this example, the old rule for growing vegetables (which is missing a crucial condition), is updated and a new rule for choosing oilseed rape is created. This is the final phase in validating the data elicited from the constrained information processing task. The output of the 'learning' program is shown in Figure 23.

```
"Is Soil is light?"
Yes
"Is the climate is warmer?"
Yes
"Is overseas production poor?"
Yes
"Under these conditions, I suggest growing Vegetables"

"Am I correct? (yes or no)"
No
"What is the crop?"
Oilseed

"What question when answered yes will distinguish Oilseed from
Vegetables?"
Is the strength of the US Dollar strong?

"Now I can guess Oilseed"
"Try again? (yes or no)"
```

FIGURE 23. Output of the learning program from a Jess example provided by E.Friedman-Hill [2001].

It is in certain instances that, at this point, the realm of *tacit knowledge*, which is often omitted or considered unimportant or 'common-sense' by the expert (and thus difficult to elicit by other methods), may be accessible. For example, in this case, after the rules have been modified, the vegetable rule may be correct, but even if it is not, the 'learning' process can continue until the correct new information is elicited from the expert. In the case of vegetables, an additional condition that would be required is the availability of irrigation and therefore this entire process could be repeated until this gap in the decision tree is filled.

While it has been important in creating this knowledge engineering process to maintain engagement with the domain expert, the reduction of bias and validation has been equally important. In relation to this, an additional advantage that has emerged from the 'learning' phase is that the expert is much more comfortable and willing to criticise a computer program if the knowledge represented is inaccurate, rather than 'correcting' the researcher/knowledge engineer, with whom a relationship may be established by this time. Therefore, the 'learning' program also provided some form of detachment from the data and encouraged robustness and additional 'checking' of the knowledge elicited [Ford and Wood, 1993].

Similar work has been done by Robert Reynolds [2001] and is referred to as Incremental Decision Tree (IDT) methodology (Section 2.9.1), although there is less participatory domain expert involvement in this method. However, this may be due to fact that so far it has only been used to analyse an archaeological record (Section 2.9.1). In the process described here, it has been important to maintain the involvement of the domain expert in entire knowledge engineering process, from acquiring the data to refining the resulting decision trees, to fill gaps in existing knowledge and to potentially reveal areas of tacit knowledge (Section 6.4.3).

6.5. Possible rule structures

The rules generated using a combination of protocol analysis (Section 6.3.1) and machine learning techniques (Section 6.4.2), mainly took the structure of **Elimination by Aspects** (Figures 24 - 26) and **Disjunctive Decision** (Figure 27) rules. These structures can also represent the pre-attentive phase of decision making as mentioned by Murtaugh and Gladwin [1980] (Section 2.10). The lexicographic rule is referred to by Burton [1993] as 'ordered choice' (rank ordering of attributes according to importance) when describing the way individuals approach the decision-making process. The **Elimination by Aspects** rule combines aspects of the **lexicographic** technique and **conjunctive** rules [Tversky, 1972, McGraw and Harbison-Briggs, 1989] and is the same as the boolean minimization technique used by Read and Behrens [1989].

An example of a type of generic framework using 'Elimination by Aspects' methodology (Section 2.10) is shown in Figures 24 - 26 which divides possible crop options into groups to which further reasoning could be applied [Furbee, 1989]. While this is constrained by the knowledge engineer's understanding of the subject matter, further work could usefully investigate whether such a series of generic questions could be applicable in different geographic and socio-cultural contexts.

TABLE 12. Description of rule types. Source: McGraw and Harbison-Briggs, 1989.

Lexicographic Decision Rule	***Conjunctive Decision Rule***	***Elimination by Aspects Rule***	***Disjunctive Decision Rule***
This rule is a simple rank ordering of attributes of each alternative according to importance.	The activation of this rule depends on selection criterion values for each critical attribute and discarding any alternative that has even one attribute that does not meet the preset criterion value.	The expert specifies a set of criterion values for each attribute that is critical to an alternative.	A specific set of criterion values is also specified for this rule, but focuses on the selection of an alternative in which at least one attribute exceeds the criterion while all others fall equal to or beneath the criterion value. This rule describes any tree structure.
The expert rank orders attributes of each alternative, listing the most important attribute first.	The expert identifies a set of criterion values for each attribute that is critical to an alternative.	The expert rank orders the attributes of each alternative, listing the important attribute first.	The expert specifies a set of criterion values for each attribute that is critical to an alternative.
The expert compares the most important (e.g. top-ranked) attribute of each alternative.	The expert compares the values of the attributes for the chosen alternative with the set of criterion values. The value of the chosen alternative attributes should equal or exceed the criterion value the expert initially set.	The expert compares the values of the rank ordered attributes.	At least one attribute associated with an alternative must exceed the criterion value for the alternative to be acceptable.
The expert selects the alternative that is most attractive or the most important attribute.	If an alternative fails to meet the criterion on any attribute, it is removed from consideration.	If the attributes for an alternative do not equal or exceed the **conjunctive criteria** for its attributes, the expert eliminates it from consideration.	All other aspects of other alternatives can be equal to or fall below the criterion values.
If two aspects of this attribute are equally attractive the expert compares the two competing aspects of the next most important attribute.		The expert repeats the procedure with attributes that fall lower in the **lexicographic order** to eliminate alternatives whose aspect values do not equal or exceed the conjunctive criteria.	

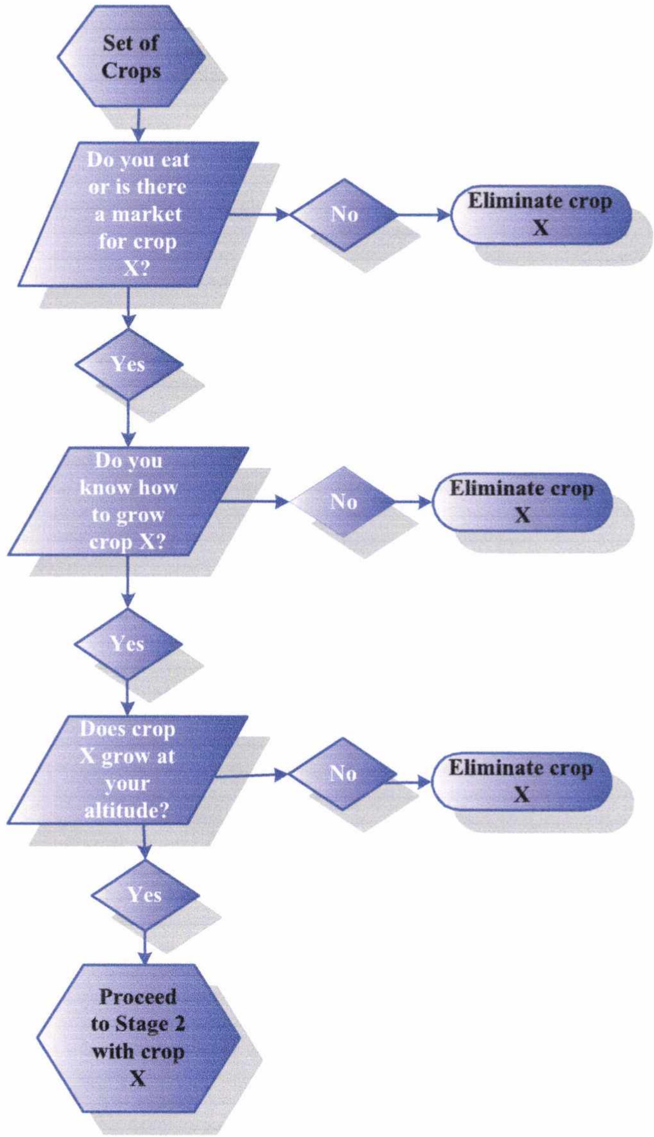

FIGURE 24. Stage 1 - Elimination by Aspects - Assessing general attributes. Adapted from [Furbee, 1989].

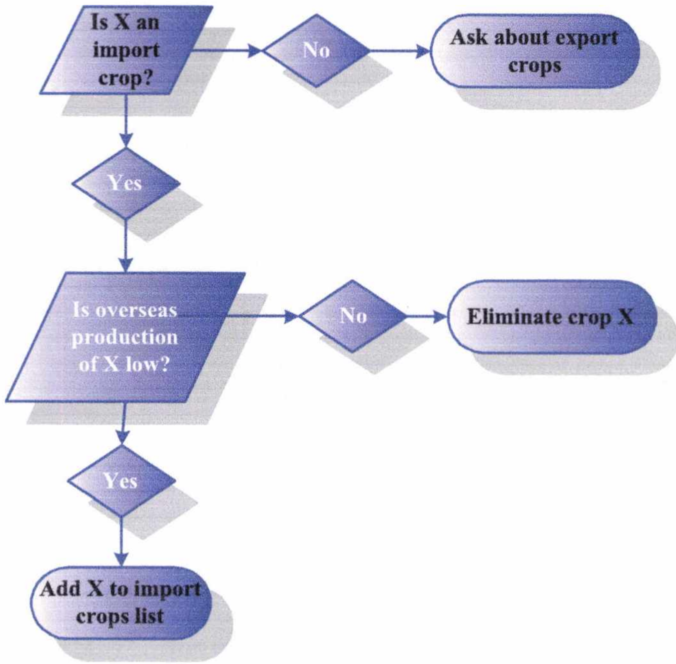

FIGURE 25. Stage 2 - Elimination by Aspects - Import Crops. Adapted from [Furbee, 1989].

FIGURE 26. Stage 3 - Elimination by Aspects - Export (weak Sterling), Domestic (strong Sterling).

6.5.1. Disjunctive Decision Rule

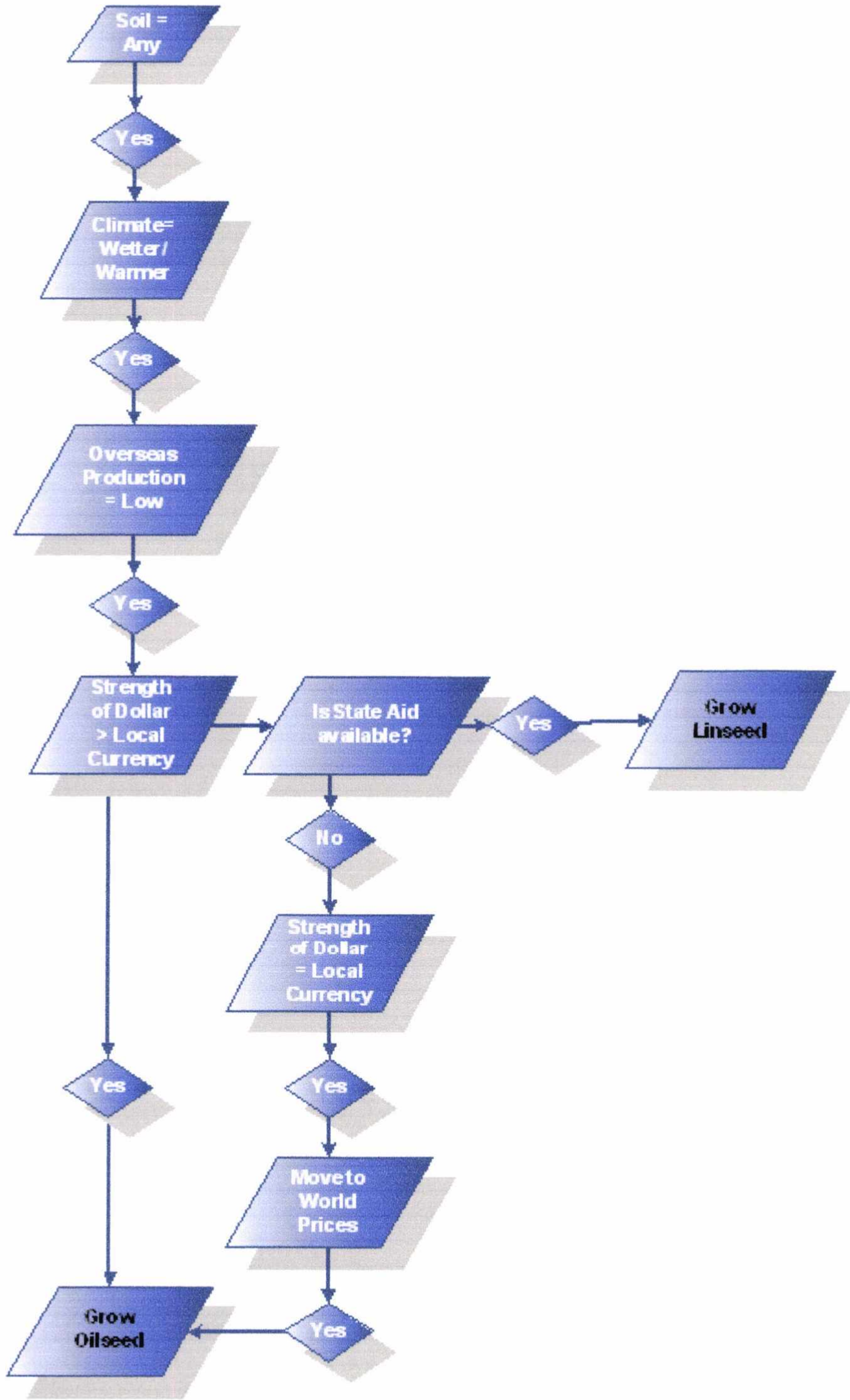

FIGURE 27. **Decision tree for oilseed rape generated by machine learning.**

One advantage of using the 'elimination by aspects' methodology for analytical purposes is to understand the *possible* 'pre-attentive' or unconscious phase of decision making [Murtaugh and Gladwin, 1980] (Section 2.10). Furthermore, it allows the potential dissection of a knowledge base into phases, which can be triggered separately depending on socio-cultural and geographic constraints and the crops remaining in the crop set, after the options in the 'elimination by aspects' phase have been exhausted.

This example rule set was mainly used to analyse the results of the ID3 algorithm rather than in the knowledge base in the final model due to the possible constraining effects it may have had on the outcome [Gladwin, 1983]. The model required freely emerging options due to the use of Bennett's framework (Chapter 5) and this required as few restrictions as possible on the input data. That is, the classification of the complex patterns of strategies which emerged was appropriate *after* the decision-making phase (according to Bennett's definition of the relationship between variables and structures of choice), but not prior to it. Therefore eliminating sets of options from the outset would limit the potential results that could emerge from Bennett's framework. Nevertheless, the 'elimination by aspects' methodology has much potential in future work due to the possibility to configure knowledge bases to differing socio-cultural parameters, which may also provide an important contribution to other work (e.g. see Dent's suggestions in Section 1.2).

6.6. Summary

A combination of anthropological and ethnographic methodology to collect qualitative data fused with knowledge engineering techniques to formalise this data has been usefully employed in this suite of tools to better understand domain knowledge. This method provides the potential to provide clarity to qualitative data, to reveal new avenues for enquiry and to broach the realm of tacit knowledge. All of this is achieved while remaining engaged with the domain expert and enabling his involvement in the entire process, from elicitation to validation. Furthermore, the fusion of these techniques is a valuable process in the construction of non-aggregated agent attributes in agent-based systems, when attempting to understand the interaction of socio-cultural and environmental models (Section 1.4). By identifying recurrent cognitive principles within different domains (Section 2.9) using the interactive questionnaire (Section 6.3.1), it is possible that processes of interaction between differing social models can be identified via the cultural themes which connect them [Spradley, 1979], particularly when analysed within an agent-based framework. Chapter 7 will describe some of the design considerations in the model, how the formalised observed ethnographic data can be incorporated into an agent-based simulation using Bennett's theory of adaptive dynamics and the features of the model which have been implemented.

CHAPTER 7

Design

This chapter will discuss features of the observed target system that have been incorporated in the design of the model using the participatory knowledge engineering process (Chapter 6) to create rules from ethnographic data (Chapter 4), and Bennett's theory of adaptive dynamics (Chapter 5) as a tool which with to interpret the model output. The features of the model that have been implemented and the nature of the interaction between agents in the both the Adaptive Dynamics and the Learnt Adaptive Dynamics Model will be discussed (Section 7.5). Details on the tools used to develop the models will be provided (Section 7.8), such as how the decision rules from the knowledge engineering process have been embedded in an expert system shell, Jess [Friedman-Hill, 2001] (Section 3.5), and interfaced with the Repast simulation toolkit [Collier, 2001] (Section 3.4). Other data which were required for the model and the sources from which they were derived will also be documented (Section 7.8.2).

The aim of the Adaptive Dynamics Model (ADM) was to abstract a system of farmers with strategies which were adaptive and non-adaptive with respect to changes in the environment to learn about successful strategies at an individual and group level and resulting behavioural dynamics (Chapter 5), based upon ethnographic evidence (Chapter 4). The parts of the target system which were represented were empirical data on adaptive strategies, income, investment, cost and hours of labour, climatic information and data on crop water requirements as stated in Chapter 3.

A salient feature elicited during interviews with the domain expert and during the knowledge engineering process, was the importance of not producing a commodity which was already oversupplied by European and overseas producers. That is, to do something different to one's competitors - to grow a crop that was in demand, to ensure as far as possible, high prices. This is even more important in the current climate where agricultural crop prices are consistently declining [MAFF, 2001, 2001a]. This requires knowledge and understanding about overseas production which was included in agent behaviour in the ADM in a simplified way using Bennett's strategic design framework, where agents reacted to the specialisation (Section 5.6.5) of other agents/competitors by choosing different crop options.

However, a further strategy that became evident during interviews was the propensity to copy the successes of one's peers, as observed in other ethnographic contexts [Henrich, 2002] (Section 2.11.4). Thus, the Learnt Adaptive Dynamics Model (LADM) introduced a method for the spread of successful strategies within the system to emulate copying behaviour from successful neighbours (Section 4.3.10). This model simulated interaction between two agents, who became adaptive as a result of weights which were derived from the results of the ADM (Section 7.7). It was hoped that the LADM might improve the results of the ADM and provide a better understanding of the behaviour that was emulated, to provide new insights which could be applied back to the understanding of the ethnographic context. Thus the models utilised data from empirical observation (Chapter 6), anthropological theory (Chapter 5) and data from external models (Section 7.8.2).

7.1. Analysing and validating anthropological simulations

As Fischer points out, simulations predating the use of computers have long been used by anthropologists to validate our analyses against observed ethnographic data, to explore the properties of our proposed models of understanding and to extrapolate them to new situations [Fischer, 2002] (Section 1.3). Simulations are often used to model situations which are not otherwise practical or easily investigated. They have been used by anthropologists in various contexts ranging from models of ceremonies and rituals by Ellen [1984], to simulations of prescriptive or preferential marriage [Fischer and Finkelstein, 2002] and the creation of improvisational music based on ethnographic rules of composition [Kippen, 1998]. While simulation techniques may not be appropriate or desirable in certain social research situations they have great potential when considered within the context of their limitations. The advantages of knowledge-based multi-agent simulations for anthropology have been discussed in Section 1.3 and Section 2.11.5 and they are in large part due to the ability to create populations with qualitative data and structural relationships between individuals rather than creating a population and individual agent characteristics as simple aggregates as has been the case in the past [Fischer, 2002]. In this way, much of the rich qualitative ethnographic data at the anthropologist's disposal can be usefully incorporated into such models and analysed.

However, as Edmonds points out in his criteria for improving work in Multi-Agent Based Simulations (MABS), such models can only be justified if they do what we design them for, such as predicting outcomes in target systems [Edmonds, 2002]. Indeed, Fischer [2002] writes that in the past few years simulation results based on anthropological fieldwork have been usefully applied back to the field with promising outcomes such as Stephen Lansing's work in Bali [Lansing, 1991] (Section 2.11.5). The aim of the model described here is not to predict outcomes but to better illuminate one's understanding of the observed ethnographic data that has been collected, using an anthropological theory of adaptation within an agent-based modelling environment. This may not lead to an entirely correct or exhaustive understanding of adaptation within the agricultural domain, but it can provide new and unexplored avenues for investigation, enhancing and complementing the reflexive anthropological research process. Furthermore, it is proposed that this understanding may emerge from an interdisciplinary analysis of the *interaction* of the different social, environmental and economic models and domains which influence behaviour [Fischer, 1994, Spradley, 1979] (Section 1.4).

When using simulation as a technique, two errors posed by Dyke [1981] must be avoided [Fischer, 2002]. Firstly, Dyke refers to *methodological* error which is the process of over-elaborating simulations in the effort to replicate the real system to the point that it is difficult to analyse the interaction of the simulation elements. Secondly, *heuristic* error refers to the assertion that a simulation is an accurate representation of the target system. It must be noted that any similarity between observed simulations and target systems does not necessarily mean that they operate on the same principles but that there is some degree of *logical similarity* between the processes in the simulation and in the target system [Dyke 1983 from Fischer 2002]. In other words the aim is for more or less logical equivalence between the processes in the simulation and the target phenomena - that is, within the limitations of the represented (simulated) system, the simulation should produce results consistent with the target phenomena. Only then, can one attempt to identify the commonality, if any, between the components of the simulation and the target phenomena.

Furthermore, while it is possible to simulate using only qualitative objects and structures, the evaluation of such simulations is often more complex than that of quantitative simulations especially with respect to validation (Section 9.1). The main reason for this is that parameters may be descriptive categories and the qualitative simulation focuses on the relationships between categories and objects where the structure is as important, if not more so than the content [Fischer, 2002a] (Section 1.4).

Specifically, complex adaptive systems are groups of agents involved in the process of *coadaptation* where adaptation taken by individuals at the micro-level, has consequences for the whole group, at a macro-level. The dynamic of interest is the ability of agents taking part in the adaptive process to self-organise, or to produce order which does not have a simple reductionist component. For example, having established that there was cooperation among individual Balinese *subaks* (local water sharing units), Lansing [1991] used the concept of 'ecological feedback' in a complex adaptive system to explain the *persistence* of cooperation among the Balinese rice farmers. Additionally, Lansing [2001] used a 'utility function' to explain the emergence of cooperation in a system where interactions produced rewards and punishments (e.g. Section 2.11.1).

The models described here explore whether there exist simple integrated patterns of cooperative adaptive behaviour [Henrich, 2002] (Section 2.11.4) based on the ethnographic evidence that has been included in the model. Bennett's framework for adaptation allows the analysis of individual micro-level adaptation (Section 5.5) and its effects at the macro-level (Section 5.6).

7.2. Design considerations

The use of an agent based model is presently the best way to replicate the effects of decision making strategies of multiple individuals over time, and to simulate the various implications and consequences that result from these interactions. Bennett's model facilitates an analysis of these interactions (Figure 14). An important design principle in the Adaptive Dynamics Model (ADM) was that individual agents were not constrained to specific group membership as in the Emergence of Organised Society (EOS) model [Doran et al., 1994, Gilbert and Troitzsch, 1999]. However, they possessed adaptive or non-adaptive (sceptical) attributes which determined the strategies they adopted. It was the specific *strategies* that were chosen by the agents that became cooperative and positive or constraining and negative. Similarly, simple strategies were not classified or grouped in any way, except as described by Bennett (Chapter 5), allowing any potential patterns of overall adaptation/strategic designs to emerge freely, and thus classifications and groupings to be expressed. As mentioned in Chapter 6, the desire to maintain as little constraint on the evolving strategies as possible, was the reason for deciding not to use Gladwin's Elimination by Aspects Methodology (Section 2.10, Section 6.5) at this stage, although it was experimented with.

The EOS model allowed agents to be autonomous and reason about the micro-properties that they were able to perceive in their local environment, and from this reasoning and the consequent action, macro-level properties emerged. But Gilbert asserts that since the agents had no means of perceiving the macro-properties which emerged, the model as a whole failed to accurately simulate the decision-making capabilities of human societies, and hence his suggestion that more sophisticated models of human interaction are essential in the simulation of human societies. The inclusion of Bennett's framework in the model, and specifically the effects of the emergent strategic designs (macro-level effects) go part of the way to allowing agents to reason about them, since it is the effects of strategic designs to which they react.

However, a key point that should be noted is that the design of this model has not followed all conventional agent-based modelling techniques (e.g. the inclusion of spatial aspects). For example, resources are not represented in a spatial sense but the modifications to Bennett's framework allowed warnings to be issued when a strategy/resource became over-utilised or 'specialised in' (Section 8.3). Though there were a lack of spatially distributed resources in the model this was not an essential feature, since resources in particular, such as irrigation and labour are not shared between farmers in the ethnographic context in reality and thus their use is of no significant impact to other farmers (however, see Lansing [2001] for an example where subsistence rice farmers in Bali *are* affected by the use of local irrigation sources by their neighbours). The purpose of this model was to formalise the ethnographic data and to analyse the resulting dynamics of interaction between strategic choices within the theoretical framework of adaptive dynamics, rather than attempting to predict the use of a particular resource.

7.3. Linking the case-study and the model

As mentioned in Chapter 4, in the area under investigation in south-east England, vegetable farming was in abundance in the 1970s and 1980s. According to the domain expert, the 1980s were extremely profitable years in farming using this strategy. However, a significant shift in cropping patterns (with the domain expert and others) occurred during the 1980s to arable farming (though, some farmers did remain niche specialists in vegetable production due to favourable environmental conditions in Kent (Section 4.2)). The domain expert reports that this was due, in part, to new and costly storage regulations that were introduced for the preservation of vegetable crops. However, he also associated the shift in prices with the fact that European producers could be very competitive in the British market, producing the same goods in larger quantities and with lower costs of production (Section 4.3.6). Hence a shift of production ensued from specialist vegetable cropping to arable farming due to a combination of factors which included the competition of other producers. Throughout this change over however, an insurance crop was grown and served as a risk reduction mechanism.

Agriculture is an adaptive and flexible enterprise since it often has to react to frequent changes in the financial arena as well as the (usually) less frequent and more gradual changes in climate. However, translating the features of a complex society into computational terms is highly complicated and while resulting models are inevitably simple abstract representations of the target system, this may allow an analysis of the interaction of system components, as suggested by Fischer [1994] (Section 1.4), which might otherwise be obscured [Gilbert, 1995]. This also serves to avoid the methodological and heuristic errors mentioned by Dyke [1981] (Section 7.1).

Based on the understanding of the ethnographic context, individual farmer agents in the ADM were designed to represent key aspects regarding options for crops and adaptive strategies. Prominent factors affecting decision-making included the labour, irrigation or machinery dependence of each crop. Irrigation levels were compared with crop water requirements (based on temperature and rainfall data) for the decision-making scenarios which evolved in the model. Clearly there were assumptions regarding agent behaviour, motivation and cognition

(Section 7.7.1). For example, non-adaptive agents were assumed to be different because they would not include *new* warmer or wetter climate crops in their decision-making. However, crops that were classified as new options due to wetter autumns or springs for example, might be considered by a 'non-adaptive' farmer in the real world, simply responding to gradual changes in the long-term. Therefore, in the model it was assumed that they would continue with traditional crops but may adopt winter or spring sown varieties instead, which is in fact a more realistic (observed) gradual adaptive mechanism.

The use of the adaptive dynamics framework allowed the configuration of these strategies over time to become classified, via the rules in the knowledge base. The key strategic design of sustained resource competition (Section 5.6.6) was taken to be a performance measure for the simulation as this represented sustained competitive behaviour. It encapsulated the empirical dynamic identified during interviews where farmers often attempted to do the opposite to their competitors and be *unique producers*. In the LADM, the dynamic of copying one's neighbours was also introduced to see if the performance of the ADM altered. If this was the case, it was important to understand how, as this might provide further understanding of the *interaction* of different behavioural models and sub-models [Fischer, 1994] (Section 1.4) and the identification of *integrated patterns of adaptation* [Henrich, 2002] through the effects that the combination of competing (ADM) and copying (LADM) dynamics had.

Using this minimal set of features and interactions has advantages and disadvantages. Clearly, much of the complexity of the real world situation is lost. However, as mentioned, this may possibly allow the explication of social phenomena that would otherwise remain indiscernible in a more complicated model [see Gilbert and Troitzsch, 1999, and Fischer, 2002 who address this issue]. Nevertheless, the conclusions of a study such as this remain constrained in their interpretation as a result of this process of simplification. These limitations and the features which could enrich the model further are discussed in Section 8.4.

7.4. Decision-making models

Parallels and comparisons with other models of decision-making and choice are useful to compare with that which is proposed here. Writing about specifically about hazard adjustment, Burton *et al.* [1993] noted that some generalisations are possible about the relationship between the process of individual and collective response. While coping mechanisms serve to reverse or minimise negative effects and enhance productivity during hazard adjustment, individuals are restricted by the limits set by their communities or nations which in turn face collective decisions in responding to hazard, again guiding the actions of their individual members [Burton *et al.*, 1993]. It is this linkage between individuals and neighbours and the larger community, institutions and markets which increases insecurity due to the uncertainty involved in predicting the actions of others, and thus the requirement to act with incomplete information which, as Wilson and Gilligan [1997] state distinguishes 'strategy', which can be adaptive, from a 'long-term plan' (Section 5.3). However, in certain situations the wider community allows the spread of risk and thus increased security (this is demonstrated by the results of the models underlying this research where copying behaviour reduces the need for trial and error and reduces the *perceived* risk involved in making new decisions (Section 9.7.2)).

Burton et al. [1993], like Bennett (Section 2.3), conclude that while the process of collective choice appears unordered by variables specific to each scenario, at the global level, particular patterns exist and that while 'the mix of constituents changes, the direction does not'. Burton writes, 'the task of hazard management involves a careful selection of strategies that will combine individual, community and national action in the most effective way possible. A decision at any one level must be understood in terms of its likely effects at other levels' [Burton et al., 1993]. Furthermore, as is the aim of agent based social simulation [Gilbert and Troitzsch, 1999], Burton *et al.* [1993] assert that emergent phenomena in the form of macro-level properties at the community and national level, in turn create new theoretical possibilities at the individual level.

Indeed this feedback between collective and individual choice is that which is addressed in the LADM, where agents copy *adaptive* agents while retaining some diversity to possibly maximise competitive potential, *combining strategies in the most effective way possible* as stated by Burton *et al.* [1993]. Furthermore, while the mix of strategies changes, the direction of change does not [Burton et al., 1993] since the system tends toward an adaptive state (Section 7.7). The competitive (global) behaviour in the ADM and the copying (local) behaviour in the LADM represent two possible levels of decision-making and their *interaction* at different levels to investigate whether new theoretical possibilities *are* created at the individual level [Burton et al., 1993] (Section 9.8).

7.5. General model features

The main features that were implemented in model will be described in the following sections. The *interaction* of social models of adaptive capacity with environmental models to potentially illuminate processes of successful and sustainable behaviour and the way in which different structures of knowledge relate to one another requires an analysis of adaptive and non-adaptive behaviour.

7.5.1. Agent attributes

As mentioned, aside from the observed ethnographic data on crop choices and farm management strategies, the desire of farmers to produce something different to their competitors in order to increase the chances of growing high value crops, was also included at an abstract level. That is, a modification to Bennett's framework was included where the specialisation (Section 5.6.5) of a particular commodity by an agent resulted in other agents growing different crops, to retain a competitive advantage.

However, in addition to this, some of the strategies that were discussed with the domain expert had uncertain costs within the context of Bennett's model, resulting in the tension between the desire to alter one's strategies and the inability to do so due to the investments that had already been made in the chosen strategy. The tension produced by this paradox was also reflected in the model where in most cases, choices did not become sustained (Section 5.6.6), or where some agents continued with the constraining strategy at the possible risk of future vulnerability (see Section 8.3 for modifications to Bennett's model).

The internal model of each agent contained the rules for each decision and strategy it could take and these differed slightly depending on whether the agent was adaptive or non-adaptive (sceptical) with respect to climate change. The main difference was that a non-adaptive agent would not grow *new* warmer or wetter climate crops - crops that are chosen as a direct result of changes in annual/seasonal temperature or rainfall (Section 4.4.2). The rules contained conditions for the soil, climate and economic requirements of each crop choice. Decision-making regarding crops revolved around their individual specialist requirements such as labour, machinery or irrigation needs (Section 4.4) all of which incurred differing social (negative and constraining effects which increase future vulnerability) and economic costs. In the model, the effects of various decisions were visible at different points in time, and this was a crucial factor relating to an analysis of the adaptive process, and Bennett's requirement regarding the need to observe adaptation over the long term (see Section 5.4).

An ideal rational agent would take actions that would maximise its performance measure. Although the goal-based agents in the ADM did not necessarily operate in the most efficient way, their actions represented the decision-making criteria of the domain expert as understood by the knowledge engineer (Chapter 6). This would not necessarily maximise profit, although the types of crop choices made and the order in which they were taken was implicitly designed to minimise potential loss as explained by the domain expert (see Section 4.4.3 on the order of crop choices and page 151 on the 'prevention of loss' strategy).

7.6. Adaptive Dynamics Model (ADM)

The specific features of agent interaction in the ADM (Figure 28) are described below for comparison with the extension to the model in the LADM (Figure 31).

7.6.1. Interaction between agents

The ADM can contain up to 100 adaptive and non-adaptive agents in total, which react according the rules in the knowledge base, which are based on ethnographic data and the desire to produce something that is in demand. Agents chose strategies that met their goals given percepts which included their 'memory' of past strategies as well as changes in the environment. The two types of agent represented in the simulation were either adaptable to a changing environment using new technological inputs (that is, willing to invest in new, warmer climate crops for example) or non-adaptive utilising a more restrictive range of strategies and crop choices (Section 4.3.11).

Bennett's classification of cyclical resource competition (Section 5.6.6) was used as a performance measure since it represented sustainable competition by meeting all of the criteria set out in Section 5.4. This category represented sustainable competitive individual choices made over time under the restrictions of limited irrigation and capital. One time-step in the simulation represented one decade, in line with the climate data used, and since resource competition was measured over 3 decades, it was a comparatively longer term measure than the other strategies in the knowledge base. Thus it was an ideal performance measure since it was an objective value which was external to the decision-making process and was measured over the long-term fulfilling the requirements set out by Bennett [1976]. Resource competition is similar to the process of 'coadaptation' mentioned by Lansing [2001] (Section 7.1).

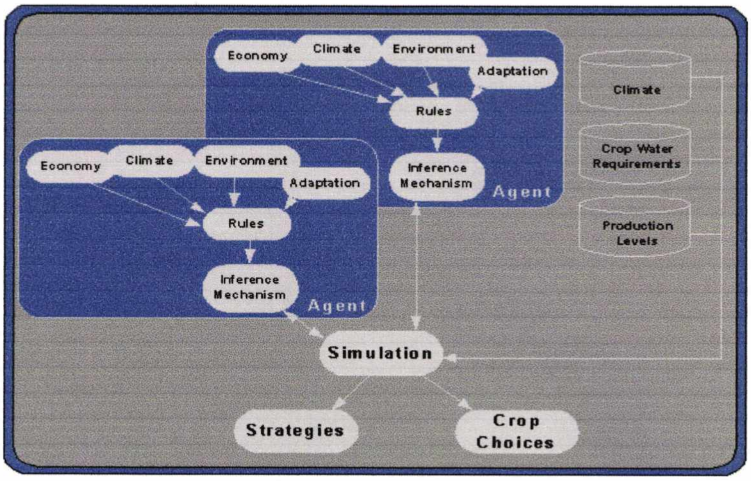

FIGURE 28. **Agent attributes (ADM)**

The emergence of a cooperative regime depends on the spread of a community of self-reinforcing strategies. Differing types of emergence are determined by the type of strategies available to the agents, the pattern of interaction among them and the processes operating that create, destroy and transform agents [Cohen et al., 2001]. Thus, the potential emergence in the system can be understood by conducting an analysis of these three factors.

7.6.2. Selection mechanism

Agents in the ADM were replaced by agents of the *same type*, each decade if

a) they did not have enough irrigation resources to make their ideal crop choices,

b) they could not meet the criteria of creating enough income to pay for the necessary inputs (labour) required to make their crop choices or

c) suitable crop choices could not be made given specialisation/over-supply of a crop by another agent.

These criteria resulted in different successful systems in the ADM. The occurrence of sustained competition was compared in homogenous (adaptive *or* non-adaptive systems) and heterogeneous (an equal mixture of adaptive and non-adaptive agents) systems composed of 16 agents with constant parameters of irrigation and capital (Section 29). In systems that were limited by finance, the homogeneous adaptive system achieved the highest degree of sustained competition since more agents had the option of the low-investment, low-irrigation 'warmer climate crop', soya (which could only be chosen by adaptive agents) as opposed to vegetables, which were expensive to produce (because of the high labour cost) and thus made it difficult to break even on the high levels of investment required. In systems unrestricted by irrigation or capital the heterogeneous system was most successful since it did not become constrained by the large range of options that incurred *uncertain* costs that were possible in a homogeneous adaptive system, under the same conditions of unlimited access to irrigation and capital.

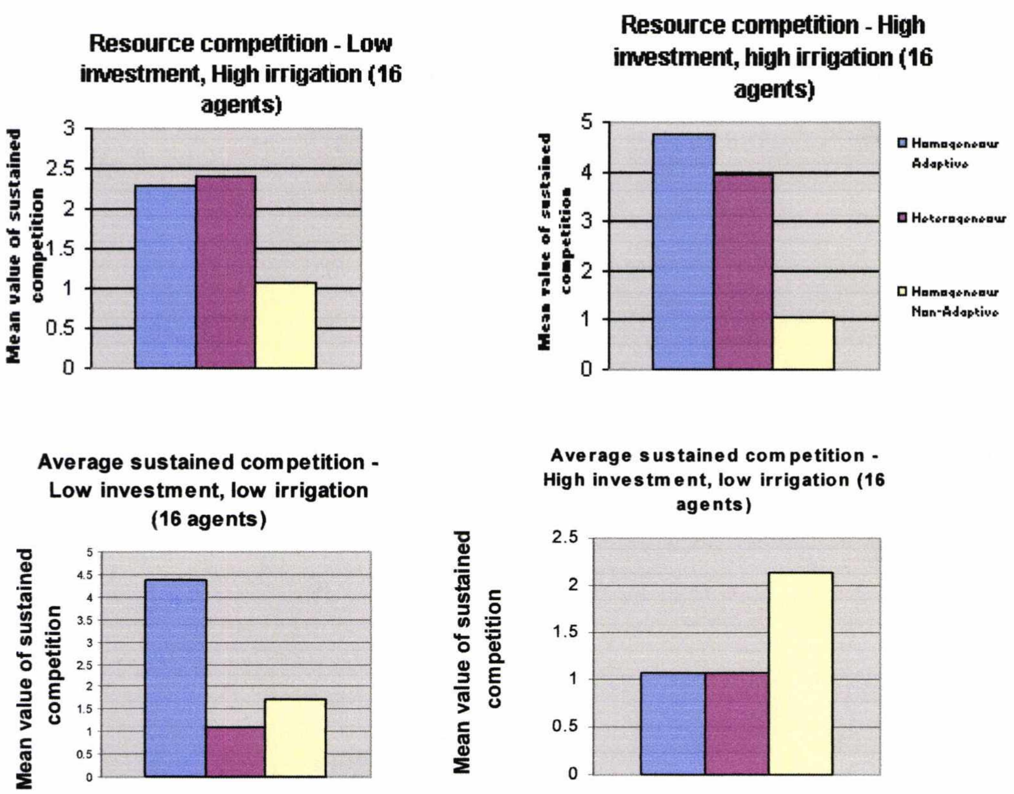

FIGURE 29. Comparisons of levels of sustainability in each system.

Analysis of the types of strategies chosen (Section 9.2) showed that non-adaptive agents in the heterogeneous system reduced the constraint of strategies which were more likely to have uncertain costs which were mainly chosen by adaptive agents. However the adaptive system succeeded in most other scenarios.

Therefore, in order that the advantages of both the adaptive and non-adaptive agent could be exploited further and to include the empirical observations of farmers' willingness to copy the successful strategies of their peers, these values were used to construct 'weights' for the LADM where agents would copy their successful peers and thus a heterogeneous system would tend towards a population of adaptive agents. In this way, 'successful' sustainable strategies could be investigated more thoroughly. The matrix of weights was of the form:

	Adaptive	Non-Adaptive
Adaptive	2,2	2,1
Non-Adaptive	1,2	1,1

FIGURE 30. Pay-off matrix

7.7. Learnt Adaptive Dynamics Model (LADM)

The salient feature that was evident from interviews apart from the desire to produce something productively different from one's competitors, was to copy the successful strategies of one's neighbours (Section 4.3.10). This has been observed by anthropologists in other ethnographic contexts and it has been argued that this cannot simply be reduced to rational economically-motivated behaviour. The cultural transmission of ideas over time by selectively copying certain individuals which generate successful integrated adaptive behavioural patterns has been studied by Henrich among Mapuche farmers in south-central Chile [2002] (Section 2.11.4).

While the type of farmers in this study are somewhat different to the subjects of Henrich's research, particularly in terms of their increased awareness of weather and price dynamics within their decision-making, their ability to make cost-benefit analyses is still limited by the incapacity of human beings to take account of the large number of variables involved in such calculations, as well as by memory bias. Furthermore, the decision-making of the large-scale western agriculturalists is also affected by personal beliefs and values and not just economics (Section 4.3.10, Section 5.4). This is highlighted in the similarity with which the planting of barley may be re-adopted in the Mapuche case-study, while soya may be introduced in Kent as a result of biased cultural transmission from higher status individuals (such as from expert crop advisers and the results of crop trials, Section 4.5.5, Section 4.3.11) or through social networks (Section 4.3.10).

This is because there is a high level of uncertainty and thus a high 'cost' associated with 'experimentation' and copying one's peers is perceived to remove some of this risk.

Thus, Henrich suggests that people who interact with the environment may possess well-adapted behaviour because of simple rules such as 'copy the most successful individual'. This context-specific heuristic generated by biased cultural transmission over several generations was included in the LADM, where agents 'copy adaptive individuals', since these were defined as successful under most circumstances in the ADM (Figure 29). This aspect of behaviour was included to see if it improved the performance of agents in the ADM who were *not* influenced by peer strategies, and if so, *in what way.* Henrich [2002] notes that the ability of individuals to learn by observation can allow the accumulation of large integrated patterns of behaviour without the need for tedious experimentation through trial and error. Furthermore, research on social learning within psychology shows that humans have the ability to infer abstract behavioural rules directly from observed behaviour. The significance of the influence of peers as well as cultural norms, religion and tradition on crop choice, area allocated, cultivar selected and thus the pattern of farming was also stated by Dent (Section 1.2 and Section 2.6) since these factors ensure to some degree the costs and output from the farm [Dent and McGregor, 1993].

7.7.1. Interaction between agents

Since, the set of operators or knowledge and action available to the agents remained unaltered, the LADM was identical to the ADM except that there were weighted preferences towards achieving an adaptive system (Figure 31). As mentioned, these weights were derived from values of sustained competition achieved in the ADM (Figure 30) and was a simplified way of sharing of knowledge on successful strategies. Sustained competition was a good indicator of system stability since a high value would indicate that agents were able to make sustained choices within their constraints of irrigation and starting capital and survive.

There is a large amount of literature on the use of Game Theory (Section 2.11.1) and recently work has been done on incorporating Game Theory into multi-agent social simulations (for example, Van der Veen [2001] has used it to establish the conditions necessary for cooperation to emerge in an entire population rather than among single dyads in the context of behaviour based on loyalty, the accumulation of wealth and so on). Lansing [2001] has used Game Theory to extend his earlier work in Bali [Lansing, 1991]. In the real world such 'learning' through a 'game' may be analogous to learning from the experiences of other farmers and other agricultural experts or being influenced by successful crop trials (see Section 4.3.10, Section 4.3.11 and Section 4.5.5 for examples of this).

The game theoretic extension to the Adaptive Dynamics Model (ADM) to emulate copying behaviour and conformist transmission (Section 2.11.4), was developed using an example of the Iterated Prisoner's Dilemma game provided by Cederman and Gulyas [2001] which implements the core functionality of Cohen, Riolo and Axelrod's [1999] Prisoner's Dilemma modelling framework. This provided the additional layer in the LADM (Figure 31) emulating copying ('tit-for-tat') behaviour (see "Appendix B"). Agents interacted on a fixed spatial grid with their immediate neighbours (i.e. the von Neumann neighbourhood) as the default, though this feature could be altered to include interaction with random agents, due to functionality provided by Cederman and Gulyas [2001]. Thus, the LADM consisted of a network of agents distributed on a 2-D lattice where more non-adaptive agents would become adaptive each time step, though some amount of variation in the form of non-adaptive agents was retained, also as a result of the weights.

In the ADM, agents were goal-based, responding to percepts and actions, making crop choices based upon the restrictions of irrigation and capital and breaking even on the investment resulting from their choices. In addition to this, agents in the LADM were utility-based to some extent, and thus attempted to maximize their own utility which was dependent on the weights defined in the payoff matrix which, in turn, was based on the competitive behaviour in the ADM.

The LADM allowed agents who had random distributions of irrigation and capital to dynamically alter their receptivity to climate change events over time, which was not the case in the ADM. Previously unsuccessful agents were replaced by other agents of the same 'type' - adaptive or non-adaptive - depending on the composition of the system being observed (Section 7.6.2). However, the game theoretic matrix encouraged agents to be replaced by the agent type which performed the best in the previous game, according to the pay-offs defined by the matrix. Therefore agents altered their type with respect to what needed to be achieved to produce a successful system relative to the ADM. Thus with the pay-offs used (Figure 30), the system tended towards an adaptive system, with agents copying *adaptive* peers, as these were defined to be successful. This aimed to explore the apparent benefits of both the heterogeneous and homogeneous adaptive systems under differing constraints in the original ADM (Figure 29).

With reference to assumptions in the LADM in particular, it is useful to address the criticisms of other work described by Edmonds [2001]. Thoyer et al. [2001] developed a bargaining model simulating negotiations between water users conforming to the French water law of 1992. This required collective and local negotiation of water regulations in each river sub-basin. One of the main criticisms of the model was that the structure of the weights used in the modelled negotiation process was arrived at by assumption and did not resemble the empirical negotiation process in large part because it took the form of a sequence of games which were solved backwards. These limitations led to unsatisfactory conclusions and prediction on unseen data unlikely [Edmonds, 2001].

The value of the model described here is that the structure of the weights in the LADM were based on the results from the ADM which was based on a abstraction of empirical decision-making collected from the domain expert and other sources (Chapter 4). Thus, while the weights do rely on assumptions regarding farmer behaviour, motivation and cognition, reducing their possible complexity to a simplistic structure, they also have some indirect empirical basis as encouraged by Edmonds [2001]. That is, the performance measure used in the ADM to construct the weights - the value of sustained competitive behaviour - was tested as a result of a lack of capital and/or irrigation using constant parameters in the ADM. Since realistic values for capital and irrigation requirements were used, the value of sustained survival as a result of decision-making behaviour had an empirical basis, and thus the results of the ADM provided a weighting for the LADM. However, any conclusions may only be drawn within the assumptions and limitations created by this framework and the theory of adaptive dynamics, within which the model is embedded. Nevertheless, the methodology described aims to explore the insights that may be gained from the reflexive process of using a theoretical basis to formalise empirical data, for representation in a computer model, with the aim of improving one's understanding of the ethnographic context, possible creating new areas for inquiry in an iterative process (Section 9.8).

Furthermore, the weights represented very simple imitative behaviour of agents in the system and aimed to represent how different decision-making model structures relate and correspond to each other (Section 1.4). Empirical observations regarding local copying (LADM) and global competing (ADM) decision-making were taken into account and in this sense agents within the model were autonomous since the optimal decision for an individual agent to take and its consequences on the group as a whole were not explicitly programmed into local agent rules.

It should be noted that the ADM represents a type of model derived from empirical observation that could be deduced from evidence, much as ID3 or other algorithms are able to do. However, the LADM represents a formal framework for representing rules/information that might have been derived. This is important for two reasons. Firstly, it eases the transmission of the kinds of knowledge and experience required to derive the empirical rules. It is easier to transmit if only the weights and outcomes have to be transmitted. However, it is difficult to transmit the weights if that is all that one has. Secondly, the framework places a set of logical constraints on the relations of the weights and outcomes to each other. That is, if one weight changes, others must change also - there are internally defined consequences to making one choice over another (for an example of this, see Lansing's work [2001] described in Section 9.6.1, where the cooperative network of Balinese rice farmers responds effectively to the introduction of a new crop or pest). The formal framework provides an ongoing basis for 'self-checking' based on internal criteria for evaluating and adapting one's understanding of the situation within which one is competing/cooperating. Thus, any anomalies or misunderstandings that may have occurred in the transmission of the knowledge can be adjusted in the light of new information and experience, without having to completely re-derive the whole system.

Of course, this is *not* to suggest that the specific formal framework used in the model is the same as that which might be culturally transmitted, but merely that it has some logical relationship with a cultural model (Section 7.1). The presence of a formal model may indeed be what makes cultural transmission in general possible, since the presence of an internal criteria for evaluating relationships provides a means to account any significant degree of commonality in a population (Fischer [2005] presents a lengthy discussion of this idea).

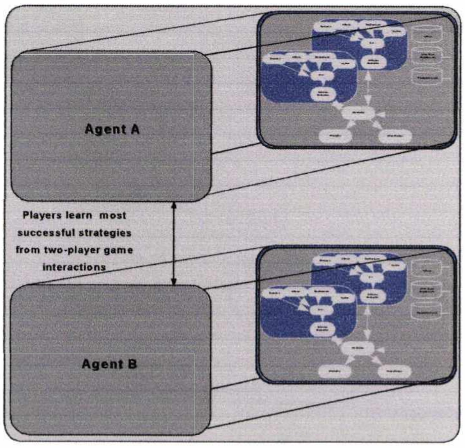

FIGURE 31. Agent interaction in the LADM.

7.7.2. Selection mechanism

As mentioned, choices made by agents were indirectly subjective 'expected utility' methods using bounded rationality. That is, at a low level, the preferences used as a basis from which 'selection' was made, were derived from strategies that were perceived as 'best' from the experts' 'subjective' point of view. However, the additional goal in modelling this domain involved a further judgement regarding the best course of action (e.g. sustained competition (Section 5.6.6) using Bennett's framework), in addition to the goal of choosing the maximum incremental return or minimising loss. The natural selection of agents in the LADM was an important dynamic which allowed the propagation of competitive strategies, particularly as a result of the effects of strategies which resulted in uncertain costs. This interaction will be explained in greater detail in Section 9.2.3 and Section 9.3.3.

7.8. Model development

After a survey of agent-based modelling software (Section 3.3) it was decided that RePast (Section 3.4) and the Java Expert System Shell (Jess) [Friedman-Hill, 2001] (Section 3.5) would be used for this research (Figure 32). The use of the example of the Iterated Prisoner's Dilemma game provided by Cederman and Gulyas [2001] required some customisation of the code to include the relevant agents and the interfacing between Jess [Friedman-Hill, 2001] and the RePast [Collier, 2001] based model. The qualitative nature of Bennett's classification (Chapter 5) of the basic subject matter in cultural anthropology and human ecology within the adaptive dynamics framework virtually pre-determined the decision to use an expert system for this study, to retain the descriptive features of the qualitative, ethnographic data as far as possible. However, as also discussed in Section 3.5 since the target system contains rules with many similar conditions and multiple outcomes a rule-based system is the best method with which to avoid many if-then statements. It allows qualitative categorisations from Bennett's model to emerge freely with potentially a minimal amount of computer code.

7.8.1. Description of the Java Expert System Shell (Jess)

The initial figures necessary for calculations in the model are 'stored' in RePast and retrieved as facts, by the expert system, by exploiting Jess's use of Java's Reflection API to implement 'store' and 'fetch' mechanisms between Java and Jess. This data is kept separate since the Java code in the simulation can be easily changed and potentially updated with new data for different crops, climate or production scenarios (e.g. in future work) while allowing the rule-base in Jess to remain as stand-alone as possible. This flexibility is one reason that Jess was chosen as it provides almost seamless integration with the Java-based simulation framework (Section 3.5). As each time step in the simulation represents one decade, the corresponding values for climate, production, temperature and precipitation are retrieved by Jess.

Java Beans are used to store agent attributes such as individual income, investment, frequency of strategies that are chosen, climatic and productive information. In contrast these values are 'stored' in Jess and 'fetched' by RePast to be recorded while the simulation is run in 'batch-mode' or 'GUI-mode'. The model can be run in both modes though GUI-mode can result in slow performance during runs with a large number of agents. Batch-mode has parameter file reader capability allowing variables to be altered via a text file as they would be via the graphical control panel, in GUI-mode (see "Appendix B" for information on how to run the model).

The Jess API is written in Java and serves as an interpreter for the Jess scripting language. This language is similar to that used by the CLIPS expert system shell, and therefore resembles LISP syntax. Like CLIPS, Jess uses the Rete algorithm [Forgy, 1982] to enhance performance. The Rete algorithm works by creating a network of nodes, forming a 'pattern network' and a 'join network', and provides enhanced performance and efficiency due to 'sharing' of nodes between both networks. As a result of this, the performance of Jess can be hindered if the rules are not written correctly, as this can lead to many partial matches of the rules if the order of the patterns on the left hand side of a rule is wrong as this affects the storage requirements of the Rete algorithm (Table 13). The rules which were generated using the ID3 machine learning algorithm (Section 6.4.2) and tested during follow-up interviews (Section 6.4.3) were translated into the Jess scripting language for inclusion in the knowledge base.

The Rete algorithm is designed to improve the speed of forward chaining rule systems by reducing the computation required to resolve a conflict set after a rule is fired by remembering old states and allowing the firing of a rule to change only a few facts and thus only a few rules are affected. However, while the speed of inferencing can be improved the Rete algorithm has high memory space requirements. This can be optimised by writing rules efficiently as illustrated in Table 13. The main convention to be followed when writing rules is that the most specific conditions should be at the beginning of the rule. The Rete network eliminates duplication between rules and also allows parts of the network of complied rules to be shared. A Rete network eliminates duplication over time, modifying itself after addition or deletion of data representing the saved intermediate state in the process of testing for the satisfaction of rule conditions.

TABLE 13. Example of rules

Rule which will result in efficient pattern matching	Rule which will result in inefficient pattern matching

`(find-match ?x ?y ?z ?w)`
`(item ?x)`
`(item ?y)`
`(item ?z)`
`(item ?w)`
`=>`
...
	`(item ?x)`
	`(item ?y)`
	`(item ?z)`
	`(item ?w)`
	`(find-match ?x  ?y ?z ?w)`
	`=>`
	...

One Rete object was instantiated for every agent and facts shared between them by saving and loading new assertions. An alternative way in which to manipulate multiple agents with multiple rule sets would be to use the defmodule construct available in CLIPS. However, this was not yet implemented in the version of Jess used to develop this model. It should be noted that multiple Rete engines reduce performance which is why the model can run slowly with large numbers of agents particularly in the graphical mode.

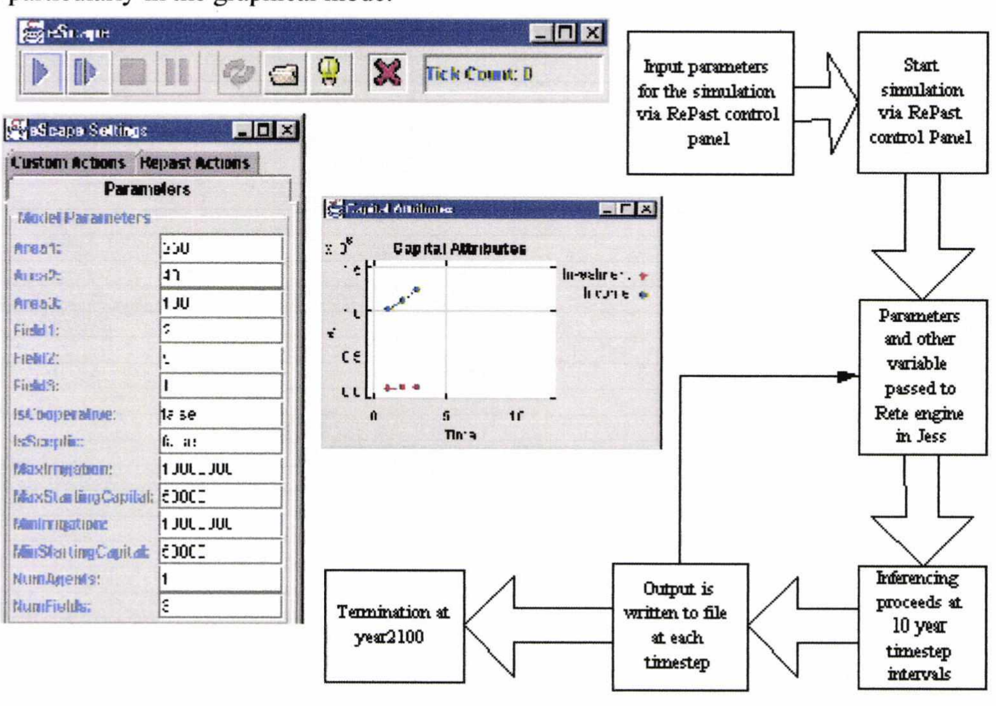

FIGURE 32. Processes when running the RePast/Jess model and acquiring results.

7.8.2. Data for the model

Two types of climate-related data were used in this analysis - crop water requirements (CWR) and general climate data. Crop water requirements were derived using CropWat [FAO, 1999], which is software provided by the United Nations Food and Agriculture Organisation (FAO). This software is accompanied by a database of climate data for over 140 countries. One possibility for the acquisition of climatic data was to use data from analogue sites in Europe whose weather patterns will most likely correspond with our own in the next few decades if global warming takes place, which is referred to as Forecasting by Analogy (page 39) [Glantz, 1991]. However, using simpler methods which were more appropriate to this research it was decided that a collection of historic and predicted future climatic data could be accessible using a program which generates climate scenarios. The use of large scale Global Circulation climate models (GCMs) is not appropriate since the objective of this research is to establish general patterns of adaptive behaviour under general climatic and socio-economic conditions, and it is important that the differences in these conditions are precisely understood. This can be achieved using a simpler climate generation model, which uses the data from GCM experiments. Using this methodology it may be easier to observe possibilities for and implications of adaptation given the behaviour that will be evident under specific conditions in the artificially generated model since these conditions can be controlled. This model will help to reveal the combinations of pure and mixed strategies that are undertaken.

7.8.3. Climate data

Thus, after an analysis of several pieces of software, the decision to use the climate generator application SCENGEN [Wigley, 2000, Hulme, 2000] - a global and regional scenario generator, was made. This is a database containing the results of a large number of GCM experiments. Almost all of the datasets used by SCENGEN have been used or assessed in different Intergovernmental Panel on Climate Change (IPCC) assessments. Figure 33 to Figure 38 illustrate the differences between baseline historical mean annual daily temperature and precipitation and predicted levels for 2100 generated by SCENGEN [Wigley, 2000].

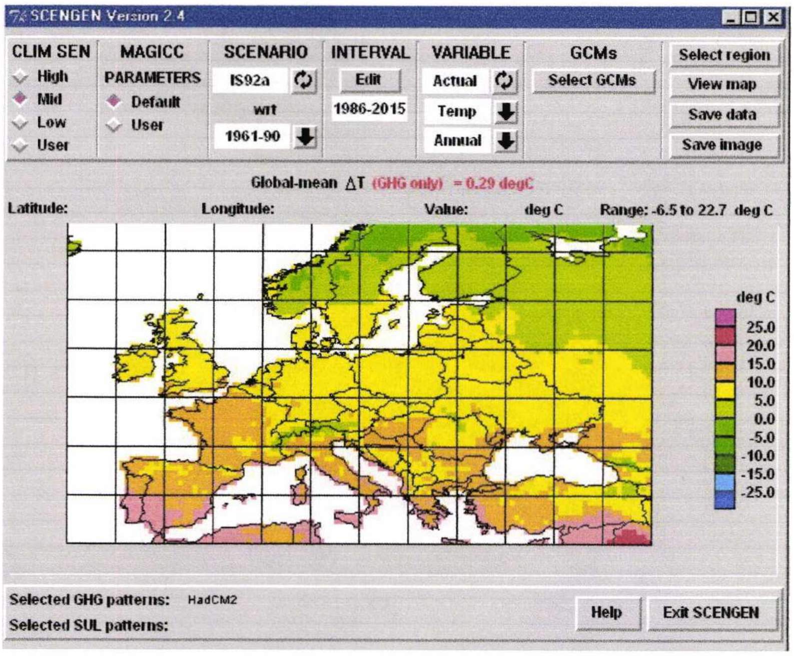

FIGURE 33. **(a) 1986-2015 Mean annual daily temperatures for Europe [Wigley, 2000].**

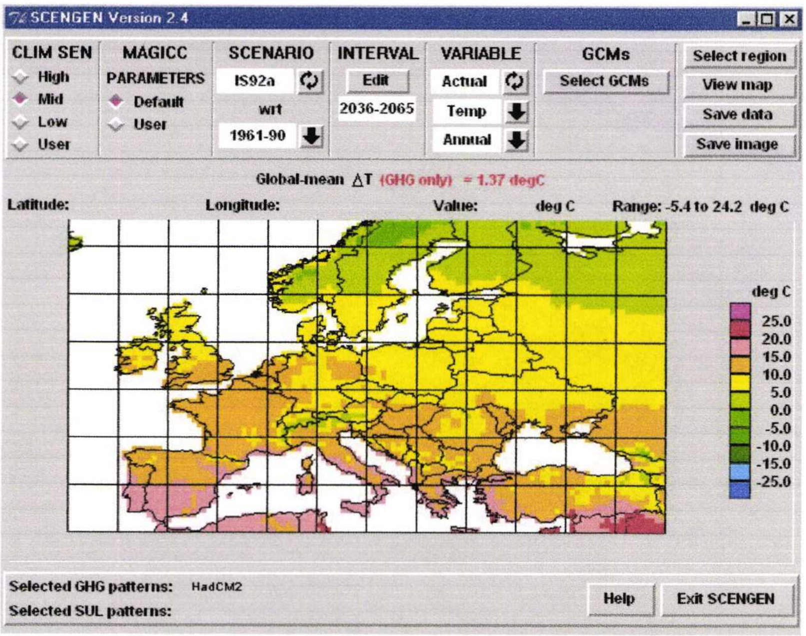

FIGURE 34. **(b) 2036-2065 Mean annual daily temperatures for Europe [Wigley, 2000].**

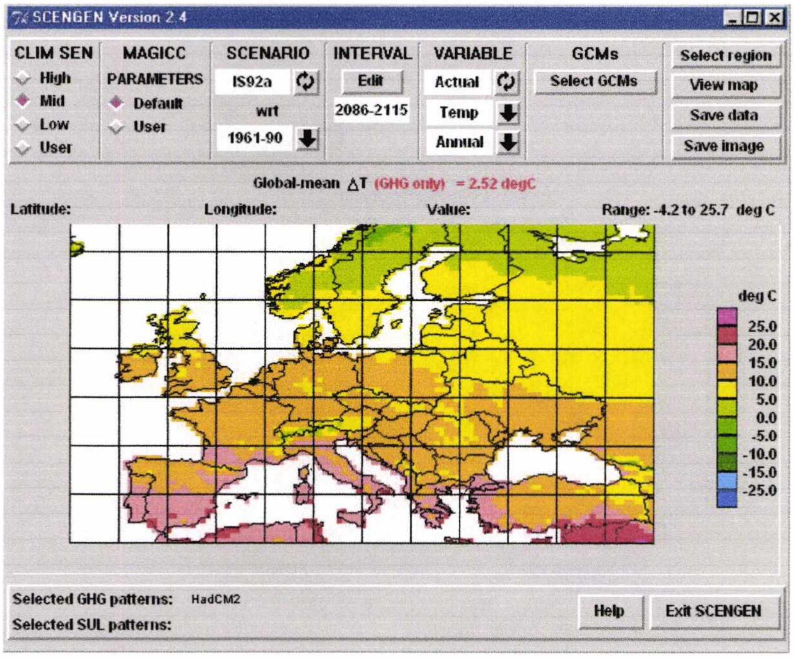

FIGURE 35. (c) 2086-2115 Mean annual daily temperatures for Europe [Wigley, 2000].

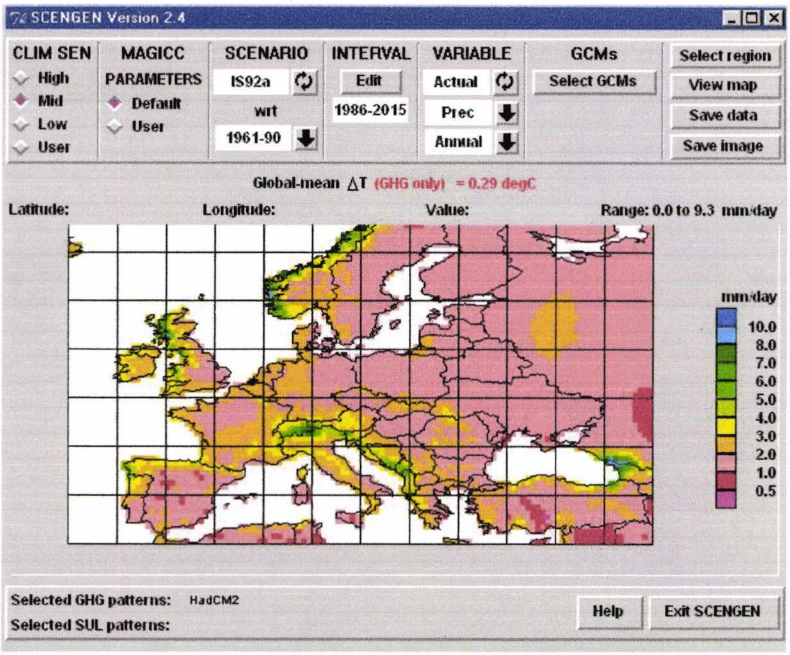

FIGURE 36. (a) 1986-2015 Mean annual daily precipitation for Europe [Wigley, 2000].

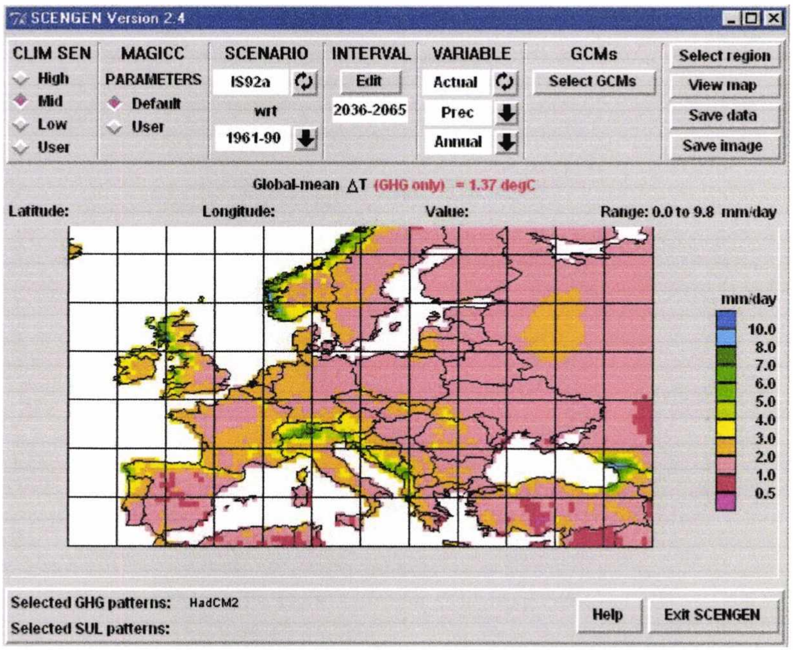

FIGURE 37. **(b) 2036-2065 Mean annual daily precipitation for Europe [Wigley, 2000].**

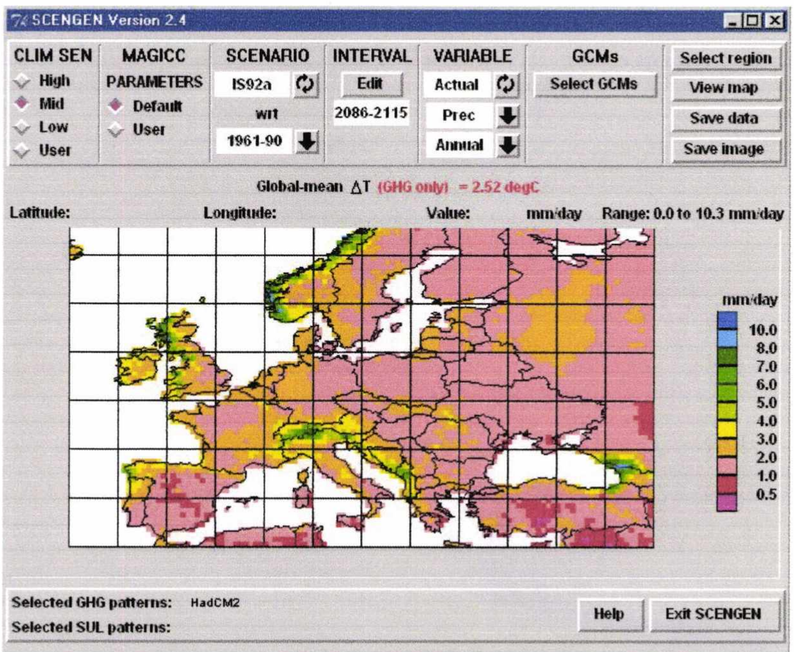

FIGURE 38. **(c) 2086-2115 Mean annual daily precipitation for Europe [Wigley, 2000].**

7.8.4. Calculation of Crop Water Requirements

CropWat uses the FAO [1992] Penman-Monteith methods for calculating reference crop evapotranspiration (ETo) and uses these estimates to calculate crop water requirements and irrigation scheduling calculations. ETo is calculated by CropWat when monthly climatic data are entered, including temperature, humidity, wind speed and sunshine hours. Since the accompanying CLIMWAT database which contains such climate data did not include the climate data for the United Kingdom, new data files were created using values from SCENGEN [Wigley, 2000] and formatted for CropWat so that ETo calculations could be made. Monthly rainfall data is not absolutely necessary, but should be used if rain falls in the growing season in the area under study.

An earlier version of CropWat (version 7.2) was used to calculate crop water requirements since it has the capability of suggesting missing values on the basis of information that is available, unlike previous versions and the graphical version for the Windows operating system that was also used, which provides graphs of irrigation schedules. The data extracted from SCENGEN [Wigley, 2000] was minimum and maximum temperature, average daily rainfall, and wind speed in metres per second. CropWat 7.2 then has the ability to estimate sunshine hours, humidity and evapotranspiration based on this information.

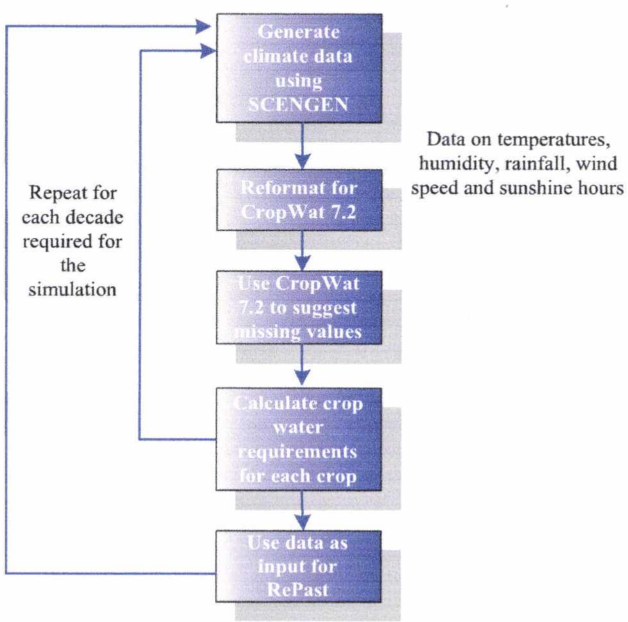

FIGURE 39. Extraction of data from external sources

Other input required by CropWat to calculate crop water requirements (CWR) include a cropping pattern, which requires the selection of a crop and its planting dates. Data regarding planting dates, soil type, irrigation timing and irrigation application were derived from further consultation with the domain expert (Section 8.1.6).

7.9. Summary

The 'game' theoretic framework used to extend the global 'competitive' behaviour in the ADM allowed the simplified emulation of local 'copying' behaviour in the LADM and the transmission of adaptive knowledge via weights, allowing the group to benefit from successful individual experiences. It was foreseen that possible inefficiencies such as the high constraint of the adaptive system in the ADM (Section 9.3.3) could be resolved by including the possibility of agents to learn patterns of successful behaviour from their peers, as supported by empirical evidence (Section 4.3.10).

Thus, weights in the LADM were the result of interaction that was produced in the original ADM (Section 7.6) which reflected competitive interaction with an awareness of the environment and resource availability while the LADM represented both competitive and imitative social interaction derived from the previous set of environmental interactions. Thus, this is a representation of cultural knowledge developed from data on human-environment interaction. Essentially, the weights represented the relationship between different (adaptive and non-adaptive) models and sub-models of decision-making [Fischer. 1994] and how they related to larger decision structures and integrated patterns of behaviour, producing the results discussed in Chapter 9.

The model works on the basis of both payoff-based (most successful behaviour) and conformist-based (most frequent behaviour) transmission. That is the most successful behaviour quickly becomes most frequent behaviour due to the weights used. The ADM served to enable an understanding of the dynamics of differing systems of agents and agent interaction under constant parameters of irrigation and capital. This aided an analysis of the greater complexity of systems with random levels of irrigation and capital in the LADM. Both models were used to gain a better insight into the interaction of empirical strategies as understood by the researcher from interviews.

Bennett's framework (Chapter 5) and the design of the model described in this chapter have been used to abstract and simplify observations in the target system. Both the theoretical basis and the design of the model might allow an improved understanding of empirical strategies (within the limits of the model and Bennett's framework (Section 8.4)) to apply any knowledge gained to one's understanding of the target system. The technical implementation of the model based on the design and data described in this chapter is documented in Chapter 8.

CHAPTER 8

Implementation

This chapter will describe the (Learnt) Adaptive Dynamics Model in detail based upon the design and data described in Chapter 7, the processes of agent interaction and selection that were documented and the parts of the target system that were implemented. The model represents decision-making processes of farmer agents whereby they must operate within the constraints of limited access to irrigation and capital and limits on their decision-making due to the choices of other agents. The constant parameters of irrigation and starting capital used in the Adaptive Dynamics Model allowed an understanding of the basic dynamics of the system and agent interaction given the rules in the knowledge base. This in turn aided an understanding of the increased complexity in systems with random levels of irrigation and capital included in the Learnt Adaptive Dynamics Model, where the copying of peers was also included. The farm management strategies agents adopted depended on their receptivity to the environmental scenario and whether they were willing to adopt warmer climate crop options - that is, whether they were adaptive or non-adaptive. The model includes data on crop-water requirements, crop prices, cost of labour and empirical decision-making that was deduced from interviews with the domain expert (Chapter 4). The remainder of this chapter entails a more detailed description of the model, an explanation of its implementation (Section 8.2) and a description of the way in which the limitations of the model constrain the interpretation of its results and thus further work which could be carried out (Section 8.4).

8.1. Model description

This section will describe the model in detail, including the data used and the agent behaviour which has been implemented (a complete list of the rules and source code can be referenced in "Appendix C"). It emerged during interviews with the domain expert (Chapter 4) and from the survey (Section 6.4.1) that several sources were consulted in making farm management decisions, including a very specific reference book on farming[1]. Thus, in addition to discussions with the domain expert and other informants, this book was also consulted for specific data for the model.

8.1.1. Agent behaviour

The variable attributes which agents possess to determine their behaviour are starting capital and amount of irrigation available. They are also either adaptive to, or sceptical of climate change which will affect the crops and the farm management strategies that they choose. The actions of agents affect each other in that some become specialised in growing particular crops and this influences overall production and therefore the choices of other agents. Thus, they are influenced by changes in the environment such as production (global and local), precipitation and temperature. Crop water requirements for each crop have been calculated using CropWat (Section 7.8.4). When the simulation is run, 'global' production levels (Section 8.1.4), annual temperatures and seasonal rainfall levels are set for the starting year. Each agent possesses an internal representation of itself, the environment, a memory and has access to the effects of the decision-making information of other agents as this has the potential to affect their choices.

1. The Farm Management Pocketbook compiled by John Nix [1998], is a highly valued reference book for farmers in the United Kingdom and contains data on all aspects of farming.

For each timestep which represents one decade[1] every agent makes a decision about the best crop to grow under its individual constraints. In the LADM, these constraints include randomly distributed levels of capital (£1,000-50,000) and irrigation (0-12 million gallons). The calculation of irrigation requirements for each crop are carried out internally within the agent, since if enough water does not exist to successfully grow the crop, it will not become a chosen option by that agent (Figure 46). A water-shortage event is logged if the only reason a crop is not chosen is lack of irrigation which allows the calculation of 'risk' (Figure 47). The working memory maintains records of the agents' chosen strategies, their effects, and their labour and irrigation usage.

Any primitive adaptive effects[2] of growing a particular crop, and thus utilising a certain strategy are recorded on the RHS of the rules in the knowledge base. The cumulation of these effects result in strategic designs [Bennett, 1976] (Section 5.6) which evolve over time depending on empirical strategies (such as growing potatoes, which has *delayed* and *multiplier* effects) that are chosen. Some strategies have uncertain costs (multiplier effects) and are available to both adaptive and non-adaptive (sceptic) agents differentially. These are shown in Table 14.

As mentioned in Section 7.5, heterogeneous and homogenous systems in the ADM and LADM will contain corresponding agents. The only difference in the construction of the LADM is that agents copy their neighbours' (using a 'tit-for-tat' strategy (Section 7.7.1)) and thus *become* adaptive agents over time if they are non-adaptive to begin with.

	Adaptive agent	**Non-Adaptive (sceptical) agent**	**Multiplier effects**
New technology warmer climate crops	X		X
New technology wetter climate crops	X		X
Spring crops	X	X	
Winter crops	X	X	
Labour-intensive crops (e.g. vegetables)	X	X	X
Irrigation-intensive crops (e.g. potatoes)	X	X	X

TABLE 14. Table of adaptive and non-adaptive farm management and crop options.

1. A decade was used as a starting point for timesteps when developing the model to correspond to the climate data that was readily available at the time (see Section 8.4).
2. The term 'primitive' has been used to describe low level effects (delayed, immediate, sustained and multiplier effects), which Bennett describes as the results of different types of empirical adaptation strategies (Section 5.5) [Bennett, 1976].

Primitive effects represent particular outcomes of farm management strategies to agents in the model and are saved to the working memory (Figure 40) as information that can be accessible by all agents who react to effects such as 'warnings' about resource use or the market saturation (specialisation) of a particular crop. For example, the 'specialisation' (Section 5.6.5) in production of one particular crop over three timesteps by one agent promotes alternative crop choices by others after a time lag of two timesteps as it is regarded as a crop that is already supplied and thus has less market demand, which in reality would attract lower prices. It is also viewed as a decision which might entail future vulnerability if not altered due to the one-directional 'adaptational drift' (Section 5.6.2) type nature of the decision and the rigidity of the relationships being forged with the environment and the market. The effects caused by certain strategies are saved as facts to a text file of the following format:

```
(effects mksat Grow_Soya year id)
(effects warning +LabCheck year id)
(effects warning NewCropsWarmerClimate year id)
(effects mktst NewCropsWetClimate year id)
(effects mktst Grow_Potatoes year id)
```

FIGURE 40. Example of effects saved to working memory.

The facts in Figure 40 identify the type of effect, i.e. whether it is a *warning* regarding the repeated (specialised) use of a resource such as labour or irrigation or the specialisation/market saturation (*mksat*) of a crop. The year the warning was issued and the identification number (ID) of the agent who caused the effect are also recorded.

Agents which repeatedly follow strategies which have uncertain (multiplier) outcomes, also alter the direction of their strategies after 2 timesteps because the nature of the strategies they choose have constraining effects and can result in increased vulnerability reducing flexibility, thus, lowering future adaptive capacity. This happens when new technology warmer/wetter climate crops or crops which require resources such as specialist machinery or irrigation are repeatedly chosen as shown in Table 14.

Having registered production, price and climatic values with each agent after retrieving them from the simulation, running the knowledge base using Jess [Friedman-Hill, 2001], causing various rules to fire and actions to be carried out by the agents, certain information is passed back to the simulation (Figure 32 shows this process). This includes the investment and profit that has been made and the number of different types of 'primitive' strategies used as a result of the chosen crops. Other important factors which are reported to the user are the overall 'strategic designs' and their attributes, risk levels (Section 8.1.7), information and advice regarding resources, and chosen crops and the adaptive patterns which emerge.

Strategic design facts are also saved to working memory. Strategic designs are the cumulation of primitive effects and strategic design facts take the form:

```
(strategy-design sust +IrrVeg year id)
(strategy-design immed +LabCheck year id)
(strategy-design del Grow_Soya year id)
(strategy-design del Grow_Oilseed year id)
(strategy-design immed +LabCheck year id)
(strategy-design del Grow_Veg year id)
(strategy-design multi Grow_Veg year id)
(strategy-design del Grow_Onions year id)
(strategy-design immed +LabVeg year id)
(strategy-design immed +IrrVeg year id)
(strategy-design sust +IrrVeg year id)
```

FIGURE 41. Example of strategy design facts saved to working memory.

The facts shown in Figure 41 are recorded with a 'strategy design' header, followed by the primitive effect abbreviation, the empirical strategy that forms part of the strategic design and the ID of the agent responsible for that strategy. The specialised use of resources such as labour or irrigation for particular labour- or irrigation-intensive crops is also recorded.

The IDs of agents which posses labour or irrigation are also stored in similar files for retrieval in each iteration of the simulation. The rule which determines which agents survive each year can be referred to as the 'break-even' rule, and checks that each agent's investment in the farm is not greater than the income that is gained from it in that particular year. It also checks that profit is greater than starting capital, since carryover capital is required to counteract the delayed effects of harvesting a crop planted one or two years earlier (Section 5.5.2).

Therefore, decisions about cropping patterns are made based on the actions of other agents, irrigation and capital available. Relative successes of individual agents result in their ability to break even in the investment in their enterprise. Agents continue making decisions (crop and farm management decisions regarding new crops, labour and irrigation) until they have insufficient resources or capital to do so.

The available choices in the decision making process may become restricted, due to specialisation (Section 5.6.5) in a particular commodity which causes alternative choices to be made by other agents. The constraining effects of strategies with uncertain costs (Section 5.6.4) also cause some agents to alter their strategic direction. In addition, the adaptive capacity of individual agents may vary since agents' personal attributes (adaptive/non-adaptive) may be different as well as irrigation levels and starting capital. The percept sequence of each agent includes climate (temperature and rainfall), overseas production (high or low), local production (what other agents are specialising in), strategic data (farm management strategies) and a personal memory (which indicates the positive and negative effects of each agent's past strategies, which is available to all agents). Crops that are chosen also depend on the order in which decisions are made (by the domain expert e.g. Section 4.4.3 and page 151), which in itself is dependant on the perceived profitability of each crop as well as irrigation available. Figure 42 illustrates the processes of the model which have been described.

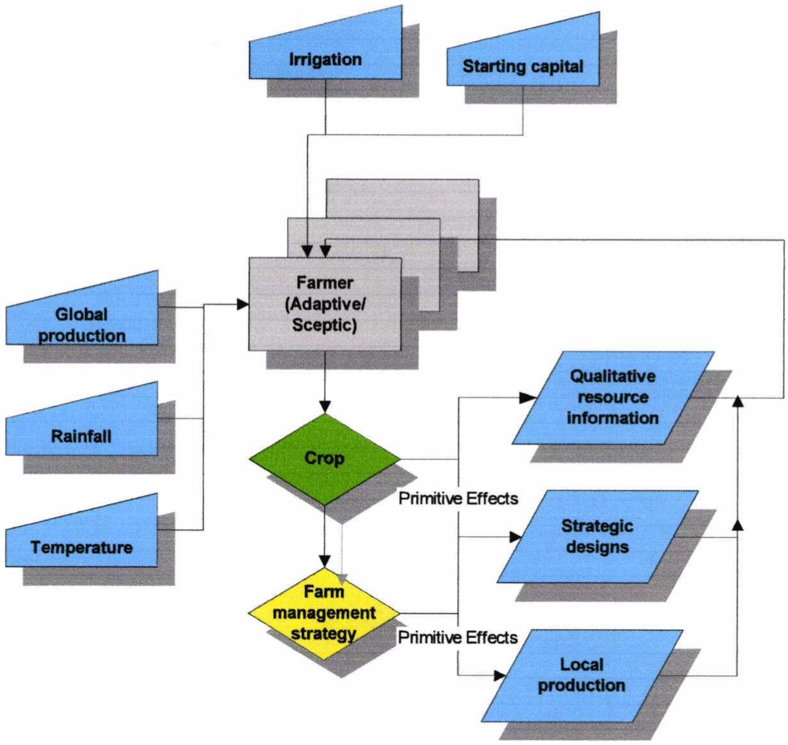

FIGURE 42. Flow chart of model processes.

8.1.2. Crop area

The areas of fields with the same soil type are aggregated and this is a static feature of the current model. Potentially, these may be retrieved dynamically for any crop chosen, since the areas of the fields in acres are stored in a data structure using the index as the numerical soil type of the field. This potentially facilitates dynamic retrieval of the area of crop to be grown, since soil type will be a part of the LHS condition of most crop rules. Once activated, the RHS action-part of the rule involves a calculation of irrigation and labour requirements, which are based on the area of the crop grown. Since the soil type is a variable that is local to the rule, and relates to how much of that crop can be grown on the area of land available with the necessary soil type, it can be used as the index with which to retrieve the area available of that particular soil type.

This flexible structure would allow an extended model to include varying numbers of fields for each individual agent in further work (Section 8.4). The functionality for this has been included in the model, but it is not necessary for use in this version as spatial aspects such as differing fields with various soil types and crop rotation are not included. The specific area that each crop is allocated are included in calculations, and this is a parameter which could be potentially be user-defined during each run, via the RePast GUI control panel or via a parameter file in a batch run in extensions to the model. At present each crop currently occupies the area grown by the domain expert.

Furthermore, soil type referred only to whether the soil was light, medium or heavy. Rules in the knowledge base did not include conditions for fertilizer or nutrient requirements, since these were taken into account before the soil was classified as belonging to one type or another (see Section 4.5.1 for the domain expert's classification of soil types).

8.1.3. Farm data

Calculations within the knowledge base are that of risk using the formula given by Gommes (Section 2.5.1), irrigation requirements, the potential profitability of growing a particular crop (see Section 4.3.9 for a discussion of fixed costs and Section 4.3.13 on investment) and the cost of labour for each crop. Gross margin, labour hours and crop water requirements per hectare of various crops are shown in Figure 43. For comparison, graphs of the potential income of the actual area (Table 15) of the crops grown by the domain expert, the labour cost and the crop water requirements are shown in Figure 43.

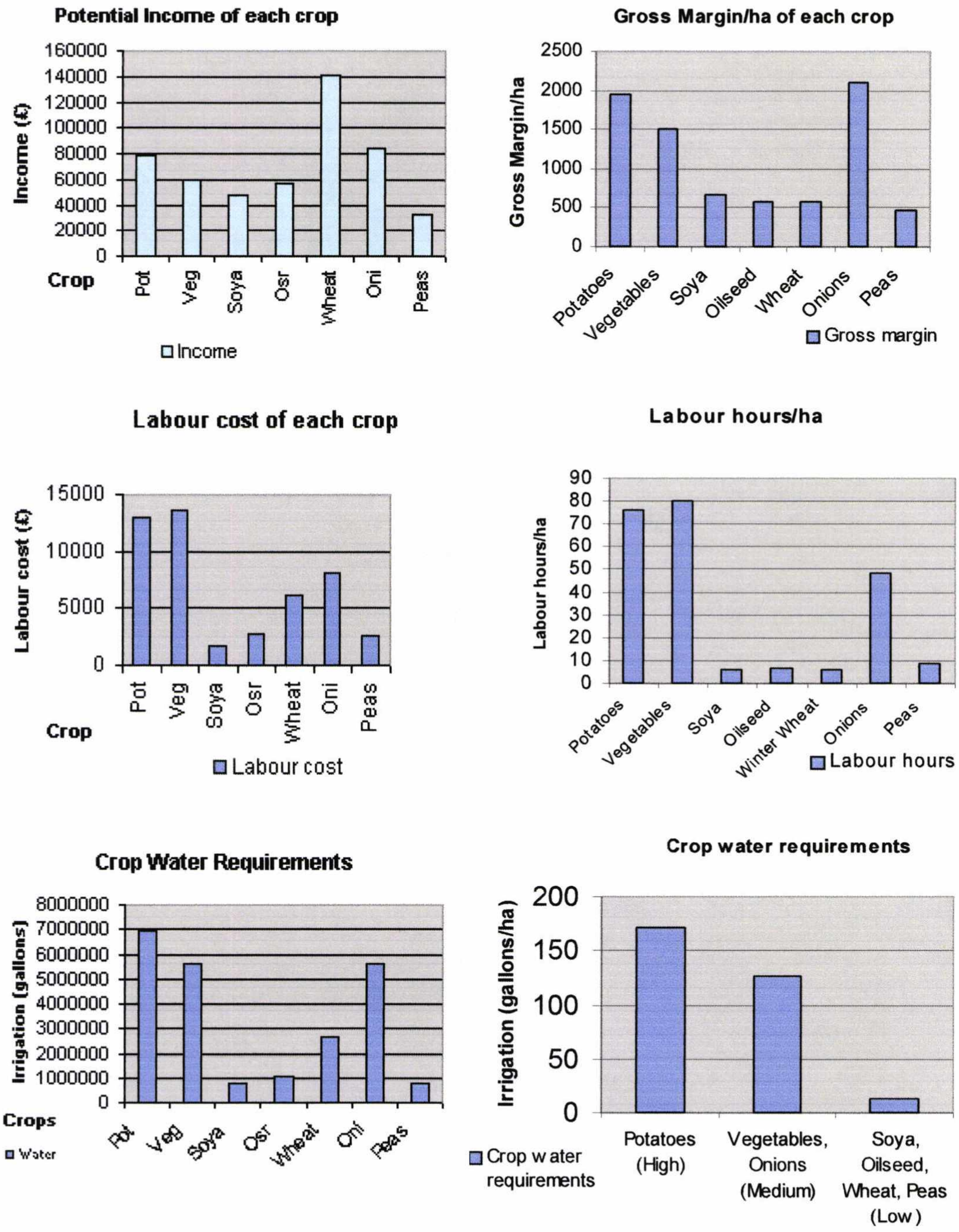

FIGURE 43. Graphs of potential income, labour costs and crop water requirements.

Crop	Area (ha)
Potatoes(Pot), Onions(Oni)	40
Peas, Soya	70
Oilseed(Osr), Vegetables(Veg)	100
Wheat	250

TABLE 15. Areas of crops grown by the domain expert.

8.1.4. Production and price

Decisions in UK agriculture are usually dependent on financial return (though not always, see Section 4.3.14) and if this is the case, production overseas and the value of global currencies are also taken into consideration, since price is affected by demand which is dependent on supply, which in itself is dependent on the climate to an extent. Since overseas production appeared to be more of an indicator of crop prices than currency, and the effects of global currencies could be eradicated to some extent by the membership of farm cooperatives (see Section 4.3.5), only production indices were included in the model, based on the subjective understanding of the domain expert and the modeller. Future production with respect to climate change is complicated to predict, though it has been attempted by climate experts [Rosenzweig and Iglesias, 1998] and there is a large literature relating to the expected productive potential of crops by other countries affected by changes in climate [Rosenzweig and Iglesias, 1998, Adams et al., 1999, Downing and Parry, 1994, Davies et al., 1997, Rosenzweig, 1990].

Production information was included in much the same way as described in McGregor's [2001] work, where farmers in the Australian wool industry seemed to ignore a great deal of information about changes in relative prices, either unknowingly or as a deliberate strategy (Section 2.10). This again relates to Rappoport's assertion that some strategies may in fact be subconscious (Section 2.2 and Section 2.3) [1969], though robust and effective. It appeared that in the longer term, the farmers McGregor studied had little confidence in predictions regarding prices and preferred to rely on their own experience. Farmers operated by criteria where prices existed in binary on/off states, regarding them as 'high' or 'low', rather than as part of a continuous adjustment process. Therefore, price response was much less than might be expected from classical economic theory. These results relating to farmers attitudes to prices are comparable with empirical data collected during interviews and binary perceptions of price, currency and production (Section 4.3.6).

In the ADM, overseas production is also classified in the form of the subjective binary values of 'high' and 'low', as discussed by Murray-Prior [1994] (Section 2.10) (where a string of binary numbers represents high or low production for each decade) based on what the domain expert perceived might happen in the future among competing countries. Implicitly, this was based on his understanding of possible future changes in the environment, higher temperatures, lowering rainfall, and the likelihood of a reduction in the availability of irrigation. Of course, this subjective binary representation is simplistic, although it does allow for many differing projections of production to be easily experimented with. If currency fluctuation were to be included in the model, this could also be applied the same binary way (e.g. Figure 54) since the strengths of currencies were referred to by the domain expert in simplified terms where the Euro (in the case of vegetables) or the US dollar (in the case of oilseed rape) was perceived to be either higher or lower than Sterling, and affected perceptions of potential productive choices (Section 4.3.6).

Production and monetary values per hectare of crop are available from agricultural sources (e.g. Nix [1998]). Production values vary between low, medium and high yields and monetary values include both price per tonne and gross margins. However, the latter is the sale value of crops including the area aid payments that farmers are entitled to and therefore, the figures for the gross margin per hectare were used in the knowledge base. Furthermore, variable costs are also included in the gross margin value, such as fertiliser and spray costs for each crop. Fixed costs such as rent and machinery are not deducted from the gross margin, though the cost of labour is, as the labour intensity of each crop is an important indicator of the sustainability of crop choices on the basis of the constraints of available capital. Therefore, income is calculated according to the price per tonne with an average yield, depending on the number of acres of crop grown. Actual yields are not needed since the simulation is not aiming to predict crop yields, though yields representing low, average and high values used were checked with those produced by the domain expert. The calculation for income is shown in Figure 44.

```
(deffunction Calculate-Profitability (?gmargin ?area ?labour-cost)
  (bind ?*profit* 0.0)
  (bind ?*profit* (* ?gmargin ?area))
  (bind ?*profit* (- ?*profit* ?labour-cost))
  ;; Variable costs(fertiliser) - fixed costs(labour).
  ;; Have not included other fixed costs, e.g. machinery, rent.
)
```

FIGURE 44. Calculation for profitability of chosen crop.

8.1.5. Cost of labour

Labour costs were included as an indication of whether the necessary levels of capital existed to grow particular crops, some of which were labour intensive. It was important that labour-intensive crops were treated as such within the model due to the specialisation in the use of resources, such as labour. Thus, decision-making regarding crops revolved around their individual specialist requirements (Section 4.4).

Seasonal values for the number of labour hours are used to calculate the total number of hours required for the actual area of each crop grown, and the thus the total cost of labour required for each crop (Figure 45). Clearly this varies depending on the area of land available for planting and how labour intensive the crop is. This is a function within the knowledge base since the area of the crop to be grown could potentially be varied in extensions of the model. The cost of labour is included as an investment that is made on the farm and is calculated as a function of labour hours which is crop-dependent and the hourly cost of labour, both provided by agricultural sources [Nix, 1998]. These values include the distribution of labour needs throughout the crop growth cycle.

```
(deffunction Calculate-Labour-Cost(?area ?lab-hrs)
  (bind ?*labour-cost* 0.0)
  (bind ?*labour-cost* (+ ?*labour-cost* (* ?area ?lab-hrs)))
  (bind ?*labour-cost* (* ?*labour-cost* ?*hourly-wage*))
)
```

FIGURE 45. Calculation of labour cost for chosen crop.

8.1.6. Irrigation

The RHS of each crop rule in the knowledge base follows a similar structure, as each must perform the same calculations and recording tasks, to keep the data that is passed to the simulation up to date. These calculations also include the crop irrigation requirements necessary for each particular crop (Figure 46). This will vary slightly in each decade of the simulation since the crop water requirements (CWR) predicted by CropWat naturally vary due to changes in evapotranspiration levels, as levels of temperature and precipitation change. Irrigation values for crops in the simulation have been categorised into low (wheat, soya, oilseed rape, and peas/pulses), medium (vegetables) and high (potatoes) irrigation-intensive crops as deduced from interviews with the domain expert. Crop irrigation requirements are calculated in millimetres per hectare and need to be calculated for the area of the crop grown and converted to gallons as the simulation has been run with variable levels of irrigation ranging from 0 to 12 million gallons (the amount available to the domain expert). This final CWR value is then compared to the actual amount of water that is available for irrigation. This is dependent on how much water has already been used up for other crops. If there is not enough water to grow the crop successfully, a water shortage event is recorded (Figure 47).

The default irrigation scheduling criteria that is used by CropWat [FAO, 1999] (Section 7.8.4) is to irrigate when 100% of readily available soil moisture (RAM) depletion occurs, from the first planting date, and to replace 100% of RAM. That is, to return the soil to field capacity (FC), so that the crop never becomes stressed. The irrigation amount will be equal to the soil moisture deficit, so the soil moisture deficit returns to zero after irrigating and no water is wasted. However, irrigation application criteria can also be set by the user and thus were set to levels determined by the domain expert which are based on experience and are subjectively believed to be optimal and efficient.

```
(deffunction Calculate-Water-Needed(?area ?cir)
  (bind ?*irr-req* 0.0)
  (bind ?*irr-req* (+ ?*irr-req* ?cir))  ;; mm/1 ha
  (bind ?*irr-req* (* ?*irr-req* 0.04))  ;; inch/ha
  (bind ?*irr-req* (/ ?*irr-req* 2.47))  ;; inch/acre
  (bind ?*irr-req* (* ?*irr-req* 22622)) ;; gallons/acre
  (bind ?area (* ?area 2.47))
  ;; to convert area from hectares to acres
  (bind ?*irr-req* (* ?*irr-req* ?area))
  ;; gallons/whole area in acres
  (bind ?*irr-req* (integer ?*irr-req*))
)
```

FIGURE 46. Calculation of irrigation requirements for chosen crop.

8.1.7. Risk

As noted in Section 2.5.1, risk has been calculated within the model as a function of vulnerability to the frequency of events causing loss, over time [Gommes, 1998]. Loss was taken to be the loss of income on a crop which could not be grown due to a lack of water resources, when all other decision-making criteria for growing the crop were met. Thus risk increases with the frequency that necessary irrigation resources are unavailable. If all other conditions for growing a particular crop are correct and there is not enough water to irrigate a crop, a water shortage event is recorded. The formula used to calculate risk is shown in Equations 1 and 2 on page 56. The calculation potentially incorporates differing vulnerabilities as a unit of measurement. Here the measurement is the loss of income, which is as a result of *vulnerability* to water shortages. The calculation in the rule base for risk is:

```
(deffunction Calculate-Risk()
  (bind ?*risk* 0.0)
  (if (> ?*av-water-shortage-events* 0)
  then
  (bind ?*av-loss* (/ ?*av-loss* ?*av-water-shortage-events*))
  ;; to get av from total loss
  (bind ?*risk* (* ?*av-water-shortage-events* ?*av-loss*))
  )
  (printout t ?*av-loss* ", " ?*risk* crlf)
  (printout t "Risk is equal to " ?*risk* crlf)
  (store "RISK-value" ?*risk*)
)
```

FIGURE 47. Calculation of risk as a function of water shortage.

The technical implementation of the rules using Jess [Friedman-Hill, 2001] (Section 3.5) will be explained in the following sections.

8.2. Rule implementation

One way of manipulating multiple agents in Jess [Friedman-Hill, 2001] was to use multiple rule sets (Section 7.8.1) and these were managed through the use of control facts (Figure 48) to enable and disable groups of rules according to the way they are invoked in the decision-making process, as understood by the knowledge engineer through discussions with the domain expert. For example, the consideration of potatoes as an insurance crop (Section 4.4.3), took place before considering break crops in the decision-making order, as it is potentially the most profitable crop to grow, ensuring as far as possible, 'prevention of loss' [Parry and Carter, 1998] (page 151).

There are six major divisions in the knowledge base (Figure 48). The first section can potentially gather general information from the user of the system in order to feed the part of the knowledge base which could implement the **Elimination by Aspects** methodology introduced by Gladwin [1983], separating crops into import, export and domestic crops (see Section 6.5). In theory, this would maximise the efficiency of the expert system narrowing the field of enquiry to a pre-determined socio-economic and cultural set of possible conclusions. However, as mentioned (Section 7.2), this was not used in the final version of the model due to the possible constraint it might place on decision-making and the particular need to observe freely emerging strategic designs in different types of system. The second, third and fourth phases contain rules which govern the type of crop choice (which are separated into **insurance**, **main** and **break** crop phases), given the constraints that have been specified in the previous phase. Adaptations are included in the fifth phase (Section 8.2.1), and the categorisation of the strategies chosen occurs in the final phase representing Bennett's framework of adaptive dynamics (Section 8.2.2).

```
(deffacts control-information
  (phase startup)
  (phase-sequence askables insurance main break crops adapt exit
   clear)
)

(defrule change-phase
  (declare (salience -10))
  ?phase <- (phase ?current-phase)
  ?list  <- (phase-sequence ?next-phase $?other-phases)
=>
  (printout t "--------" crlf)
  (printout t "----++++ phase change " ?current-phase " --> " ?next-
  phase crlf)
  (printout t "++++++++" crlf)
  (retract ?phase ?list)
  (assert (phase ?next-phase))
  (assert (phase-sequence ?other-phases ?next-phase))
)
```

FIGURE 48. Rule to control phases in the knowledge base and fact containing phase sequence.

The Java language integration feature of Jess [Friedman-Hill, 2001] allowed the knowledge base to be constructed using Java classes with bean-like properties which became the equivalent of deftemplate slots (attributes within a domain), representing features of the environment inhabited by each individual agent and personal attributes such as income and adaptation strategies. In this way a class could be used to represent a separate sub-domain of the overall target. Therefore, the domains considered of importance during the interviewing phase of the research were represented individually (environmental, economic, climatic and strategic - see Section 6.3.1 for the domains identified). The use of bean PropertyChangeListeners allowed any rapidly changing facts to remain updated in the working memory, and thus any rules which were satisfied during the course of a time step would be fired. Without the use of PropertyChangeListeners the facts on the knowledge base would only have been updated when a `reset` command was issued, and this would not have allowed agents to react dynamically to one another. Figure 49 illustrates the use of environmental, economic, climate and strategic domain classes with varying properties and how they can be used in the Jess [Friedman-Hill, 2001] language.

```
(defrule Grow-Oilseed_Rape
   (not (break-crop oilseed))
   Check that the crop has not already been chosen in the current choice of crops
   (phase break)
   Phase in which break crops are chosen in the decision-making process
   (not(effects mktst G_Osr ?year1&:(= ?year1 (- ?*year* 10))
   ?id&~?*id*))
   Check for local oversupply of this crop in the system by other producers
   (env (soil ?soil&:(= ?soil 5)) (OBJECT ?env))
   Environmental properties: Light soil, which allows water to drain better and therefore
   beneficial in wetter conditions.
   (econ (prodOsr 1) (OBJECT ?econ))
   Global economic properties: Poor overseas production.
   (clim (weather ?temp)(prec ?prec&:(> ?prec ?*av-ann-prec*)) (OBJECT
   ?clim))
   Climatic properties: Wetter climatic conditions than present.
   (cap (input ?input) (output ?output) (OBJECT ?cap))
   Local economic properties: Represent income and investment.
   (adapt (delayed ?del) (OBJECT ?adapt))
   Adaptive properties.
=>
   (assert (break-crop oilseed))
   Check that crop has not already been chosen for any other reason.
   (bind ?index ?soil)
   Get soil type.
   (bind ?area (call ?*v* elementAt ?index))
   Get area of land available of required soil type.
   (bind ?*osr-cir* (fetch "OSR-CIR"))
   Get irrigation requirements value for this crop.
   (bind ?*cir* (call ?*osr-cir* get (new jess.Value ?*year* 4)))
   Get irrigation requirements value for this crop for this year, which varies and is dependent
   on temperature and rainfall variables.
   (if (neq ?*cir* nil)
   then
   (bind ?*water-needed* 0)
   (printout t "Crop irrigation requirement is " ?*cir* crlf)
   (bind ?*water-needed* (Calculate-Water-Needed ?area ?*cir*))
   Calculate water needed for area of crop to be grown (Figure 46).
   (printout t "Irrigation required for oilseed to be planted on all
   suitable land available is" ?*water-needed* " gallons." crlf)
   )
   (bind ?*osr-water* ?*water-needed*)
   (bind ?*cwr* (+ ?*cwr* ?*water-needed*))
```

```
(printout t "Total crop water requirements are " ?*cwr* " gallons"
crlf)
(if (> ?*cwr* ?*water-available*)
Check to see if there is enough remaining irrigation to grow this crop.
then
(bind ?*events* (create$ OsrWet ?*events*))
(printout t "There is not enough water available to irrigate a
oilseed crop." crlf)
(bind ?*av-water-shortage-events* (+ ?*av-water-shortage-events* 1))
If there is not enough irrigation, record this as a water shortage event for calculation of
risk.
(bind ?*av-loss* (+ ?*av-loss* ?*osr-gmargin*))
Calculate loss of income for crop not grown.
(bind ?*cwr* (- ?*cwr* ?*water-needed*))
Return irrigation available to original level before this choice was made.
else
(printout t "There is enough water to irrigate a oilseed crop." crlf)
(printout t "**** Grow Oilseed Rape as a break crop. ****" crlf crlf)
(bind ?*advice* (create$ Osr ?*advice*))
Add to advice of suitable crops to grow.
(set ?cap output (+ ?output (* ?*osr-gmargin* ?area)))
Add income from crop to output.
(bind ?*labour-cost* (Calculate-Labour-Cost ?area ?*osr-hours*))
Calculate the labour cost for this crop (Figure 45).
(set ?cap input (+ ?input ?*labour-cost*))
Add this to the cost of growing this crop.
(store INPUT (get ?cap input))
(store OUTPUT (get ?cap output))
Stored for retrieval in RePast.
(bind ?*osr-profit* (Calculate-Profitability ?*osr-gmargin* ?area
?*labour-cost*))
Calculate profit (Figure 44).
(printout t "The potential profitability (variable costs - fixed
costs) of osr is £" ?*osr-profit* crlf)
(bind ?*advice* (create$ ?*osr-profit* ?*advice*))
(bind ?*advice* (create$ ?*water-needed* ?*advice*))
(bind ?*advice* (create$ ?*labour-cost* ?*advice*))
(bind ?*adapt-advice* (create$ OsrWet ?*adapt-advice*))
Add advisory information to a list for output.
(set ?adapt delayed (+ ?del 1))
(store DELAYED (get ?adapt delayed))
Increment primitive effects
(assert (strategy-design del G_Osr ?*year* ?*id*))
Create fact for evolution of strategic designs.
(save-facts .//strategy.txt strategy-design)
Save all facts with a 'strategy-design' header (Figure 41).
)
)
```

FIGURE 49. An example of a rule using Java Bean properties

Decisions were taken by the modeller regarding adaptation strategies and their overall effects on the system (Section 8.3), with regard to Bennett's framework (Section 5.4). The four primitives are strategies with immediate, delayed, sustained and multiplier effects (Section 5.5). Using Bennett's classification of the various 'strategic designs' that are composed of strategies with these types of effect, adaptation mechanisms within the rule base are manipulated accordingly. For example, each property which describes primitive adaptive effects, is incremented according to the type of strategy that is invoked. A strategy such as the implementation of an irrigation system is relatively certain to produce results with a quick return, and since its effects can be assumed to be immediate, these numeric properties are incremented. However, the effects of implementing an irrigation system are also sustained, and this property can also be incremented. According to Bennett, such a strategy has a low risk factor. This adaptation advice is included in the list of advice that is fed to the simulation. As additional information in the knowledge base, the *type* of adaptation is also recorded in the terminology of Rosenzweig and Parry [1994], who discuss Type I and Type II adaptations[1] (Section 2.7.4 and Section 5.2) in their paper on the effects of climate change on world food production.

8.2.1. Strategies with primitive effects

A rule set is invoked for the specific adaptation mechanisms that are required to fulfil crop choices. Figure 50 shows an example of a rule which invoked certain primitive effects.

```
(defrule Spring-Variety "Delayed-Effect"
   (not (strategy new-spring-sow-date))
   Check that this strategy has not already been invoked.
   (phase crops)
   Phase in which crop strategies are chosen in the decision-making process.
   (clim (autumn ?prec&:(>= ?prec ?*av-aut-prec*))(OBJECT ?clim))
   Autumns are too wet for current varieties.
   (cap (input ?input) (output ?output) (OBJECT ?cap))
   (adapt (delayed ?del) (OBJECT ?adapt))
=>
   (printout t "Change to Spring crop varieties, as the autumn season is
   now producing too much rainfall to continue with those varieties
   grown in the past. This is a low risk strategy, if it is relatively
   certain to produce results. The advantage of growing a spring variety
   is that spring crops are inexpensive to maintain. This is a strategy
   with delayed effects." crlf crlf)
   (set ?adapt delayed (+ ?del 1))
   Delayed effects property is incremented.
   (assert (strategy new-spring-sow-date))
```

1. Level 1 implies little change to existing agricultural systems, and easy, low-cost farmer adaptations, such as changes in planting date, increases in irrigation and in variations of currently available crops. Level 2 reflects more substantial adaptation such as the expansion of irrigation systems and development of new cultivars and crop varieties (see Section 5.2).

```
15. (bind ?*adapt-advice* (create$ Spring-Variety-Type-I ?*adapt-
    advice*))
16. (bind ?*LI* (create$ SprVar ?*LI*))
17. Strategy and whether it is Type I or II is recorded for analysis [Rosenzweig and Parry,
    1994].
18. (store DELAYED (get ?adapt delayed))
19. (store INPUT (get ?cap input))
20. (store OUTPUT (get ?cap output))
21. Storage of data as bean properties for retrieval by the simulation.
22. (assert (strategy-design del Spring_Sown_Crops ?*year* ?*id*))
23. Delayed effects produced by the strategies chosen are asserted as new facts which will
    invoke particular strategic designs. Growing any crop has delayed rewards. Addition-
    ally, note that growing new crops which may have uncertain costs invokes multiplier
    effects.
24. (save-facts .//strategy.txt strategy-design)
25. Strategies are saved to working memory. All facts with the strategy-design header are
    saved which includes the year the strategy was invoked and the ID of the agent which
    invokes it (Figure 41).
26. )
```

FIGURE 50. Adaptation mechanism rule

8.2.2. Strategic designs

The last phase in the rule base is dependent on the primitive effects of strategies chosen in the previous phase (Section 8.2.1) according the Bennett's model (Chapter 5). For example, the strategic design of *incremental change* (Section 5.6.1) is a pattern of behaviour composed of short-term strategies which are taken to provide *immediate results*.

```
1.  (defrule Incremental-Change
2.    (phase adapt)
3.    (strategy-design immed ?y ?*year* ?*id*)
4.    (strategy-design immed ?y ?year1&:(= ?year1 (- ?*year* 10)) ?*id*)
5.    These conditions represent strategies which are chosen which have immediate effects
      and are taken in two consecutive decades by the same agent.
6.  =>
7.    (printout t "Incremental change. Strategies are being taken to serve
      immediate ends of profit or output. Are future costs and long-range
      planning for change in the whole system being considered? Strategy
      chosen is " ?y crlf crlf)
8.    (bind ?*strategy-design* (create$ ?y IncChg* ?*strategy-design*))
9.    (bind ?*IC* (create$ ?y IncChg* ?*IC*))
10.   Strategic design and corresponding primitive effect is recorded in a list for retrieval by
      the simulation.
11.   (bind ?*incr-change* (+ ?*incr-change* 1))
12.   Counter for frequency of strategic design pattern is incremented.
13. )
```

FIGURE 51. Rule for incremental change.

During the final phase, which records the strategic designs, a new fact is asserted which includes information about the type of strategic design, its primitive effect, the year it is invoked and the ID of the agent which invokes it (Figure 41). Therefore, a history of the adaptation carried out by each agent is accessible by all other agents and causes further strategic design rules to fire, highlighting emergent patterns of adaptation which can be analysed.

The construction of strategic design rules requires a certain amount of subjective judgement on the part of the modeller. For example, the action constraint rule is invoked by strategies which result in multiplier effects, according to the adaptive dynamics framework, and what constitutes such strategies must be judged by the modeller. Though the application of these rules is based on empirical evidence, it is inevitably constrained by one's own understanding of the domain (Section 7.2). These rules belong to the final phase and the conditions on the rule LHS check for instances of particular patterns of primitive effects. The constraining factors determining when a strategic design can be invoked are the type of primitive effect involved in the adaptation, the years in which the adaptation mechanism was chosen, and the agents that chose to implement these mechanisms.

If strategic designs emerge, the *type* of design can imply further effects on the system requiring agents to react to these emergent properties. If these overall effects are negative, a new fact will be asserted in the action part - the RHS - of the rule to include information about the strategy design and the types of primitive effect involved, the year and the ID of the agent responsible, with the additional information that the strategy is negative. Negative strategies invoke other types of strategic design over a number of years such as the buffering mechanism, which warns against resource depletion and is common in most growth oriented systems, where gain is large and risk of loss is correspondingly felt to be severe [Bennett, 1976] (Section 5.6.3).

8.2.3. Resource competition

Used as a measure of the most stable state of the system, the cyclical resource competition rule identifies patterns of sustainable competition between pairs of agents over 3 decades. This timeframe is used since resource competition is a measure of a long-term pattern of sustainable behaviour in the model, as opposed to most other strategic designs, which are invoked over a shorter period, usually 2 time steps. Since this can only be achieved by agents that make successful choices *over time* (Section 5.4) under constraints of capital and irrigation availability, the invocation of this rule represents resilient choices and a stable, cyclical, homeostatic rhythm.

This is the only adaptation rule which compares the strategies of agents with one another and represents a cooperative strategy. In Bennett's framework this strategic design represents a movement towards an stable allocation of resources by a group, allowing it as a whole, to survive (Section 5.6.6). The subtle difference in the model is that the rule represents crop choices which are based on a sustainable use of resources although resources are not 'shared'. However, it is based on sustainable competitive behaviour under *individual* resource constraints. Since the dynamic is sustainable between pairs of agents over time, it also means that it is a 'cooperative' (though not conscious (Section 2.3)) dynamic.

```
(defrule Resource-Competition
    This rule represents a movement towards a pattern of accommodation, where choices are
    made by particular groups/individuals representing a cooperative strategy.
    (phase adapt)
    (strategy-design del ?b ?*year* ?*id*)
    (strategy-design del ?d&~?b ?*year*  ?id&~?*id*)
    (strategy-design del ?b ?year2&:(= ?year2 (- ?*year* 20)) ?*id*)
    (strategy-design del ?d ?year2&:(= ?year2 (- ?*year* 20)) ?id)
    (strategy-design del ?b ?year1&:(= ?year1 (- ?*year* 10)) ?*id*)
    (strategy-design del ?d ?year1&:(= ?year1 (- ?*year* 10)) ?id)
    Strategies are complementary and represent a homeostatic rhythm. Resource competi-
    tion is intended to reflect a complementary accommodation of the utilisation of resources
    or strategies.
    Strategies are repeated in three consecutive decades in a cycle.
    =>
    (printout t "Resource competition. Competitive choices are proceeding
    cyclically, as strategies have attained a steady/homeostatic rhythm,
    whereby there is a movement towards a particular use of resources by
    individuals allowing the sustainability of the group. The strategies
    chosen are " ?b ", and " ?d " the effects of which are delayed."
    crlf crlf)
    (bind ?*strategy-design* (create$ ?b ?d RC* ?*strategy-design*))
    (bind ?*resource-competition* (+ ?*resource-competition* 1))
    Update the counter monitoring the frequency of this cooperative strategy.
)
```

FIGURE 52. Rule for achieving homeostatic 'resource competition'

8.3. Modification to Bennett's framework

Adherence to Bennett's rules was enforced and necessitated by the need for a true analysis of individual and group *adaptive dynamics* and *adaptation as a social process* [1976]. Thus the adaptation strategy rules in the knowledge base, embody Bennett's framework of primitive effects. However, two main modifications were made to the rules in the knowledge base, to include empirical observations. This took the form of feedback between agents regarding resource depletion and market saturation/specialisation.

8.3.1. Warnings regarding resource depletion

The important issue regarding the adaptation mechanism that was chosen was the type of effects that it had in the short and long term on the system. Therefore, there were conditions relating to resource use which had to be satisfied in the adaptation rules. That is, if there was drift (Section 5.6.2) in a decision leading to its specialisation (Section 5.6.5) over a number of years, it was no longer a choice that was accessible by other agents. This was achieved by issuing a warning on the resource/commodity in question. A condition on the LHS of each crop choice rule, checked whether any agent other than the current agent was over-utilising a resource. If this condition was true, the LHS of the rule could not be satisfied and therefore the rule could not become activated. However, this assumed that if the resource was being over-utilised by the current agent, it could continue using this strategy, as long as other agents did not use it also. The buffering rule invokes a warning, as it is closely related to the step function described by Bennett [1976], where a control is placed on a resource due to its over-use and the need for its preservation (Section 5.6.3).

```
(defrule Buffering
   (phase adapt)
   ?f2 <- (strategy-design neg ?x ?y ?z ?year1 ?*id*)
   ?f1 <- (strategy-design neg ?x ?y ?z ?year1&:(= ?year1 (- ?*year* 
   10)) ?*id*)
   Negative strategies are repeated by the same agent in at least two consecutive decades.
=>
   (printout t "Buffering - A negative strategy is persisting because 
   other factors encourage it to do so, in spite of the danger." crlf 
   crlf)
   (assert (design buffering ?x ?y ?z ?*id* ?*year*))
   Invokes a warning.
   (assert (effects warning ?y ?*id* ?*year*))
   This agent is consuming resources/specialising in a strategy dangerously - a warning is 
   issued so that agents will avoid this resource/commodity ?y.
   (bind ?*warnings* (create$ warning ?y ?*warnings*))
   Add the warning to a list.
   (bind ?*buffering* (+ ?*buffering* 1))
   Increment counter for strategic design.
   (bind ?*strategy-design* (create$ neg ?x ?y ?z Buffering ?*strategy-
   design*)))
   Log negative strategies that are persisting in a list.
```

FIGURE 53. Buffering mechanism warns against resource depletion and identifies agents whose strategies result in negative strategic designs.

The buffering mechanism is invoked after a time-lag of 2 time-steps of a negative strategy persisting (note there may be an additional timestep before a strategy is *registered* as being negative, due to the *systemic lag phenomena* mentioned by Bennett [1976]). Warnings also influence the use of labour and water by an agent over time and by doing so, influences their crop choices.

8.3.2. Warnings regarding market saturation (specialisation)

Figure 54 illustrates the structure of certain rules, where feedback between agents is included in the form of the market saturation/specialisation of a commodity if certain agents are specialising in producing a particular crop (e.g. line 6 in Figure 49 and Figure 54). This causes other agents to make alternative crop choices in the next time step.

```
1.  (defrule Grow-Potatoes-High-Osr
2.    (not (break-crop potatoes))
3.    Check that crop has not already been chosen.
4.    (phase insurance)
5.    Insurance crop phase in the decision-making process.
6.    (not (effects mktst G_Pot ?yearl&:(= ?yearl (- ?*year* 10))
      ?id&~?*id*))
7.    Check that a warning about specialisation of this crop by other agents has not been
      issued for the last time step.
8.    (econ (sterling 0)(OBJECT ?econ))
9.    Global economic properties: Weak British currency discourages competitors from invad-
      ing British markets. Results in a high price for export crops, though potatoes are grown
      for the domestic market.
10.   (econ (prodOsr 2)(OBJECT ?econ))
11.   Global economic properties: High overseas production of oilseed.
12.    (env (soil ?soil&:(= ?soil 2)) (OBJECT ?env))
13.   Environmental properties: Med-heavy soil type.
14.   (adapt (irrigation 1)(OBJECT ?adapt))
15.   Adaptive properties: Irrigation is required for this crop.
16.   (adapt(labour 1) (delayed ?del)(multiplier ?multi)(OBJECT ?adapt))
17.   Adaptive properties: Labour is required for this crop.
18.   (clim (weather ?w&:(>= ?w ?*av-ann-temp*))(OBJECT ?clim))
19.   Climatic properties: Weather conditions should be the same or warmer than at present.
20.   (cap (input ?input) (output ?output) (OBJECT ?cap))
21. =>
22.   ...
```

FIGURE 54. Example of checking for market saturation in a crop rule.

Figure 54 is also an example illustrating some rule conditions which were not used, but which show the way in which decisions that are based on overseas production of *other crops* (oilseed rape in this case) and currency fluctuations (strength of Sterling) could be implemented in a binary way in the same way as production indices, as suggested in Section 8.1.4 and Section 2.10

[Murray-Prior, 1994]. As noted in Chapter 6, since potatoes are grown for the domestic market overseas production is not a consideration. However, the domain expert had indicated that potatoes would be a choice if overseas production of other commodities was good lowering their market value, reducing the desire to grow export crops. For example, as shown in Figure 54, if the production of wheat or oilseed is high, potatoes could be grown to compensate for this (Table 11).

It is the specialisation strategic design which invokes warnings about the market saturation of a crop since it is measured as a repeated, one-directional crop choice over three time steps.

```
(defrule Spec-of-Potential
   (phase adapt)
   ?f1 <- (strategy-design ?a ?y ?*year* ?*id*)
   ?f2 <- (strategy-design ?b ?y ?year1&:(= ?year1 (- ?*year* 20))
   ?*id*)
   ?f3 <- (strategy-design ?c ?y ?year2&:(= ?year2 (- ?*year* 10))
   ?*id*)
   Strategies are repeated in at least 3 consecutive decades.
=>
   (printout t "Specialisation of potential. There is an increasingly
   focused use of particular resources over long periods of time. The
   specialization of the use of this resource results in particular pro-
   ductive regimes. The resource that is being specialized is " ?y " and
   this has " ?x " effects." crlf crlf)
   (bind ?*strategy-design* (create$  ?y SpecPot* ?*strategy-design*))
   (bind ?*SP* (create$ ?y SpecPot* ?*SP*))
   Log strategic patterns in a list.
   (assert (strategy-design neg ?b ?y SP ?year1 ?*id*))
   (assert (strategy-design neg ?a ?y SP ?*year* ?*id*))
   (assert (strategy-design neg ?c ?y SP ?year2 ?*id*))
   Assert this as a negative strategy since it has been specialised in over three decades. This
   will trigger the buffering mechanism.
   (assert (effects mktst ?y ?*id* ?*year*))
   This agent is specialising in producing for this niche in the market forcing other agents
   to target other niches.
   (bind ?*warnings* (create$ mktst ?y ?*warnings*))
   Add the warning to a list.
   (bind ?*spec-of-pot* (+ ?*spec-of-pot* 1))
   Increment counter for strategic design.
)
```

FIGURE 55. Example of the specialisation rule.

Thus, this rule is fired when a 'drift' in decision-making is occurring which itself is logged over 2 timesteps and recorded as 'adaptive drift' (Section 5.6.2). However, specialisation (Figure 55) is a longer term strategic design recorded over 3 timesteps when one agent is opting for the same crop choice. This results in a warning regarding 'market saturation' in effect encouraging other agents to pursue other productive choices, allowing the specialising agent to continue in its productive regime, due to its longer term 'investment'. In the LADM, more singular agents specialise depending on their variable adaptive capacity, therefore there is more system variation overall.

8.3.3. Warnings regarding market saturation (constraint)

The action constraint rule also triggers agents to alter their productive regimes. However, this rule is invoked when two strategies with uncertain costs are chosen by an agent over two time steps. This results in the tension to try and alter choices and the inability to do so due to the binding power of previous investments incurred by these high risk strategies (Section 5.6.4) [1976]. An agent with a longer history of pursuing such a strategy will continue with it, but other agents will successfully alter their choices. Therefore, action constraint can result in specialisation by some agents (Figure 55), and diversity among others (however, it is usually constraining and does not lead to sustained choices which are measured over 3 timesteps - the resource competition rule in Figure 52) because new choices have to be made every two time steps.

```
(defrule Action-Constraint
    Similar to resource competition, but here the increased no of variables, increases con-
    straint. Strategies are defined by their uncertain costs, which have multiplier (multi)
    effects.
    (phase adapt)
    ?f1 <- (strategy-design multi ?a ?*year* ?*id*)
    ?f2 <- (strategy-design multi ?b&~?a ?*year* ?*id*)
    ?f3 <- (strategy-design multi ?a ?year1&:(= ?year1 (- ?*year* 10))
    ?*id*)
    ?f4 <- (strategy-design multi ?b ?year1&:(= ?year1 (- ?*year* 10))
    ?*id*)
    Two adaptation strategies with uncertain costs are repeated in two consecutive decades
    in a cycle by the same agent.
=>
    (printout t "Action constraint - The number of variables in the long-
    term strategy have increased to the point that they are limiting or
    controlling future decisions and changes. There is a tension between
    the desire to alter the pattern and the impossibility of doing so due
    to the binding power of decisions produced by a very heavy invest-
    ment. The strategies are " ?a " and " ?b " and they have multiple
    uncertain costs." crlf crlf)
    (bind ?*strategy-design* (create$ ?a ?b ActCon* ?*strategy-design*))
    (bind ?*AC* (create$  ?a ?b ActCon* ?*AC*))
    (assert (strategy-design neg multi ?a AC ?year1 ?*id*))
    (assert (strategy-design neg multi ?a AC ?*year* ?*id*))
    (assert (strategy-design neg multi ?b AC ?year1 ?*id*))
    (assert (strategy-design neg multi ?b AC ?*year* ?*id*))
    Assert facts describing this as a negative strategy, which will invoke buffering.
    (assert (effects mktst ?a  ?*year* ?*id*))
    (assert (effects mktst ?b  ?*year* ?*id*))
```

```
Assert warnings promoting agents to alter their strategies due to the uncertain costs
involved in the strategies previously chosen.
(bind ?*warnings* (create$ mktst ?a ?*warnings*))
(bind ?*warnings* (create$ mktst ?b ?*warnings*))
(bind ?*action-constraint* (+ ?*action-constraint* 1))
)
```

8.4. Limitations and further work

The assumptions and limitations of this model cannot be overlooked since any conclusions that are drawn are inevitably constrained by them. Clearly, the use of Bennett's framework is based on an understanding of domain by the modeller and subjective decisions that were made regarding the relationship and application of the theoretical framework to empirical observations, to achieve the goal of furthering one's understanding of the ethnographic data.

There has been discussion (Section 7.7.1, Section 9.1) regarding the assumptions of farmer motivation and cognition in the model particularly with respect to the weights used in the LADM (Figure 30). Therefore, a useful possible extension to the agents, in addition to their 'adaptiveness', would be a representation of the varying motivational goals of different farmers, such as farming to maximise profit, to break even, for subsistence or for traditional, family oriented or lifestyle reasons as suggested in interviews (Section 4.3.14) and in the survey (Section 6.4.1). However, such decision-making is also influenced by the subsidies available on particular crops (Section 4.3.4 and Figure 27 on page 200) and thus this would also be a valuable addition to an enhanced model, though it has been attempted by others [Bonfanti et al., 1998].

Accounting for differing socio-economic contextual variables would enable such a model to be more useful in its application. Differing goals of subsistence, income, technology and productivity requirements could be included using Gladwin's 'Elimination by Aspects' methodology (Section 2.10 and Section 6.5). This would allow customisation to include the constraints of different geographic locations which involve different sets of socio-economic and cultural constraints.

The purpose of the values used in the model was to identify categories of crops which were labour and irrigation intensive, rather than to analyse the complex details of costs and other inputs on the farm. For example, although the cost of irrigation is available from agricultural sources [e.g. Nix, 1998], it was not used in the model as it was assumed that a license for irrigation has already been acquired at a fixed cost, regardless of the volume of water usage, as is the case with the domain expert. Furthermore, the cost of this license is only a small yearly charge at the moment, though this may increase in the future if water usage increases and thus becomes monitored in an attempt to control access and conserve it (Section 4.5.3). However, realistic levels of irrigation capacity were used. Similarly, while the final profit for each crop is calculated using the gross margin which does include the variable costs of fertilizer and sprays, and the cost of labour is deducted, it does not include the costs of machinery and rent. Clearly this would be a more realistic addition to the model, though not necessary for the purposes of identifying decision-making regarding categories of irrigation- and labour-intensive crops.

A decade was used as a starting point for timesteps when designing and developing the model to correspond to the climate data that was available. It was envisaged that as the model developed, a finer granularity of time steps could be used with more detailed climate data to allow year to year decision making in order to make the model more realistic. However, when experimenting with the model, it became clear that the insights gained from this study, which are discussed in Chapter 9, would not benefit from this further development. Clearly, acquiring more detailed climatic data would be useful, although the unpredictability of the frequency of extreme weather events would remain an issue.

The inclusion of realistic production and consumption data could be pursued at both national, regional levels and international levels to inform agents about what should be grown with respect to specific market demands. While a farmer in the UK may be influenced by what is being grown in Europe and the USA, a small-scale farmer in an underdeveloped country will not. However, they may be in a better position to decide which crops to grow, if they are informed about the regional demands of their area, and various government run incentive/development schemes. The inclusion of the effects of Type I and Type II adaptation (Section 2.7.4) within the predicted values of overseas production in work conducted by Rosenzweig et al. [1994] would also be a valuable resource for the exploration of adaptation and productivity with respect to long-term environmental change.

Crop yields and variation in the amount of land available to agents could also be added to an extended model, though values for crop water requirements in CropWat (Section 7.8.4) do take account of the success of a crop yield to some extent. The flexible structure of the rules in the current knowledge base would allow an extended model to include varying numbers and sizes of fields for each individual agent in further work. However, the decision to retain the decadal timestep in the model meant that varying fields, for the purposes of crop rotation for example, would be unnecessary.

If the model were designed at a finer level of granularity it may be more realistic to create agents which compete for land in a defined landscape guided by their decision making processes. Competition for land would not have been realistic in the LADM since time steps represent decades to correspond with climatic data. However, incorporating this into the model given the correct data would be possible with the current design since the benefits of acquired (e.g. contracted land (Section 4.5.12)) land can be calculated with the aggregation of particular soil types (Section 8.1.2) and the associated calculations of crop water requirements. All other calculations also mean that certain extensions to the model would not be a major undertaking and this could be complemented with the use of RePast's new GIS functionality (Section 3.4) to represent different types of land-use. This would relate to adaptation strategies identified by Parry and Carter [1998], where 'changing location' is an option (page 152).

There is a great deal of future work which could be done to improve this model, and there is a vast amount of ethnographic data which has not been utilised. For example, the trading status of each agent is an important consideration since this affects the price that is commanded by each crop (Section 4.3.5). Agents trading as individuals are vulnerable to the strength of the various currencies that the crops are dependent on, and this affects the prices they receive. However, agents which belong to cooperative farmers' associations eradicate the effects of fluctuating currencies. In this case-study, the domain expert only belongs to a potato cooperative and prefers to market most of his crops independently. Furthermore there is a greater tendency for individual marketing in the UK than in other European countries or the United States [Kirby, 1999]. However, investigation could be conducted into the possibility that belonging to a cooperative entails less risk than trading as an individual for all crop types or whether it is beneficial to be a cooperative member for certain commodities but not for others, as the domain expert has done in the past. This is an empirical reflection of the trading behaviour of some farmers. However, overseas production seemed to be more of an important factor in the decision-making process than currency fluctuations, and while both are related to price, production is related to weather events. Therefore, in a more realistic model, prices would also be coupled to climate to represented fluctuations as a result of supply and demand, as well as changing over time as a result of inflation.

To satisfy Bennett's analysis of adaptation further it would be beneficial to include a more detailed definition of resource utilisation to understand how individuals in social groups make decisions about natural resources, how these resources are 'socialized' and whether they become nships as described in Section 2.2.

8.5. Summary

The combination of methodologies used in this study could have other applications in the anthropological domain (Section 10.2). The results of such a model based on ethnographic data can often raise new and interesting questions for further consultation with the domain expert, or for new lines of enquiry. Though this may seem a time-consuming exercise, the use of tools such as Repast, Jess and the IPD tutorial provided by Cederman and Gulyas [2001] facilitate ease of use for the novice, and were chosen specifically for these reasons (Section 3.4) as all of the software used is very well documented [Friedman-Hill, 2001, Collier, 2001, Cederman and Gulyas, 2001]. Thus, this is an example of an application that while simple in its representation of qualitative data, can still enhance an understanding of the ethnographic data using an appropriate theoretical framework. Furthermore, the initial collection of data, testing of the model and the final analysis is often more time consuming than the implementation itself.

Using guidelines described in literature on agent-based modelling and linking qualitative and quantitative models [e.g. Edmonds, 2002, Fischer, 1994], this chapter has attempted to show how the proposed abstraction of the target system as described in Chapter 3 has been implemented. While this abstraction is a simplified representation of the target system and only certain empirical features have been addressed, it is precisely because certain ethnographic insights can still be gained *despite* this simplicity (avoiding 'methodological error' [Dyke, 1981] (Section 7.1)) and perhaps *because* of it [Gilbert, 1995], that it may encourage anthropologists to use similar techniques to complement their analyses. Chapter 9 explores the results of the model, whether they do in fact illuminate the ethnographic data and could add any value to traditional anthropological methods, and thus whether the model does have any explanatory power regarding the target system *within the context* of Bennett's theory of adaptation.

CHAPTER 9 Analysis and Results

The (Learnt) Adaptive Dynamics Model has been used to apply an anthropological theory of adaptive dynamics as an abstraction of observed farmer behaviour to provide a better understanding of the decision-making processes in the target system. Thus, the results of the model must be considered within the context of the limitations of the model (Section 8.4) and this theory of adaptation (Chapter 5). Bennett's framework of adaptive dynamics is useful for the translation of qualitative data to a formalised type of ethnography which can enhance subtleties and provide a sharper focus if not allow the data to be incorporated into a computer based model[1]. This process has allowed the preservation of qualitative ethnographic categories and thus, less loss of information, which has provided an understanding of the interaction between qualitative and quantitative models [Fischer, 1994] (Section 1.4) and aids an analysis of regularities and variation in social behaviour [Spradley, 1987] (Section 2.9).

1. Discussion regarding the applicability of Bennett's framework above other similar models of strategic choice can be found in Section 5.3.

The remainder of this chapter will discuss the results of the Adaptive Dynamics Model (ADM) (Section 9.4) which provided some insight into the nature and effects of various farm management strategies and thus prompted the implementation of the slightly variant Learnt Adaptive Dynamics Model (LADM) (Section 7.7). The comparative results of this model (Section 9.7) are discussed and the insights that were gained were then applied back to the understanding of ethnographic context prompting additional enquiry with the domain expert (Section 9.8). The new results from the model informed the researcher's understanding of the ethnographic context further. The possible conclusions that can be drawn from this reflexive process are suggested in Section 9.9. The documentation of the results of the model is preceded by a discussion regarding the verification and validation of qualitative models (Section 9.1).

The implementation of this research resulted in several areas of observation regarding behaviour in the target system. Primarily analysis of the ADM has been conducted in isolation, using constant parameters of irrigation and capital to gain an understanding of the dynamics of the system and the behaviour that was implemented. The ADM contained information regarding competitive productive behaviour with local and non-local neighbours. The LADM represented the sharing of successful knowledge by imitative learning behaviour via *conformist transmission* (Section 2.11.4, Section 7.7.1) whereby the system tended towards the most successful type of agent in the population, which was pre-defined as the adaptive agent, using weights (Figure 30). These models represented only the most salient aspects of interview data to investigate whether empirical observations and indigenous strategic knowledge did lead to more successful behaviour for both the individual and the group within the context of Bennett's framework. At an abstract level this represented the dynamic that farmers have been seen to employ which is to copy the successful strategies of one's neighbours and to do the opposite of one's competitors and attempt to be a 'unique' producer (Section 4.3.10). Results from the (competitive) ADM and the (imitative) LADM have been compared to assess whether 'conformist transmission' or 'copying' behaviour did indeed produce better performance than that of agents in the ADM, which were only reacting to the specialised productive behaviour of other agents.

9.1. Verifying and validating anthropological simulations

The use of Bennett's framework to achieve a greater level of ethnographic understanding, raises the question of how realistic the adaptive dynamics framework actually is and whether its use is justifiable or can be validated. Fischer [1994] has stated that validation is difficult to achieve in any simulation of a qualitative nature (Section 7.1). However, the aim of using Bennett's framework is not to precisely replicate farmer behaviour but rather to better understand the range of decision-making processes, their interactions within other external and reflexive systems and the consequences of these interactions (Section 1.4). The framework has been applied to indigenous knowledge regarding the domain expert's *own* perceptions and classifications of crops and the attributes he appears to associate with differing strategies. The effects that they have in the model are plausible in the sense that they identify the uncertainties which he appears to associate with some specialist crops as well as new warmer climate crops (see Section 4.3.11). Copying behaviour emulates real world processes since farmers are more likely to adopt strategies (even if they have uncertainties associated with them) of their peers if they perceive their peers as successful in using these strategies, removing the need for tedious and expensive 'trial and error' (Section 2.11.4). As mentioned, on a wider scale, there is evidence that farmers will simultaneously try and be 'unique' producers in the empirical context (Section 4.3.10).

Specifically, the adaptive dynamics framework, serves as a classification mechanism of empirical strategies with micro-level effects. While one cannot suggest that Bennett's framework is observable in daily interaction, it may serve as a useful aid to ethnographic investigation in a range of circumstances (Section 10.2). That is, people may not always recognise their strategies as adaptive [Rappoport, 1969], but they may exist as a subconscious part of their behavioural repertoire or as a part their cultural values [Wilbert, 1996]. As such, these strategies can result in sustainable and cooperative, integrated patterns of adaptive behaviour as suggested by Henrich [2002] and Lansing [2001]. Structured analysis such as the use of Bennett's framework, may help to identify such behaviours if they exist.

For example, in this case, the empirical foundation of this research should mean that any observations of the model could provide an indication of the effects of the introduction of a new crop and allow this to be evaluated by both the model and the informant. Since the structure of the model is an abstraction of observations of the target system and its development has been guided by fieldwork from the beginning, necessitated by its ethnographic underpinnings, it has some explanatory power. The adaptive dynamics framework has a minimal constraining effect on the model, since primitive strategies evolve in a fairly unrestricted way into strategic designs. Thus, the framework provides a theoretical abstraction of observations in the target system which can aid understanding if not provide new insights, when considered within the context of this abstraction, acknowledging its assumptions and limitations (Section 7.7.1).

9.1.1. Historical crop choices and those reflected in the model

Actual yields dependent on temperature and rainfall were not used in the simulation since the aim of the model was not to predict crop yields, though the values representing low, average and high yields used from Nix [1998] were checked with those produced by the domain expert, since it was necessary to determine how accurately the model reflected the domain expert's historical decision-making.

A change of cropping patterns from vegetables to cereals at the end of the 1980s was correctly recorded for some agents as was the use of an insurance crop and a new break crop during the change-over period. Strategic choices reflected the evidence that some actors become niche specialists in crops such as potatoes and cereals while other became specialists in vegetable production. Farmer agents used vegetables as a *main crop* with oilseed as a *break crop* and potatoes as an *insurance crop*. However, the driving factor during the 1980s was production by overseas competitors (as this would affect prices) and not changes in environmental conditions, such as temperature and rainfall. This output was discussed and verified with the domain expert with reference to his cropping records to aid his recollection of historical crop choices.

Specialist crops such as vegetables and potatoes were reflected as such within the LADM since agents were created with randomly distributed levels of capital (£1,000-£50,000) and irrigation (0-12 million gallons which is the amount currently at the disposal of the domain expert) and therefore few agents had the irrigation and capital resources necessary to grow these resource-intensive crops.

Break crops

Oilseed Rape was often chosen as a break crop in the model, as opposed to the specialist irrigation-intensive potato crop (in reality, oilseed rape is a popular break crop, as the United Kingdom is short of alternative, inexpensive break crop options (Section 4.4)). It is grown currently, and according to the domain expert would remain an option in both warmer and wetter weather. New warmer climate crops may address the lack of choice in break crops, if they could be grown to a certain quality and yield (Section 4.3.2 and Section 4.3.11). This is shown in the results of the

LADM (Section 9.7) where soya, which represents a warmer climate crop can be chosen by adaptive agents.

In the model, peas were chosen if overseas production of soya was low, and in all other circumstances since it is one of the only other current break crop choices but it does not provide a very high income. Peas are currently grown as spring crops by the domain expert and do not require a lot of fertilizer or herbicides which makes them fairly inexpensive to grow, but as a result they are not a high value commodity (Section 4.5.1).

Main crops

In reality, vegetables are an alternative main crop option to wheat, particularly in warmer conditions, but irrigation and a large labour force are essential. [Kirby, 2000]. Currently, better prices would also be necessary (Section 4.3.6) since it is an expensive crop to grow, due to its labour requirements. In contrast, wheat is a very flexible main crop option, which does not require many inputs, and thus is grown under most conditions (and is consistently chosen by agents in the model). Although its gross margin per hectare is not as high as other crops (Figure 43), the domain expert explained that if a good quality can be maintained, growing large quantities means that it is the crop which consistently produces the largest income (Section 4.3.2). However, this means growing 'first wheats' which requires a good choice of break crops which are not currently available.

9.1.2. Historical crop varieties and those reflected in the model

Transitional phases were identified during experimentation as the years 1990-2000 due to high overseas production of vegetables, 2000-2010 due to increasing temperatures, 2020-2030 due to increasing autumnal and annual precipitation, 2050-2060 due to increasing spring precipitation and 2100 as a result of lowered summer precipitation. The simulation begins with winter-sown crops and changes to spring varieties when average autumn precipitation increases, reflecting empirical behaviour. Currently winter wheat and oilseed are grown and the advantage of growing a winter variety is that they tend to produce high yields. However, this may change to the spring sown variety if autumns become too wet (as has been the case over the last few years [Environment Agency, 2004]) as reflected by the model. The advantage of growing a spring variety is that spring crops are inexpensive to maintain as they need less herbicides.

While the model begins with wetter climate crop options it changes to include warmer climate crop options at the year 2010, when average annual temperature increases above current levels. However the difference between spring and winter crop varieties and those for warmer/wetter climates/seasons is that the former are strategies both adaptive and non-adaptive farmer agents would invoke in the model, but the latter are actually new innovative crops and would only be chosen by adaptive agents (Table 14). As a result, these agents invoke differing degrees of specialisation in the crop types and crop varieties mentioned, usually at the points of transitional change, shown by the increases in specialisation at these points in Figure 56. Individual crop choices and all other data described can be viewed in output files which are generated when the when the model is run (see "Appendix B" for details on how to run the model).

Vegetables were chosen historically (when overseas production was low) and oilseed rape was included as a break crop. Oilseed continued to be a viable choice in 2020 despite wetter annual conditions, reflecting the domain expert's choices. Spring varieties of relevant crops were chosen from 2030 onwards due to wetter autumnal conditions (Section 4.5.2 and Section 7.8.3). New warmer climate crops become an option for adaptive agents from the year 2000 onwards. By 2040 there is specialisation once again in vegetables (by singular agents which can represent productive sub-units in the population) due to possible low overseas production in a warmer climate. Production of wetter and warmer climate crops is specialised and the use of irrigation and labour resources has also become specialised.

Options considered at the beginning of the simulation representing historical choices mainly included the introduction of labour and irrigation intensive crops (vegetables and potatoes) and wetter climate crops. At the end of the simulation new crops for wetter autumns and drier summers were chosen by adaptive agents. There were various points in time when specialisation (Section 5.6.5), drift (Section 5.6.2) and delayed choices (which represent crop options) (Section 5.5.2), increased markedly and these were at transitional phases - points of economic (based on overseas production) or environmental (based on temperature and rainfall) change (see Figure 58).

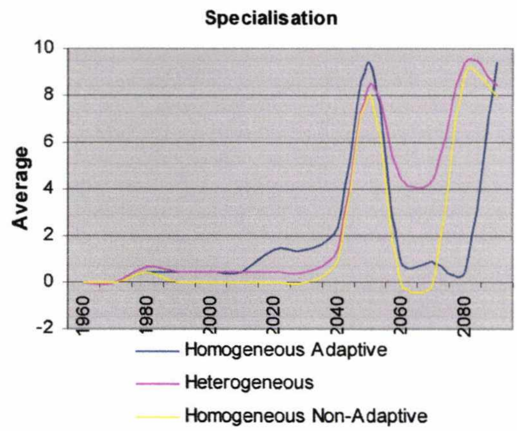

FIGURE 56. Specialisation of crops, varieties and resource-use over time, which peak at transitional phases.

The behaviour of agents within the model was supported by empirical data on strategic action collected during interviews (Chapter 4). Thus, this provided a basis upon which to map Bennett's framework of adaptive dynamics to explore whether this could provide an enhanced understanding of the strategies used and their effects on the individual and the group.

9.1.3. Validation

Fischer [1994] writes that the results of a simulation can be evaluated in a number of ways. If the simulation is basically an empirical one, which has a number of random or statistically generated events within it, we can often evaluate the results by using a statistical test. However, in many cases we are interested in using the data to establish some point for which we have no direct data. Here we are exploring the structural possibilities given what we do know. Simulations are useful for 'what if' situations, where we are attempting to extrapolate from what we do know to areas for which we have little or no data. One method of some use in evaluating simulations is examining its structural stability. This is useful where we are estimating a number of values for the different models because the information is simply not available. This is common in ethnography; of necessity we collect an account of events that are idiosyncratic to the time of study, which is often less than a year. However, we have some confidence that the behaviour that we observe during this time is not simply idiosyncratic behaviour. The particular events and situations we observe are, but we assume that the responses to these are derived from general principles of the society, and this is usually the object of ethnographic analysis. Simulation can give us an opportunity to validate some of these assumptions and analyses, because we can create contexts and situations that did not occur during our study. If the various 'solutions' we find in the social group are likely to represent general processes, we expect that they will work, and the social group will survive in a wide range of possibilities. While we cannot be sure of our simulation model, we can establish the various limits which the simulation can adapt to and therefore, the various points at which it breaks down [Fischer, 1994].

Thus, once a model appears to be valid for particular initial conditions and parameter values, it is necessary to carry out a sensitivity analysis. The aim of this is to question the extent to which the behaviour of the simulation is sensitive to any assumptions that have been made to investigate the robustness of the model. If the behaviour were very sensitive to small differences in the value of one or more parameters, one would have to question whether the particular values used in the simulation were the correct ones. In this model, one of the important parameters to test was whether a small change in the number of adaptive agents resulted in a small or a large change in the success and sustainability of the system which was the performance measure. Figure 57 illustrates the increased sustained competition in heterogeneous systems in the LADM with increasing weight towards an adaptive system. Since there were no significant fluctuations in this value by altering a parameter (number of adaptive agents) which was known to affect it, we could have some confidence in the results obtained.

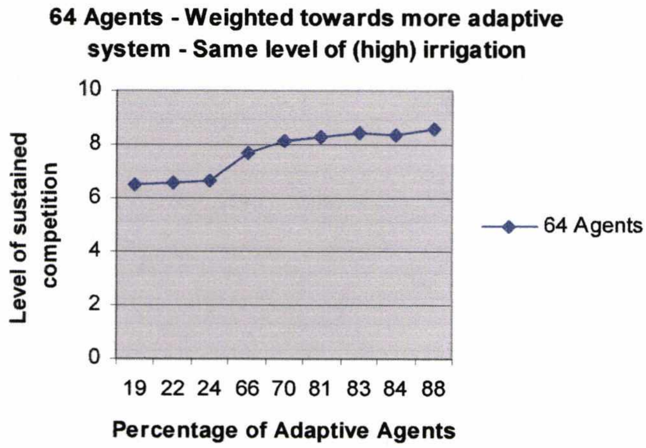

FIGURE 57. Variation of sustained competition in the LADM with increased weight towards an adaptive system with all agents with high irrigation and low financial constraint.

9.2. Variation in primitive effects of adaptation strategies

While it was apparent that an emergent property of the ADM was the success (Section 5.6.6) of a heterogeneous system of agents when constrained by neither irrigation nor capital (Section 7.6.2), it was necessary to examine the evolution of this system-level property in greater depth. An investigation was conducted into the micro-level properties individual agents possessed (including strategies with primitive effects) to produce emergent phenomena (strategic designs) at the macro-level.

The following sections will explain some of the observations made from the results of experimentation with the ADM, where the variables of irrigation and capital were held constant to provide an understanding of the increased complexity of the LADM where agents operated with variable adaptive capacity (Table 4). 'Primitive effects' here refer to the long or short-term effects of a strategy or choice taken by an agent. For example, the choice to grow any crop, results in 'delayed effects' since there is a time lag before any benefit can be felt from the harvesting of it, while the implementation of an irrigation system has *immediate* benefits in the short-term and *sustained* benefits in the long-term also.

9.2.1. Delayed effects

Figure 58 shows the occurrence of strategies which result in delayed effects that are undertaken in the three types of system, when unconstrained by irrigation or capital. According to Bennett, strategies with delayed effects are relatively low risk strategies, if as in this case, they are relatively certain to produce results. However, it is notable that the homogeneous adaptive system invoked more delayed effects than the heterogeneous system, since there were more possible available crop choices than in the heterogeneous or homogenous non-adaptive system. As one would expect, delayed effects (crop choices) also varied with increasing irrigation.

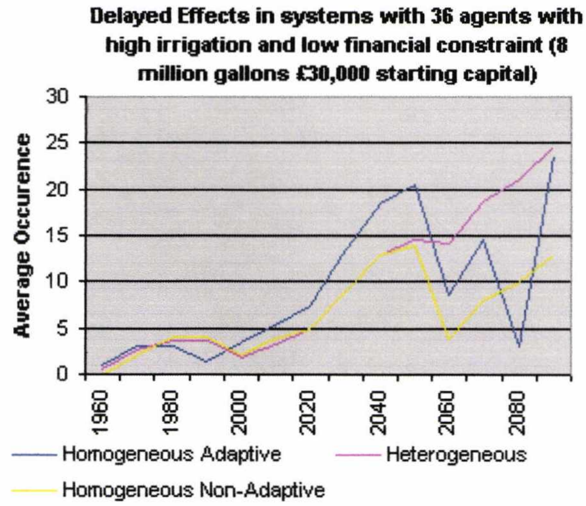

FIGURE 58. Variation in delayed effects in different systems. Multiplier effects represent the same trends since both are the effects of crop choices.

The peaks in Figure 58 represent points of transition when new crops become options due to changes in production, temperature or rainfall. Delayed effects (crop choices) and thus specialisation (Section 5.6.5) and drift (Section 5.6.2) increase at these points. Warmer climate crops become an option from the year 2000, while crops for wetter autumns (spring-sown varieties) are chosen from the year 2030 and crops for wetter springs from 2060 onwards. The troughs represent the reduced choice of agents due to the constraining effects (Section 9.3.3) of previous options.

9.2.2. Immediate effects

Immediate effects refer to any short-term strategies taken and these were invoked mostly by non-adaptive agents since these have a narrower range of crop options which require short-term strategies since they include labour and machinery intensive crops (Figure 59).

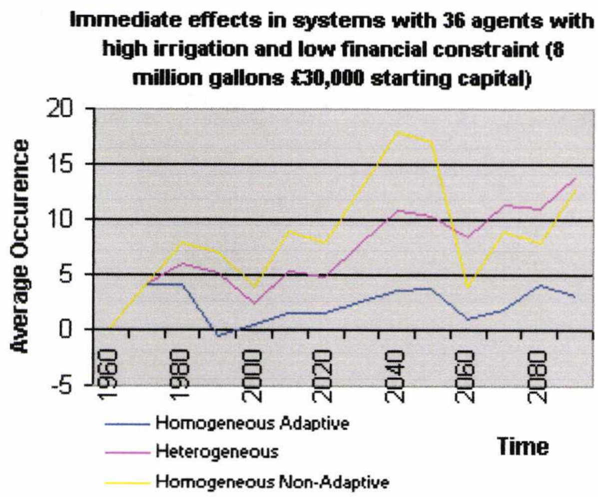

FIGURE 59. Increase in immediate effects in the non-adaptive system due to the narrow range of crops which require irrigation and labour in the short-term.

9.2.3. Multiplier effects

As mentioned in Chapter 5 (Section 5.5.4) multiplier effects result in variable levels of risk according to Bennett and refer to any uncertain costs associated with a decision such as the input of a new and unknown technology when previous inputs have failed. New varieties of crops which are developed for a changing climate are considered new technological inputs, thus it was expected that the occurrence of multiplier effects would vary with the availability of irrigation in an adaptive system. However, the introduction of any crops which require specialist equipment or labour also fall into this category and therefore even the non-adaptive system invokes strategies with multiplier effects. This was indeed reflected by the model. The frequency of multiplier effects in each type of system is illustrated in Figure 60. Agents incur more of these effects in their choices if:

a) they are opting for a warmer/wetter climate crop or any other unknown climate driven crop choice, which may require uncertain inputs, such as fertilizers and herbicides, for example (to treat unknown pests or disease with which the farmer has no past experience), or

b) if they choose crops which require additional specialist machinery or labour.

Hence, adaptive agents will invoke more strategies with uncertain effects than other agents, and this is greatest at points of environmental change when warmer/wetter climate crops become possible options. As mentioned, non-adaptive agents specialising in crops such as vegetables and potatoes may also invoke uncertain costs due to the binding power of the investment required for such labour- and machinery-intensive choices (see Section 9.3.3).

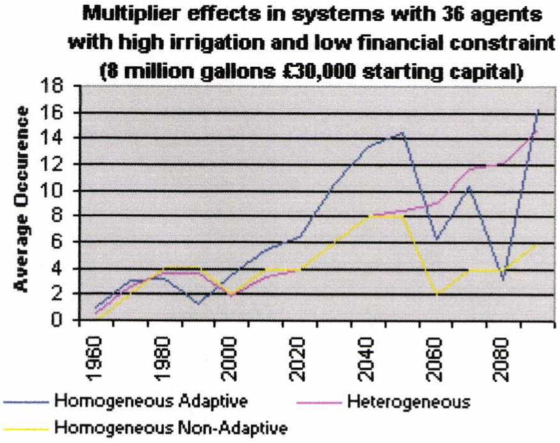

FIGURE 60. Variation in multiplier effects in different systems. The adaptive system has greatest number of strategies with uncertain costs due to 'new' crops chosen at transitional points of environmental change.

9.3. Variation in strategic designs

'Strategic designs' refer to the cumulation, over time, of patterns of the long or short-term effects (Section 9.2) of combinations of strategies. The following sections will provide examples of these based on the primitive effects described above.

9.3.1. Adaptive Drift

Adaptive drift varies with the amount of irrigation available due to the movement of decisions in a particular direction and repeated choices of particular crops being made due to the increased availability of water resources. Figure 61 illustrates the average occurrence of adaptive drift in each type of system and reflects the range of crop choices (which result in *delayed effects*) available to agents, where homogeneous adaptive and heterogeneous systems have the broadest range and thus the least 'drift' until choices become specialised and constrained at the end of the simulation, after most of the transitional phases have been overcome. The heterogeneous system has less drift overall than both homogeneous systems.

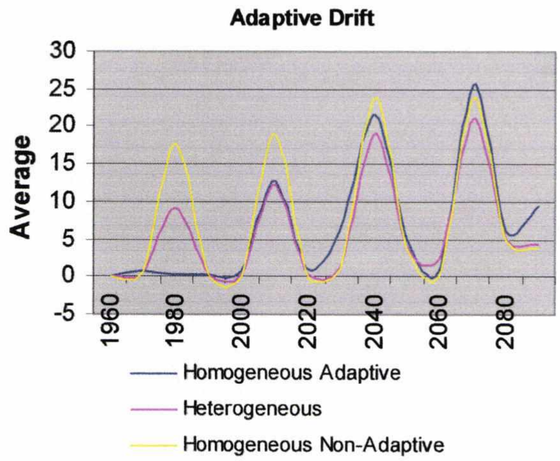

FIGURE 61. Variation in adaptive drift in different systems.

9.3.2. Incremental change

Strategies which result in immediate effects (Section 9.2.2) invoke the strategic design of incremental change after 2 time-steps. This strategic design occurs most in non-adaptive systems since these agents have a narrower range of crop choices which are more labour intensive than the new crops which are available to adaptive agents. Crops such as potatoes and vegetables require short-terms decisions such as to increase labour and this has immediate effects (Section 5.6.1).

9.3.3. Action constraint

Action constraint is similar to resource competition, but the increased number of variables in the decision making process, increases constraint rather than providing a measure of stability, due to the *uncertain* nature of the strategies/variables concerned [Bennett, 1976] (see Section 5.6.4). That is, it is a macro-level property which reflects choices which have uncertain costs and thus can become constraining or increase vulnerability over time. Action constraint results from actions that cause multiplier effects (Section 9.2.3). This results in the tension to alter strategic choices and the inability to do so due to previous investments (Section 5.6.4). Within the model, an agent that had a longer history of one choice with multiplier effects, specialised in this crop while other agents changed their choices to reflect the tension described by Bennett. This may be a non-maximising crop overall, but it will be maximising under the decision-making criteria (order in which choices are made) of the domain expert. This is designed to prevent loss by taking anticipatory decisions in vulnerable circumstances developed from past experience and accepting adverse impacts in the short term (see "Prevention of loss" and "Tolerating loss" on page 151). This reflects the unsustainability of these choices since they were altered every two time-steps. Obviously, since this strategic design is based on multiplier effects, action constraint was greatest at points when warmer climate crops (or crops for wetter autumns and springs) were options since these new choices are relatively unknown and thus have uncertain costs. This is an example of mal-adaptation since adaptive agents have a larger number of options available to them, but the uncertain investment they require can be counter-productive in the long-term, by increasing vulnerability. Winter or spring sown crop varieties can be chosen by non-adaptive agents and these do not incur uncertain costs.

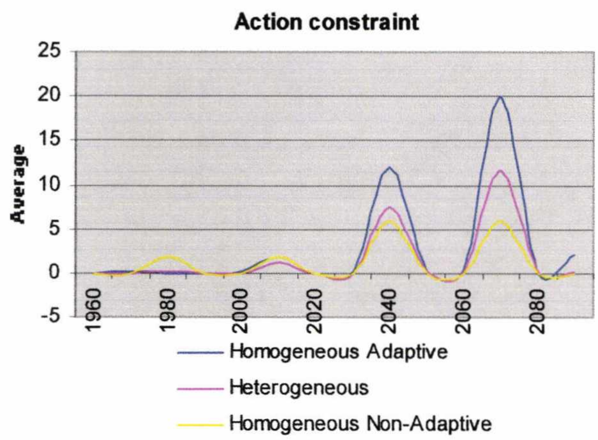

FIGURE 62. Frequency of action constraint rule (invoked every 2 time steps) in each type of system.

However, as mentioned, labour- and machinery-intensive crops such as vegetables and potatoes can be chosen by non-adaptive agents and do invoke multiplier effects, due to the large investment required and the depreciation of machinery over time (Section 4.3.9 and Section 4.5.10) which can increase future vulnerability or adaptive capacity. Therefore, they do result in some degree of constraint for homogeneous non-adaptive agents as shown in Figure 60 and Figure 62, though not as great as for those agents who are additionally opting for new and unknown crops.

Empirically, action constraint also corresponds to the hesitancy of the domain expert to forego previous investments, and make new ones by switching to the new crop Northern Soya, despite his own admission of the need for new break crops in British farming (Section 4.3.2 on page 115). The ability to be able to supply such a crop to the domestic market would provide a desirable competitive edge to British producers. Of course, the decision to grow a new crop would only be taken not only if it could command a high enough price at market to adequately cover the cost of its production, but importantly, it would also need to be worth more than the break crops that are currently being grown (see Section 4.4.1).

9.3.4. Buffering

Buffering was invoked as a strategic design when a negative strategy was persistently chosen. In Bennett's framework, if buffering persisted for several years, a step function was invoked which was a control mechanism designed to protect the particular resource under threat (Section 5.6.3). In the model, Bennett's framework was modified to issue a warning on the specialised choice allowing other agents to alter their choices accordingly (Section 8.3.1). Buffering persisted with increased specialisation, which varied with increasing water availability (Figure 63). The adaptive system operated with the greatest negative strategies such as constrained action, and thus invoked the highest degree of buffering, resulting in warnings to control the use of the resource or to change the productive regime. However, initially the non-adaptive system has the most buffering due to the specialised use of labour and water for a narrow range of crop choices.

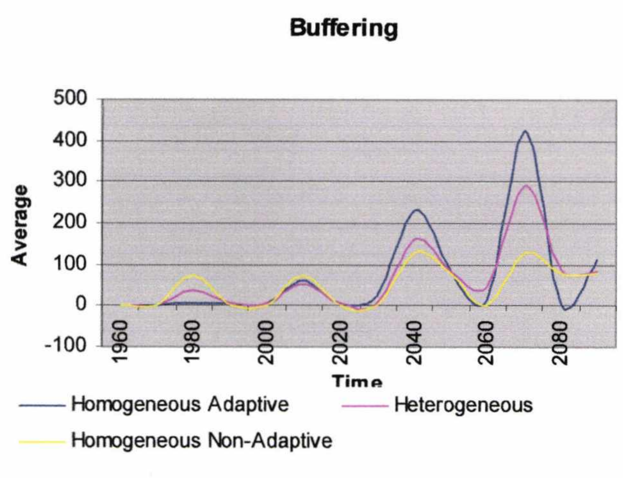

FIGURE 63. Variation in buffering strategy in different systems.

9.3.5. System Stability

Bennett's definition of *resource competition* or *homeostasis* was used as a measure of the most stable state of the system and this was justified since it is a representation of sustained cooperative competitive strategies between agents, due to the implicit requirement to make *sustainable* productive choices with respect to other agents' choices. Agents chose individual strategies which were constrained by other agents choices and thus dependent on market saturation/specialisation, *over several decades* as stated by Bennett's requirements for long-term analysis (see Section 5.4). Thus, resource competition represented a cooperative pattern of strategic designs resulting from strategy choices with varying primitive effects *over time* by successful agents (see Section 5.6.6). This relates to Henrich's comments that farmers should avoid copying short-term successful strategies (Section 2.11.4), which supports the reason that resource competition was chosen as a performance measure (and as the basis for the weights in the LADM (Figure 29)), since it represents the short-term copying of successful behaviour (tit-for-tat), on the *basis* of *longer-term* success (Section 5.6.6).

9.4. General model observations

As shown in Section 9.2 and Section 9.3 useful observations regarding the behaviour of the system became evident after detailed analysis of singular runs of various model scenarios with constant parameters of irrigation and capital in the ADM, as suggested by Edmonds [2002]. To summarise and as mentioned in Section 7.6.2, when the ADM was run with a homogenous system of adaptive agents with high levels of irrigation and low financial constraint, their sustained survival in the face of further environmental changes looked impossible due to the constraining strategies invoked as they operated with more negative strategies and lower cyclical stability (resource competition). This was not an expected result since adaptive agents possessed more overall strategies than non-adaptive agents and thus one would expect adaptive agents to be able to compete successfully and sustainably with one another which was the case in most other systems (Figure 29).

9.4.1. Specialisation

A heterogeneous system is analogous to a situation where the niche specialism of some producers (i.e. those who are sceptical towards any form of new technology, including new crop varieties) allows adaptive agents to implement new types of cropping patterns, without undue strain to the system in terms of the overproduction of one particular commodity. Therefore, adaptive agents became specialised and constrained in their decision making over time and the system did not survive without the existence of non-specialist producers to maintain variety within the system.

It was apparent that individually the adaptive agents that survived adopted warmer climate crops, but then tended towards specialization, rather than diversification because of the limit on water requirements, land available, the need to be profitable on a simple crop rotation, and to receive as much benefit from the investments made. Ironically this led to more vulnerability in the long run (less sustainable choices, even though there may be many possible options). However, it was clear from interviews with the domain expert that this could also be attributed to the lack of a broader range of break crop choices within the United Kingdom and a consequent *drift* in decision-making directed by investment (see Section 4.4). Thus specialisation varied with the availability of irrigation resources and increased because the range of available crop options in the decision-making process remained the same, unless warmer climate crops were considered. Homogenous non-adaptive agents also became specialised as they had an even narrower range of crop choices than adaptive agents without the option of warmer climate crops.

Therefore, in the ADM, most agents changed their productive regime when there were too many producers of the same commodity, but a singular agent could specialise (Figure 56). Hence, the more crop options that were available the more likely agents were to survive since they could continue with other crops that were not already being specialised in. So, while specialisation was important for some agents, maintaining a large diversity of crops was simultaneously important for others to allow them to continue being competitive producers, alongside specialist agents. This dynamic observed in the ADM, was positively exploited to improve stability and the sustainability of agents within the LADM (Section 9.7).

9.4.2. Constraint

As a result of the innovative choices available to adaptive agents, such as warmer climate crops, which have uncertain costs (Figure 62), in addition to traditional resource-intensive crops, which also have uncertain costs (e.g. vegetables and potatoes), they were more likely to become constrained by their *mal-adaptive* choices as opposed to non-adaptive agents (Section 5.6.4). That is, though agents were not constrained by irrigation or capital they were constrained by their own choices and the choices made by other agents. Therefore, it was deduced from analysis of the model output that *at transitional points* it was desirable to retain some non-adaptive agents in the system as this reduced the constraining effect of negative strategies within the system. In this way the system was more able to survive multiple disturbances and transitional phases since the non-adaptive agent represented increased flexibility at a group level. The system required those actors who were willing to make a non-optimal profit for some years, though they could benefit in the case of further climate/market-related 'events'. That is, they may be non-maximising for a time, but they were *flexible* as they had not made a large investment in a (new) technology causing them to become constrained or vulnerable to future changes, allowing the system as a whole to become more sustainable (Figure 29).

In some cases constraint resulted in the niche specialism of the agent concerned which promoted diversification among other agents. The value of this assessment is the identification of the *types* of strategies that are chosen and their benefits at both an individual and a group level. That is, the micro-level properties which were necessary to produce successful macro-level properties over time in both heterogeneous and homogeneous systems could be better analysed using Bennett's framework within a multi-agent environment.

To summarise, within heterogeneous systems in the ADM, the constraint of choice on one agent had a positive effect on the choice of another agent and specifically provided *new niches* which other agents could exploit (Section 9.7). In both homogeneous adaptive and non-adaptive systems choices remained constrained. This could be interpreted to mean that the system required some disorder to prevent agents from over-adapting and becoming restricted in their decision-making, within the context of Bennett's framework. The degree of disorder that the system could sustain was explored in the extension to the original model, the LADM, where disorder/variation was distributed among agents and imitative behaviour was included to investigate whether this would improve the range of choices further and the ability of agents to exploit them (Section 9.7).

9.5. Summary of initial observations

Stereotypical views of farmers are that they exhibit conservative behaviour and are resistant to change. However, the results of the model show that the maintenance of diversity and heterogeneity in a system, which in this domain is analogous to farmers with differing modes of production was advantageous to the system as a whole. While heterogeneity is known to be beneficial in competitive models such as in minority games [Caraa, 2004, Challet, 1997], the heterogeneity in this model emerges more as a result of decisions to alter strategies based on multiplier effects which are mainly chosen by adaptive agents *and* not to opt for a strategy that is already being specialised in, rather than solely due to the need to compete and maintain different strategies over time. Hence, the heterogeneity that is maintained is actually an outcome of a reaction to a secondary effect - action constraint - rather than solely in response to specialisation and competition.

Bennett's framework [1976] (Chapter 5) has enabled the benefits of the non-adaptive actor to be revealed, with the adjustment of particular rules to include strategy feedback, such as market saturation and resource depletion both resulting in constraint and specialisation (Section 8.3). The framework indicates that while certain strategies may result in positive short-term outcomes, choice constraint, specialisation and resource depletion may be high. As has been noted from empirical evidence gained through interviews, the initial historical transitional phase (1960-2000) had to be survived by farmers who could react to changes in the economic climate in the 1980s which was the high overseas production (poor prices) of vegetable crops in which some UK farmers had become specialists. During the second transitional phase (2000-2010), the system was required to overcome changes in the physical climate and the adaptation to warmer climate crops. Though these were modelled at a simplified and abstract level (Chapter 7) these points of transition within the simulation were important to the dynamics of decision-making among the agents and have been interpreted using Bennett's classification of strategic choice.

Experiments suggested that a system with heterogeneous agents was more sustainable and less constrained and survived the entire cycle of the simulation, that is from 1960-2000 *and* from 2000 onwards. The *transition period* between these two phases benefited from the existence of actors willing to adopt warmer climate crops *and* those who were resistant to doing so, as this resulted in a flexible system with less negative strategies than the homogenous adaptive system. Hence the hypothesis that a system comprising both types of agents would be more sustainable, even though the agents would be required to pursue differing and non-optimal roles of production was tested. That is, the system could not remain viable if the adaptation to warmer climate crops was made at the expense of becoming vulnerable or constrained by future negative impacts on the system. Since the very nature of farming itself is dynamic and responsive to gradual changes over long periods of time, this seemed a plausible though counter-intuitive hypothesis, not least because it required some actors to be non-maximising in certain years.

An investigation into the actions necessary to reduce constraint further or to take advantage of its effects in sometimes creating market niches was conducted. A solution to this issue was sought by extending Bennett's framework further to include further ethnographic data - the copying of successful strategies from peers within the system (Section 4.3.10) or *conformist transmission* [Henrich, 2002]. As a result, Bennett's framework has been used in two ways - both to identify the many interesting properties of systems at transitional and non-transitional points in the ADM and to identify additional transitional problems, for which a solution was generated, using the LADM. It seemed possible that such an extension to the ADM would emulate the decision-making described by the domain expert more accurately. Interviews had revealed that there was a dynamic of sustained competition in production with local and non-local neighbours but imitative behaviour with close neighbours - imitative behaviour unrelated to rational cost-benefit analysis has been observed in other agricultural settings [Henrich, 2002] (Section 2.11.4). The dynamic of imitating neighbouring agents was achieved by introducing weights (Section 7.6.2) in the system so that agents could copy successful neighbours at the simplest level, meaning that a heterogeneous system, would tend towards a more adaptive system, while retaining a minimum of non-adaptive agents (Section 7.7).

The results of the model indicate that a successful adaptive system must maintain diversity in order to maintain adaptiveness over time which may suggest that we must expect variation as a basic principle for social systems to survive over time. While it may be argued that the same conclusion could be reached using genetic algorithms (Section 2.11.2), this would not have been appropriate in this study as the *process* by which the evolution of adaptiveness takes place is of interest and not merely the end result. Only the *process* has explanatory power and potential in the context of the ethnographic data since we are interested in how and why choices are made as well as their consequences at many different levels. The model provides a qualitative explanatory framework and yet allows the ethnographic data to be subjected to a useful classification system, within a simple multi-agent environment.

9.6. Linking empirical evidence

Some explanation of the model can be sought in Burton's [1993] comparison of small and large scale farmers and his analysis of the similarities and differences between them (Section 7.4). Burton wrote that in dealing with drought, farmers in industrialised societies with wealth and large scale technical and collective support have more adjustment options available to them in comparison to a traditional farmer in a small scale society. These include large scale irrigation, continuous breeding and distribution of new seed varieties and financial insurance. The pre-requisite for many of these adjustments is large capital investment and extensive pre-planning neither of which would be prevalent in a small scale society. However, for both types of system in the long term, increasing hazard adjustments involve increasing efforts at the level of collective action [Burton et al., 1993].

Individuals in small-scale societies have better/denser collective social structures than those in industrialised societies, such as kin networks. However, individuals in both large and small scale societies participate to some extent in collective religious and political life, market their crops through organized cooperative or corporate institutions and look to community, region and nation for certain services to which they also contribute their support. They also possess common knowledge, and recognize knowledge that is not common in others. The services available to the mechanised farmer in industrialised countries are in greater number though he is less self-sufficient, society is more *specialised and diversified* and links to the collective society are more distant and complex. Linkages to neighbours, kin, communities and near and distant markets complicate the actions of individuals and increase their vulnerability as they depend on the *uncertain* actions of others, although this can also provide security by spreading risk [Burton et al., 1993].

In the model, the performance measure of resource competition was similar to the local and non-local competitive dynamic of Burton's [1993] near and distant markets and the uncertain actions of others (see Section 9.6.1) while the weights allowed imitation of the experiences of neighbours and *conformist transmission* (Section 2.11.4) [Henrich, 2002] possibly increasing security by spreading perceived risk.

9.6.1. Conflicting constraints

Lansing's study [2001] can be referenced to understand the conflicting constraints of cooperation and competition in the model. Lansing attempted to explain the persistence of multi-subak (local water-sharing unit) cooperation in Bali despite the apparent conflicting constraints that rice farmers acted within. Restrictions on the availability of water and labour at crucial times during the cropping calendar when farmers planted synchronously led to the expectation that successful cooperation would be difficult to achieve. However, Lansing knew that a complicated pattern of coordination among multiple subaks existed from aerial photographs of the Balinese rice terraces which showed crops at the same stage in the growth cycle. Farmers planted synchronously in line with ancient practises and in his earlier work Lansing attributed this to the need to reduce the pest population [Lansing, 1991]. However, it seemed that the practise of synchronised cropping should have led to labour and water shortages. Thus in his later work, Lansing investigated differences in yields in different scenarios of synchronised cropping and the conditions that led to region wide patterns of cooperation. Clearly the problem is a complex one, since it is difficult to find the synchronization which optimises the trade off between water shortages and minimum pest damage. A peak in demand of irrigation is caused by too much synchronisation of cropping patterns and too much pest damage is caused by too little synchronization. The action of choosing a particular cropping pattern by a subak, actively modifies the environment for its neighbours which in Lansing's case are the pest population and irrigation water flows.

Within the *Learnt Adaptive Dynamics Model* there was also an implicit goal to maximise the apparent conflicting constraints between competition and sustainability which was represented by the resource competition rule. However, the effects of environmental conditions were different to Lansing's model. In the LADM, if the use of a strategy such as labour or irrigation was being specialised in it would affect the availability of that choice to the farmer that was specialising in it, rather than neighbouring farmers since, in this scenario farmers are not dependent on the use of local resources by neighbours. However, they are vulnerable to the negative effects of dependence on a resource and the 'drift' in decision-making that would eventually trigger a control (or a buffer (Section 5.6.3)) on resource usage. However, as mentioned, local effects caused by the production of particular commodities by farmers affected neighbours and competitors choices.

Lansing's [2001] aim was to investigate how the Balinese farmers, at a micro-level, minimised pest damage and maximized water usage in a near-optimal way, while the irrigation was actually managed by the higher level subak, the farmers' association. The aim of the *Learnt Adaptive Dynamics Model* was to emulate decision-making processes, where the 'conflicting' constraints of competition and sustainability could both be achieved. The point that Lansing wished to address was how local level patterns produced by neighbouring subaks led to region-wide patterns and therefore stability. Lansing has used Game Theory (Section 2.11.1) to analyse the way in which cooperation emerged in the subak system, as a result of local interaction. The Learnt Adaptive Dynamics Model investigated the dynamics of macro-level sustainability and competition which emerged in the ADM as a result of local rules of interaction, and the topology that emerged by copying successful neighbours.

From his experiments, Lansing concluded that while subaks only connected with their closest neighbours, the larger the search space the faster the coadaptive process and the arrival at a Nash equilibrium. However, he found that if distant neighbours were included, the process of coadaptation ceased and the system remained chaotic. Lansing used this result to conclude that expecting individual farmers to replicate the behaviour of distant neighbours, such as experimental crop trials at research stations, are unsuccessful precisely because both sets of farmers are not responding to the same environmental signals, which are represented by pay-offs in the game. Lansing writes that the ability to respond to local environmental cues aids *stable* and *productive* adaptation. Not responding to these cues leads to a loss of local information which in reality leads to unsuccessful adaptation. Lansing believes that the decision to try the strategy of one's neighbours in Bali, is a myopic one which does not take into consideration the true complexity of the situation. It so happens in the Balinese example that the mathematics of the complex adaptive systems are such that the neglect of all the variables in the situation still allows a collection of autonomous agents to form networks of cooperation in a few short years. Lansing explains that the network has a structure, in which the value of both cooperation and non-cooperation varies according to spatial location. This structure is itself adaptive since perturbations that change local pay-offs trigger small cascades of change that allow the entire network to respond effectively to events such as the addition of a new irrigation system or a new rice pest (see Section 7.7.1 for why such a structure might be important). Therefore, empirically the water temple networks articulate patterns of cooperation and facilitate communication among subaks. The ritual system alone did not appear to have the capacity to generate the overall structure of the patterns of cooperation in watersheds and thus Lansing used a game theoretic methodology to propose an explanation for how these patterns could have developed. Furthermore, a point which is interesting for this research is that Lansing suggests the water temple networks of Bali are probably far from unique, but rather that wherever groups of farmers are engaged in iterative games with nature, there remain complex patterns that have yet to be revealed [Lansing, 2001].

9.7. Analysis of the Learnt Adaptive Dynamics Model (LADM)

The aim of the original Adaptive Dynamics Model was to observe the pattern of user choice within the system, and the effects of one agent's choice on another, as a result of specialised productivity and specialised use of resources such as irrigation and labour. Though adaptive agents possessed a larger repertoire of strategies and could successfully compete with one another, the heterogeneous system, with both adaptive and non-adaptive agents, emerged with a higher degree of sustainable competitive behaviour, when unrestricted by irrigation or capital. A game theoretic framework was used as a method to investigate and possibly improve the preliminary results from the ADM due to the ability of the agents to 'copy' the adaptive status of successful neighbouring agents with the additional constraints of variable irrigation and capital randomly distributed among the agents in the system (Section 9.8).

It seemed possible that the degree of sustainable competition could be improved with the spread of adaptive strategies within the system since discussions with the domain expert had revealed that farmers utilise copy-cat strategies at a local (micro) level and the reverse at a national/global (macro) level (Section 4.3.10). The 'copying' of successful adaptation mechanisms provided a more realistic perspective on the adaptation scenario, since in the real world farmers will adapt to a previously undesirable strategy if they are convinced that it works for their peers and others have received a better reward or 'pay-off' than themselves by following an alternative course of action (Section 4.3.10).

The weights (Section 7.7) in the game theoretic matrix were constructed from experimentation with the ADM and the ability of each type of system to achieve stability/homeostatic rhythm in the form of a sustained competition (representing the accommodation pattern of coordinated strategy choices (Section 7.6.2)) where agents were solely responding to environmental and competitive signals. Therefore this appeared to be a valid structure on which the base imitative behaviour. Within the LADM this represents a way of formally introducing and transmitting, as in culture, shared knowledge about the emergent properties of the ADM (Section 7.7.1). These were the high degree of stability and low negative strategies in the heterogeneous system when unrestricted by irrigation and capital and the superiority of the homogeneous adaptive system when restricted by finance or irrigation (Table 16).

TABLE 16. Summary of the performance of different systems in the ADM with constant parameters of irrigation and capital.

	High irrigation	Low irrigation
High capital/ low investment	Heterogeneous system is most successful as less constrained (than the corresponding homogeneous system) by the investment effects of the large range of options (both traditional crops and new warmer climate crops), which would become available with unlimited irrigation and capital.	Homogeneous adaptive system is most successful in systems with low irrigation since irrigation intensive crops such as vegetables do not become sustainable choices. They can opt for new low irrigation crop, soya.
Low capital/ high investment	Homogeneous adaptive system is most successful in systems with high financial constraint since high investment crops such as vegetables do not become sustainable choices due to expensive labour required. Can opt for new low investment crop, soya.	Homogeneous non-adaptive system is best with low investment and low irrigation due to reduced choice and constraining strategies in corresponding adaptive systems, which are not financially viable. Reduced choices available in systems with low investment and low irrigation can be sustained financially by non-adaptive agents.

The structural relationship of the weights functions to distribute successful strategies throughout the group, by agents copying their most successful peers and this is beneficial to the system as a whole. This copying behaviour results in productive sub-groups of adaptive agents which increase opportunities for achieving sustainable competition with more spatially dispersed non-adaptive agents and agents which are niche-specialists.

9.7.1. Baseline 'adaptive capacity'

Primarily the copying experiments in the LADM were conducted with constant parameters of irrigation and capital and this resulted higher degree of sustained competition than the homogenous and heterogeneous systems in the ADM (Figure 64). 'Copying' resulted in a large number of adaptive and an essential but smaller number of non-adaptive agents, which improved the results of the totally heterogeneous and homogenous systems (resulting in higher stability). This was as a result of the flexibility of agents at transitional points which could make innovative choices, while at the same time not becoming constrained by them, due to the degree of heterogeneity (and thus, increased range of crop options) that was still present in the system.

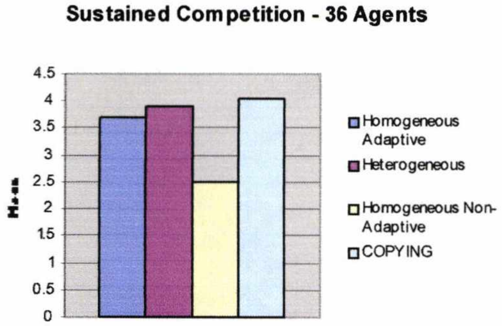

FIGURE 64. Copying in LADM with constant parameters was beneficial.

9.7.2. Variable 'adaptive capacity'

Experiments were then carried out with the LADM with randomised levels of irrigation and capital with homogeneous and heterogeneous agents. The comparative results also illustrated the benefit of imitative behaviour (Figure 65). This suggests that the weights distributed sustainable strategies throughout the group. Exogenous values in the pay-off matrix represented the composition of agent types in the system, and endogenous performance values generated by these agents were those of resource competitiveness. It is significant that an optimal system did not represent a system with the greatest number of adaptive agents. In the ADM with varying levels of capital and irrigation stability declined when the system was over-adaptive. In the LADM, agents benefited from *becoming* adaptive due to the less labour- and irrigation-intensive crop that became an option (e.g. the new warmer climate crop, soya) which increased their chances of survival.

They benefited from heterogeneity to reduce the constraint of adaptive choices which had uncertain costs, resulting not only in more available choices, but ones which *could* become sustainable. The aim to reduce the constraining effects within the ADM was achieved in the LADM due to copying behaviour since this also resulted in more differing agents at transitional points, which had a larger repertoire of crop and strategy choices, when an adaptation was required. Thus agents were again more likely to survive and also had an increased likelihood of achieving sustainable cooperative competition. This dynamic spreads and thus reduces the risk in decision-making since following the 'adaptive' status of one's peers, in this case, results in strategies which are less expensive and less resource-intensive overall e.g. soya. In reality, the effects of constraint are analogous to the specialisation of a minority of producers in a niche crop, which promotes diversity among other farmers.

Therefore, it was hypothesised that even if *constraint* or *uncertain costs* were an attribute of available choices it was still beneficial to copy existing *adaptive* strategies due to the increased chances of survival, simultaneously allowing some choices to become sustained though perhaps not those (e.g. specialist resource-intensive crops) that were being adopted in the short-term. As noted previously, 'copying' behaviour or 'conformist transmission' also removes the need for 'trial and error' which again allows this process of making successful, sustainable choices more efficient and is perceived to incur less risk.

The results of experiments with variable adaptive capacity in LADM, show that each system had different effects on the value of sustainable competition due to the low 'p-value' (Figure 65). Furthermore, the system with copying behaviour, is significantly more sustainable than the homogeneous adaptive system. It is notable that while the heterogeneous system was most successful in the ADM, it is not significantly more sustainable that the homogenous system in the LADM, but copying behaviour increases this markedly. *This is because imitative behaviour allowed global competition to be increased with niche specialists while local competition was increased with spatially dispersed non-adaptive agents.*

n	69

rc by TYPE	n	Mean	SD	SE
ADAPT	18	1194.667	362.585	85.4622
COPY	38	1481.053	384.882	62.4361
HET	13	1273.462	361.937	100.3832

Source of variation	SSq	DF	MSq	F	p
TYPE	1142621.164	2	571310.582	4.06	0.0217
Within cells	9287901.126	66	140725.775		
Total	10430522.290	68			

Contrast	Difference	Dunnett 95% CI
ADAPT v HET	-78.795	-388.741 to 231.151
COPY v HET	207.591	-66.020 to 481.203

n	69

rc by TYPE	n	Mean	SD	SE
ADAPT	18	1194.667	362.585	85.4622
COPY	38	1481.053	384.882	62.4361
HET	13	1273.462	361.937	100.3832

Source of variation	SSq	DF	MSq	F	p
TYPE	1142621.164	2	571310.582	4.06	0.0217
Within cells	9287901.126	66	140725.775		
Total	10430522.290	68			

Contrast	Difference	Dunnett 95% CI	
ADAPT v COPY	-286.386	-530.043 to -42.729	(significant)
HET v COPY	-207.591	-481.203 to 66.020	

FIGURE 65. Comparative results of ADM and LADM both with randomly distributed irrigation and capital among agents showing the benefits of copying behaviour in achieving sustainable competition.

The results of the model showed that increased variability and choice at points of change was most beneficial. This was illustrated by the fact that the constraint/specialisation caused by the choice of one agent could be exploited most, over time, by those agents that had the maximum number of choices available to them when a minority became specialized or constrained. The LADM allowed *increased* exploitation of the niche specialism by some agents as suggested by the initial results of the ADM. Therefore if an agent was adaptive it had more available choices especially those such as warmer climate crops which were not labour or irrigation intensive (Section 9.2.3).

At one level, the spatial dynamics in the *Learnt Adaptive Dynamics Model* emulate the near and distant links of the *specialised* and *diversified* society described by Burton [1993] (Section 7.4) since the dynamic of copying successful peers allowed the increased distribution of sustainable competitive behaviour, with individual specialisation and group level diversity, allowing agents to exploit niche specialisation. Since the some degree of heterogeneity provided stability, this seemed to suggest that diversification at a group level, rather than at an individual level was beneficial at both levels. That is, individually agents could pursue specialist regimes for a limited time, if operating within a diversified system. However, variability and flexibility among agents and by agents must be maintained over time and crucially at points of change.

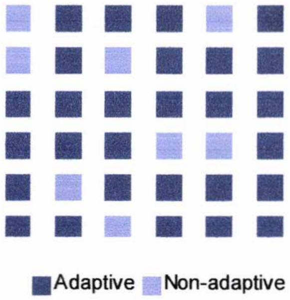

FIGURE 66. Grid topology showing spread of adaptive agents when copying successful neighbours.

Figure 66 illustrates the topology of a system with copying behaviour of agents with high levels of irrigation and minimum financial constraints. An agent is more likely to achieve sustainable competition with agents that are different, and the spread of adaptivity throughout the population increases the chances of achieving this with neighbours, as well as due to the larger range of crop options available and also the types of primitive strategies employed, which sometimes promote diversity (Section 9.3.3). In essence, copying behaviour meant that when transitional points were reached, there was an increased *opportunity* for sustained global *and* local competition. Implicitly therefore, it was most beneficial for agents that were different to be as spatially dispersed as possible allowing local *and* non-local competitive behaviour to occur. Thus, in Figure 66, non-adaptive agents became more dispersed as copying of adaptive agents occurred, and sustained competitive behaviour was more likely between these agents of *differing types*, due to the greater chance of differing strategies and crop options, *as well as* with *niche specialists* within the larger population.

9.8. Using the model to further ethnographic enquiry

Observations of the model showed that it was the effects of choices with *uncertain costs* which had the greatest effect on the possible number of sustainable choices within the system, and thus the resulting value of sustained resource competition. This led to further empirical ethnographic investigation into alternative farm management strategies and their effects and whether they could be made more sustainable by introducing choices that did not have these types of uncertainties associated with them.

This required further discussions with the domain expert which revealed that there were indeed strategies which had been discussed and were thought to have risks surrounding their implementation, which could be reduced in certain circumstances. Thus, the hypothesis developed from the model suggested that strategies which involved less constraint (identified using Bennett's framework) and vulnerability should in theory lead to more sustainability. This hypothesis could be tested with new data provided by the domain expert.

The two crop choices thought to have uncertain costs were those of onions due to its specialist machinery requirements and the new warmer climate crop soya, due to the risks surrounding a move to a new crop. Follow-up interviews with the informant identified particular circumstances in which these options would not involve as many uncertainties as originally thought. For example,

> *the big advantage [with onions] is that you can use the same machinery as for potatoes and of course the thing with onions is ... they sit on top of the soil and are better suited to marsh*

> *land conditions [as on the domain expert's farm] than anything like a potato which is under the soil.*

Furthermore, it was highly significant that at the time of this interview, onions were becoming more and more of an option since they did not depend on subsidies, so presumably if one was successful at growing them without subsidies from the start, when they are removed from agriculture altogether, the domain expert would be no worse off, and may be at an advantage over his competitors, if it was not a crop that was oversupplied (Section 4.3.6). Indeed, in these later interviews, the informant no longer believed that vegetables would actually be a successful alternative main crop due to the continuing competitiveness of European countries and strength of Sterling, and began to favour onions as a serious alternative. The advantage of this in his case was that he already possessed much of the necessary machinery through his specialist potato production and had some heavy marsh land which could still be used for onions. This would reduce many of the risks and costs in depreciation that new specialist machinery would normally incur.

The other crop which had been discussed as a future possibility was the soya bean. However, there were understandably many uncertainties and perceived risks associated with switching to a new crop, specifically bred for changing climatic conditions. But, discussion with the domain expert indicated that many of the uncertainties previously associated with this crop would be reduced as the informant already had a large repertoire of experience growing legumes, such as peas and beans and this specialist knowledge is very similar to that required for the soya bean. While,

> *the biggest problem with a new crop are the herbicides that you need, and the diseases it gets, I think the agronomy side of it [new Soya bean] is not too different from [peas and] beans, so I think we should be okay.*

Risks associated with new crops are further reduced by the ability to visit crop trials to assess the quality and yield of a new crop and to assess the diseases it is susceptible to and the herbicides it requires. It is notable that as soon as the quality of new crops such as Northern Soya are seen to be high quality and high yielding and they are of comparable value to current break crops they will become a serious viable option. As mentioned in Section 4.5.5,

> *... without doubt, I mean* ***we are all looking for new crops. We are fed up with the old crops, because they are all becoming overproduced*** *... It would have to be worth going for money-*

> *wise, and* ***it would want to be worth more money than peas and rape. Because we know how to grow rape and peas, we are reasonably good at it.*** *I mean if it was valued at similar sort of gross margins as peas and rape it would just be another one to discuss almost ...*

Thus, the LADM was run with the new information regarding the removal of uncertain costs/ multiplier effects (Section 8.3.3) when onions were chosen if potatoes were grown in the past and when soya was chosen if there was knowledge and experience of growing legumes. Experiments with the model with strategies without uncertain costs resulted in a higher level of sustained cooperative competition as expected (Figure 67). This was particularly the case, since onions require less irrigation than potatoes and less labour than vegetables, making them a real consideration and a viable main crop alternative. While soya is a less resource-intensive crop overall and therefore a suitable break crop alternative, the results of the model and further ethnographic enquiry have also allowed a new main crop option to be identified.

n	92

rc by TYPE	n	Mean	SD	SE
ADAPT	18	1194.667	362.585	85.4622
COPY	38	1481.053	384.882	62.4361
COPY-NEW-DATA	23	1557.348	422.902	88.1812
HET	13	1273.462	361.937	100.3832

Source of variation	SSq	DF	MSq	F	p
TYPE	1766106.396	3	588702.132	3.92	0.011
Within cells	13222514.343	88	150255.845		
Total	14988620.739	91			

Contrast	Difference	Dunnett 95% CI	
COPY v ADAPT	286.386	19.086 to 553.686	(significant)
NEW-DATA v ADAPT	362.681	68.697 to 656.666	(significant)
HET v ADAPT	78.795	-261.226 to 418.816	

FIGURE 67. Comparison of results of strategies with and without hidden costs resulting in choice constraint.

9.9. Conclusion

The conclusions that can be drawn from the results of the model, are that implementing Bennett's framework within a multi-agent model has allowed a greater understanding of the ethnographic data that was collected. Primarily, salient features about particular types of system could be identified such as the greater frequency of immediate effects (short-term strategies) in non-adaptive systems (Section 9.2.2) and increased multiplier effects (strategies with uncertain costs) in adaptive systems (Section 9.2.3). Secondly, the model illuminated the constraining effects of strategies with multiplier effects which led to the identification of the heterogeneous system as that which was more stable when unrestricted by irrigation or finance (Figure 64). Conformist transmission increased this stability (Figure 65) due to the increased opportunities of imitative adaptive agents to achieve stable choices with agents which were niche-specialists as a result of constrained choices, due to the greater number of strategies available to them. That is, heterogeneity was beneficial in reducing the constraint of purely adaptive choices, and allowing agents to become specialist producers rather than becoming restricted and vulnerable as a result of choices which entailed greater uncertainty and risk.

Observations of the ADM showed the constraint that the homogeneous adaptive system operated under as a direct result of the further costs associated with adaptive strategies. The choices of new crops for a warmer and wetter climate *and* labour- and irrigation-intensive crops such as potatoes and vegetables resulted in options which rarely led to sustained choices between multiple agents in the system. However choices which had constraining effects did have differential outcomes as explained by Bennett. Constraint led to a paradox whereby individuals would like to alter their strategies due to the mounting uncertain costs associated with their chosen strategies, and the simultaneous difficulty in doing so, due to the binding power of the previous investments incurred by these uncertain but necessary costs. Therefore, the benefit of the heterogeneous system was that it reduced this potential vulnerability since there were fewer agents that were likely to become caught in this paradox as non-adaptive agents would not opt for warmer/ wetter climate crops. This allowed adaptive agents in a heterogeneous system to exploit the niche specialism of those agents who became specialised as a result of constraint, as well as non-adaptive agents who simply followed certain strategies that were different.

The additional reason that copying behaviour improved the performance of the ADM was that the system benefited from agents that had a greater option of crops which included one that was less labour, machinery and irrigation intensive than other specialist crops - soya - which led to a greater chance of survival since agents were endowed with random levels of capital and irrigation in the LADM. Furthermore, it was important that at transitional points of change within the simulation - that is when warmer/wetter climate (wetter autumn/spring) crops were chosen, there was some heterogeneity since this was when constraint and vulnerability was greatest (Figure 60). However, it was also important that when new crop options were chosen there were a large number of adaptive agents which could make the innovative choice especially when some constraint did require agents to alter their strategies. This increased competitive opportunities in the heterogeneous system which evolved (due to the weights) to contain a majority of adaptive and a crucial minority of non-adaptive agents, as the constraint of the homogeneous adaptive system was reduced but the benefits of the adaptive agent were still co-opted and exploited.

Copying behaviour (referred to as a tactical adjustment by Parry and Carter [1998] (Section 5.1)) emulated real world processes in the sense that farmers will adopt strategies of their peers if they are perceived as successful and simultaneously try and be unique producers in the wider context. The combination of becoming constrained by one's choices and copying ones' neighbours and becoming adaptive corresponds to the need to have the capacity to make new choices at times of change. That is, the *ecological transition* [Bennett, 1976] to a new regime requires maximum flexibility, while 'copying' allows the evolution of agents with the greatest range of choices, and thus less risk and vulnerability, when existing choices become constrained. As mentioned, copying adaptive status in this case also means increasing possible crop options to include a crop that is not resource-intensive (soya) and this means that agents are less likely to fail because they are less likely to choose crops which are speciality crops and require high levels of inputs. This is illustrated by the interaction between adaptive and non-adaptive agents in the model where the wider community allows spread of risk as the imitation of peers and sustained competition enables increased security, in terms of the probability of making successful choices.

Global competition was increased with niche specialists and local competition with spatially dispersed non-adaptive agents. The identification that multiplier effects resulting from strategies with uncertain costs, also led to less possible choices becoming sustained, encouraged further exploration of empirical strategies, which would in theory lead to more sustainable options. Thus, a theoretical abstraction of ethnographic observations was used to create the model and the model output allowed the formation of a hypothesis within the context of this theory, regarding the properties of past strategies and their effects on the individual and the group. This informed further ethnographic enquiry, which provided new inputs for the model which could then be experimented with to test the hypothesis, in an iterative process. The hypothesis was then validated by both the model and by the domain expert.

In conclusion, empirical strategies of producing something different to one's competitors and copying one's neighbours strategies did lead to greater group stability within the context of Bennett's framework resulting in specialist productive sub-groups within population. Stability was measured as sustained survival taking into account variable irrigation and starting capital and the preference of producing something that is not being overproduced. Strategies adopted by farmer agents were most sustainable if they were diverse at a group level at points of change. *Furthermore, avoidance of resource-intensive traditional crops (such as vegetable and potatoes) at transitional points of environmental or economic change is advantageous to reduce the probability of the additional and uncertain costs associated with 'new' crops which may become options at these transitional points.* Though this may result in non-maximisation of income for a time it promotes sustainability of the individual and the group. If this is not possible due to the narrow range of crop choices available in British farming, any possible uncertainties associated with a new strategy should be minimized to increase the possibility of sustainable choices. *That is, if tools or knowledge and expertise required for a new option can be 'carried over' and utilised from a past strategy, as was demonstrated in the case of onions and soya in Section 9.8, this is most beneficial in reducing vulnerability, maintaining adaptive capacity and flexibility and thus increasing sustainability (Section 9.8). This may mean that new warmer climate crops will be more readily adopted by farmers if they do correspond in some way (e.g. in terms of agronomy, harvesting or target markets) with crops they already have knowledge and experience of growing.*

New insights in to the ethnographic data that were provided by the combination of qualitative and quantitative methods used in this research, have provided an analysis of the ways in which poorly understood social models of adaptive behaviour relate to more well understood environmental and economic models. An analysis of the ways in which these structures of knowledge interact and their resulting effects has allowed an understanding of the empirical data which has been usefully applied back to the ethnographic context using an appropriate theoretical framework to gain further insights regarding adaptive behaviour.

CHAPTER 10 Conclusion

The main objective of this research has been to use a variety of tools to better understand ethnographic data exploring adaptation options which focus on how environmental and economic changes in the agricultural domain have been dealt with in the past, to suggest how such effects could successfully be absorbed in the future. In this way existing mechanisms for adaptation may be exploited and optimised for future benefit. This required an understanding of the extent and way in which social, economic and climatic factors have been the drivers of decision-making, and how these different spheres of knowledge interact. This has been facilitated by the methods described in the previous chapters which have attempted to achieve the objectives set out in Chapter 1. The extent to which these objectives have been met will be discussed in the remainder of this chapter.

10.1. Conclusions of the research

One of the specific objectives identified in Chapter 1 was an investigation of the relevance of Bennett's anthropological theory of adaptive dynamics [1976] to how farmers adapt to changes in environmental and economic contexts. In the agent-based model created for this research the adaptive dynamics framework was modified (based on ethnographic data) to include the feed-back effects of specialisation and resource use in order to analyse the effects on adaptive and non-adaptive structures of knowledge. While the Adaptive Dynamics Model (ADM) was intended to simulate competitive decision-making behaviour among agents, where agents attempted to be unique producers, the Learnt Adaptive Dynamics Model (LADM) introduced a component where agents imitated the behaviour of their most successful neighbours. These dynamic structures of competition and imitation are evident in farming behaviour. The imitative behaviour in the LADM results in a minimal spread of heterogeneous agents invoking the competitive productive local agent rules in the ADM, improving flexibility and stability and reducing the effects of constraining negative strategies. That is, as adaptive status spread throughout the population, as a result of agents' propensities to their copy their neighbours successful strategies, their chances of being *productively different* from their competitors and niche specialists improved. This dynamic required a certain degree of diversity (heterogeneity) within the system, and particularly at times of change when new choices could be made.

Observations of the ADM showed the constraint that the homogeneous adaptive system operated under was as a direct result of the further uncertain costs associated with adaptive strategies. The choices of new climate-related crops invoked in combination with labour and irrigation intensive crops resulted in constraint which could not lead to sustained choices for individual agents (specialisation) or between agents (resource competition). The benefit of the heterogeneous system was that it reduced this potential constraint since there were fewer agents that were likely to opt for innovative crop options and therefore there was less uncertainty associated with their decisions, as is perceived in reality.

Social science is less concerned with prediction than with identifying how behaviour evolves and influences other processes [Gilbert and Troitzsch, 1999]. Bennett's framework made possible the identification that multiplier effects resulting from strategies with uncertain costs, also led to less possible choices becoming sustained. This encouraged further exploration of empirical strategies which would in theory lead to more sustained choices. Thus, ethnographic information was used to create the model and the model output allowed the formation of a hypothesis regarding the properties of past strategies. This informed further ethnographic enquiry, which provided new inputs for the model which could then be experimented with to test the hypothesis. The hypothesis was then validated by both the model and by the informant.

The additional objective was to use and evaluate agent-based methods for modelling farmer knowledge and interactions with their changing context. This methodology has been successful in this domain since it has allowed dynamic structures of knowledge which were formalised using Bennett's framework, to be represented in a way that facilitates analysis of the emergence of behavioural phenomena at the macro, group level and whether this creates new theoretical possibilities at the individual level (Section 9.7). Local copying behaviour in the LADM improved the performance of the (globally) competitive ADM since the system benefited from adaptive agents that had more crop options when required to diversify, which included one - soya - which was less labour, machinery or irrigation intensive than other specialist crops such as potatoes or vegetables. This led to a greater chance of survival, since agents were endowed with random levels of capital and irrigation in the LADM. The narrow choice of crops available in British farming is often limited to specialist traditional crops which are resource intensive and require high levels of investment. This explains some of the problems farmers are facing in increasing their incomes in the current economic climate, and thus they are seeking to diversify (e.g. introducing new crops (Section 4.5.5)) and subsidise their incomes in other ways (e.g. farmers' markets (Section 4.5.13)).

The model showed that it was important at times of *environmental transition* - that is when warmer/wetter climate crops became viable options - there was some heterogeneity since this was when the constraint associated mostly with adaptive agents was also greatest. Nevertheless, it was also important that when new crop options were chosen there *were* a large number of adaptive agents which could make innovative choices especially when some constraint did require agents to alter their strategies. It emerged that to try and be a unique producer involved choosing crops which had uncertain costs whether they were traditional specialist crops or new crops altogether. That is, agents benefited from being adaptive as long as they could maintain some degree of flexibility. Thus, in the LADM, the advantages of both the adaptive (larger range of options) and non-adaptive (range of crops with fewer uncertainties attached) agents were exploited increasing competitive opportunities at transitional points in heterogeneous systems where there was an element of conformist transmission. In a heterogeneous system the niche specialism of some producers (e.g. specialist non-adaptive agents) allowed adaptive agents to implement new types of cropping patterns, without undue strain to the system in terms of the over supply one particular commodity as a result of specialised production. Therefore, global competition was increased with niche specialists and local competition with spatially dispersed non-adaptive agents.

In reality the combination of becoming constrained by one's choices and copying one's neighbours by becoming adaptive corresponds to the need to have the *adaptive capacity* to make new and alternative choices at times of change. That is, the *ecological transition* [Bennett, 1976] to a new regime requires a high level of flexibility and 'copying' allows the evolution of agents with the greatest range of choices, when existing choices become constrained. This flexibility is in contrast to the time lag often associated with adaptation (e.g. Section 2.1, Section 5.6.3) which is the time taken to respond to, or recognise, an impact or a negative effect, the result of which can often be mal-adaptation.

To summarise, the empirical strategies of producing something different to one's competitors and copying one's neighbours strategies led to greater group stability within the context of Bennett's model resulting in specialist productive sub-groups within population. Furthermore, strategies adopted by farmers were most sustainable if they were diverse at a group level at points of transitional change, which may be environmental or economic. However, avoidance of high input traditional crops (such as vegetable and potatoes) at transitional points was advantageous to reduce the probability of additional and uncertain costs associated with new climate-driven crops. Though this may result in non-maximisation of income for a time it promotes sustainability of the system and the group. If this is not possible due to the narrow range of crop choices available in British farming, any possible uncertainties that may be incurred by a new strategy should be minimized to increase the possibility of sustainable choices. That is, if tools or knowledge and expertise required for a new option can utilised from a past strategy, as was demonstrated in Section 9.8 where the knowledge of growing legumes removed socio-economic costs to facilitate a transition to growing soya and the use of potato machinery for onions, reduced the costs and depreciation associated with machinery-intensive crops, this is most beneficial in reducing vulnerability and increasing sustainability. Thus, simple heuristics such as *unique production* and *conformist transmission* do not just make sense economically, but adaptively also, by increasing the *opportunity* for competition between local *and* non-local competitors. The key to understanding differing behaviours lies in the cultural processes that create and maintain differences in beliefs and ideas - these create and maintain diversity - the model shows that beliefs relating to copying and competition are the same ideas which create and maintain diversity, but also sustainability, and thus the expert knowledge described by the domain expert did result in successful strategic choices. And, as Rappoport [1969], Lansing [2001] and Henrich

[2002], amongst others, have demonstrated, while such strategies may not consciously be cooperative, they can nevertheless result in integrated patterns of *sustainable* adaptive behaviour.

The recognition of the benefits of diversity in a system at transitional points of change, is not a new conclusion and has been suggested in other work using genetic algorithms. However, one of the benefits of this research and the methodology used here is the identification of the *processes* required to create and maintain this diversity i.e. that of copying local neighbours and simultaneously competing with near and distant ones and its *effects*. In additions to this, it should be noted that this does not appear to be a *conscious strategy* (first raised by Rappoport [1969] (Section 2.2)), or at least its significant and far reaching effects do not seem to be fully recognised by farmers themselves. However, it provides a sustainable solution regardless of direct consideration of cost-benefit analyses.

The final core objective of this study was to attempt to integrate conventional ethnographic methods with knowledge-engineering techniques. The results show that the expert knowledge described by the informant, which is documented in Chapter 6, results in successful strategic choices within the context of Bennett's model. Indeed, computer modelling techniques combined with theoretical anthropological approaches have aided a better analysis of the *process* with respect to adaptation and *transitions*. Bennett's framework has helped to identify important properties about different systems (Section 9.2, Section 9.3) and to illustrate the importance of diversity at points of change within the transition process. The value of using an agent-based model to embed the expert knowledge and for analysing a theory such as the adaptive dynamics framework lies in the potential to reveal new areas for exploration and analysis in further research.

The particular computing tools used have allowed the relationship of the differing structural domains involved to be better understood [Fischer, 1994] by revealing recurrent cognitive principles [Spradley, 1979] in the decision-making process (Chapter 6). The use of Jess [Friedman-Hill, 2001] (Section 3.5) as a plug-in for RePast [Collier, 2001] (Section 3.4) has successfully allowed these structures of knowledge to be represented. This has facilitated analysis of adaptation processes retaining the qualitative theoretical framework required to interpret the results of the simulation model which represented environmental constraints. Thus, this methodology has successfully used observation and theory to create a model which can usefully be re-applied to initial observations and analyses of the target system.

Furthermore, the research process, and in particular the models and techniques described here are simple enough in their implementation that similar work could be carried out by anthropologists to *complement* their other research methods since relatively simple models can be created with limited programming knowledge as explained in Section 3.4.

10.2. Applications in anthropology

This research has demonstrated some of the potential of computational methods to analyse anthropological problems. Since agent-based methods no longer depend on the aggregation of human activity which would make them inappropriate for the anthropological study of many areas of human behaviour, this simultaneously creates opportunities to apply anthropological theory to a range of computational methods, such as the knowledge engineering techniques documented in Chapter 6.

The model described here suggests that system level diversity is essential for agricultural systems. In Chapter 1, a theme identified for exploration was the producer-consumer dialectic and the sensitivity of the world food system due to the dependence on 'bread-basket' countries for imports and the vulnerability of these countries to the effects of climate change. At an individual level, farmers may specialise in a number of crops but flexibility is essential to the enterprise. For small farmers in developing countries this would also mean choosing crops which have a wide diversity of end uses while the maintenance of a diversity of crops also aids food security in the case of crop failure. Thus, while the main goal of small farmers in developing countries may be food security and for those in more developed countries it may be to access a niche market in which they can compete, both types of farmer benefit from the maintenance of flexibility.

Specialisation can produce sustained yields, but it can also lower the capacity for adaptation due to rigidity of relationships forged with natural resources and consumer markets. While farmers in developing countries are even more vulnerable to such lowered adaptive capacity due to the additional effects of environmental shocks, producers in developed economies can also be vulnerable if there is a heavy dependency on a narrow range of crops, as is the case in the UK (Section 4.4). This is illustrated by non-adaptive agents in the model where the wider community allows spread of risk as the imitation of peers and sustained competition enables increased security and reduces the risk of trying new options by removing the need for 'trial and error'.

As mentioned, farmers in developed economies are attempting to diversify their incomes by growing speciality crops or resorting to new types of agriculture altogether which are appealing to consumers, such as organic farming. Presently this includes the introduction of new crop varieties bred for a changing climate, but also relates to discussions regarding 'genetically modified' crops and the effects that banning the introduction of them in the UK has on the potential competitiveness of farmers (Section 4.3.8). As the domain expert pointed out....

> *I do see it as a terrific threat because here is America, South America, and Africa or wherever these GMOs are appearing - they are all getting their produce to the market cheaper than we can do it in Europe. This is part of the reason why our produce prices are so bad in the UK at the moment, and that is going to get a lot worse quickly. So a 5-year ban on the introduction of GM crops is a huge threat and a terrific disadvantage [BBC, 2000]. In that case, there may be an opportunity for us to take advantage because so many crops are soiled with GM crops. Nationally we might gain because our crops will not be GM contaminated but internationally we would lose out. Big competition factor.*

Applications in anthropology could benefit from Bennett's agent-oriented framework due to its generic nature. It is a useful method of formalising interview material and could serve as an important transitional vehicle for use in a simulation. The patterns of primitive effects and strategic designs could be applied to a range of problems allowing macro-level properties to be analysed using primitive micro-level identifiers. While Bennett's model has merely facilitated a formal representation of the modellers understanding of the knowledge within this domain and does not claim in any way to exhaustively represent it there are many advantages in creating a more formalised, though simple representation of domain knowledge within anthropology. Thus, Bennett's model could make a significant contribution to the study of social phenomena which exhibit similar general characteristics to the research questions addressed here. The benefits of modelling a complex adaptive system using this framework lie in the ability to identify characteristics - macro-level strategic patterns/designs - which are important to the functioning of a successful system and its essential underlying components - strategies with primitive effects - micro-level effects which can also be easily identified and analysed. Other computational methods such as genetic algorithms (Section 2.11.2) may not be as useful to anthropologists who are interested in the *process* in attaining the solution and not simply the end solution itself, as well as in the way such constituent processes and models *interact* with one another in the course of reaching the solution.

Though the ADM and LADM are highly simplified models of farmer decision-making they serve to exemplify the benefit of simulation techniques for the implementation of frameworks such as Bennett's as an aid to traditional ethnographic analysis, especially when we try to apply this analysis to our proposed models of understanding. While some dynamics have not been included, the major factors and contexts within which the informant discussed his options have been captured, and this is enough to guide further ethnographic investigation along better informed avenues.

10.3. Final comments

Bennett's model was useful in avoiding some of the criticisms of previous studies in cultural ecology, such as the lack of an analysis of historical change and the neglect of an assessment of solutions to past problems (Section 2.3). Moreover, Bennett's model itself allowed the identification of transitional problems, as a result of using old solutions, such as 'constraint' for which a modified approach was sought. New solutions emerged in terms of the possibility of the heterogeneous system to relieve the constraint of homogeneous adaptive systems and conformist transmission in the LADM to improve sustainable behaviour further.

The conformist transmission described by Henrich (Section 2.11.4) and demonstrated in the LADM suggests that *the combination of copying the behaviour of most successful individuals in a system while simultaneously following simple heuristics regarding unique productive potential is enough to produce strategies that maintain sufficient flexibility within the system for agents to remain adaptive over time.* This relates directly to that which Henrich has observed among Mapuche farmers who also employ context-specific heuristics when economic circumstances call for behavioural flexibility. Central to Henrich's argument is that in contrast to the effect of the *static transmission* of knowledge, cultural transmission is heavily biased in ways that have substantial and often adaptive consequences, causing changes in the distribution of the population over generations. Therefore, he writes that it is possible that people may possess well-adapted behavioural repertoires, not because they are good cost-benefit calculators, but because they follow simple rules such as copying the most successful individual which generates well-adapted behaviour in cultural evolutionary time [Henrich, 2002] (Section 2.11.4). The reduction of constraint in a heterogeneous system which sometimes promotes more diversity with niche-specialists is enhanced by copying behaviour and thus, this combination of strategies is possibly one of the well-integrated, adaptive behavioural patterns that can be observed ethnographically, described by Henrich.

Fischer writes that the failure to successfully adopt natural sciences methods in the social sciences has been due to a failure to address the *fundamental differences* between social science and natural science phenomena [Fischer, 2002]. It is hoped that this study is one example that does recognise these differences and in doing so synthesises such diverse methodologies in a way that *is* insightful by assessing the performance of social models, such as that of 'farmer adaptation', in context with 'well-understood' models, such as those of economics and environmental change. That is, the dynamics of the models of human-environment interaction can be better understood using inter-disciplinary methods which address the fundamental differences between these domains.

As mentioned in Section 9.5, successful adaptive systems must maintain diversity in order to maintain adaptiveness over time. This suggests that we must expect social systems to possess variation as a basic principle for social systems to survive over time. That is, monocultural positions are unstable positions unless they are insulated from direct interaction with the environment and the context within which they are embedded. However, even the small Hutterite communities that Bennett studied in 1966 were not insulated from the effects of the ranchers' strategies, external institutions and bureaucracy, though they aspired to be an enclosed community [Bennett, 1966].

The results of the model documented here demonstrate the important benefits of heterogeneity in conjunction with 'cooperative' competition. This research has provided evidence that successful competitive systems lead to cooperative behaviour if they are to be sustainable. Furthermore, since the world around us is a changing place - as a result of our collective past behaviour, ideational innovations by ones self and others, and since environments are always a locus of trends rather than deterministic systems - heterogeneity is necessary for sustainable communities of either a cooperative or competitive nature. This supports the notion that any society, however small, must have access to sources of variation to be adaptive, and probably will require mechanisms to ensure this variability is available. In the model documented here, integrated empirical local rules used by farmers to *produce something different to one's competitors* while *copying successful adaptive strategies* provide these sources of variation and diversity and the sustainability of the resulting *cooperative competitive* dynamic is a mechanism which ensures this variation is available over time. Other examples of such mechanisms are the *'microcosm-macrocosm'* relationships observed by Bennett [1966] among Hutterites with respect to ranchers, farmers and the wider economy; the cooperative competitive implications of cyclical 'Kaiko' rituals among the New Guinea Maring which served to reduce warfare with neighbouring groups [Rappoport, 1968]; and in the case of the isolated environment of the Warao Indians, their adaptive 'toolkit' which included the translation across successive generations of oral histories and a weather religion revealing an 'ecological mythology' or a 'blueprint of interrelationships between humans and the environment which revealed a treasure of adaptive wisdom', promoting the variable and sustainable use of finite resources [Wilbert, 1996].

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Name: ______________________ Date: ________________

Appendix A

Climate & Agriculture Questionnaire

This is questionnaire is to part of Ph.D. research that is being conducted at the University of Kent at Canterbury.

It aims to assess the best possible agricultural adaptation options for dealing with climate change. A computer model is being created to analyse the effects of these options.

I would appreciate any feedback that you can offer, and your answers to the questions below. There is no need to provide a name, if you wish to remain anonymous.

Thank you in advance.

Question 1. What are your opinions on climate change and global warming? Do you think it will affect agriculture? If so, in what ways?

Question 2. What measures will you take in order to cope successfully with changes in global climate, even if these changes will be very gradual?

Question 3. How do you deal with drought?

Question 4. How do you deal with floods?

Question 5. What crops do you grow?

Question 6. How much land do you farm?

Name: ______________________ Date: ________________

Question 7. Which of the following describes the way in which you acquired this farm?

a) Inherited: from previous farmer as sole legatee

b) Inherited: from previous farmer, jointly with sibling(s)/other relatives

c) Purchased farm

d) Rent farm

Question 8. Personal farming history. Please can you tell me whether you have

a) Always been in farming?

b) New to farming?

Question 9. Do you contract farm?

☐ True

☐ False

Question 10. What are your goals in farming? E.g. maximize profit, maintain a reasonable living, carrying on family tradition, develop farm for a successor, etc.

Question 11. Do you have access to irrigation? If so, from what source?

Question 12. How many people do you employ to work on your farm?

Question 13. Are you a part of a farming cooperative?

☐ True

☐ False

Question 14. Are you a part of a machinery ring?

☐ True

☐ False

Question 15. How much do you rely on subsidies, and how do you think that the changes in subsidy payments are going to affect your decision-making in the future?

Name: ______________________ Date: ________________

Question 16. When making long-term farming decisions, who most influences you? Circle more than one if appropriate.

a) Family members
b) On-farm employees
c) Other farmers
d) Landlord
e) Local Government Adviser
f) Local Non-Government Adviser (e.g.: farmer's union; environmentalist, etc.)
g) Other specialist adviser (specify):
h) Other (specify):

Individual Crops

Please answer the following questions for each of the crops that you grow/know how to grow. If you do not know how you to grow the crops listed in any of the following sections, cross out the crop name and replace it with a crop that you do know how to grow.

Potatoes

Question 1. Which of the following conditions are considered in any way when deciding to grow POTATOES? Please circle all that are applicable.

a) Needs warmer weather
b) Needs cooler weather
c) Needs wetter weather
d) Needs drier weather
e) Needs current climate
f) Price of crop will benefit from strong pound
g) Price of crop will benefit from weak pound
h) Price of crop will benefit from strong U.S. Dollar
i) Price of crop will benefit from weak U.S. Dollar
j) Price of crop will benefit from strong Euro
k) Price of crop will benefit from weak Euro
l) Price of crop will benefit from good overseas production
m) Price of crop will benefit from poor overseas production
n) Irrigation must be available
o) Extra labour must be available

Question 2. Are there any other conditions which must be considered when choosing to grow POTATOES?

Name: ____________________ Date: ________________

Question 3. What types of adaptive action would you take in order to grow POTATOES in a warmer climate?

Question 4. What types of adaptive action would you take in order to grow POTATOES in a wetter climate?

Wheat

Question 5. Which of the following conditions are considered in any way when deciding to grow WHEAT? Please circle all that are applicable.

a) Needs warmer weather
b) Needs cooler weather
c) Needs wetter weather
d) Needs drier weather
e) Needs current climate
f) Price of crop will benefit from strong pound
g) Price of crop will benefit from weak pound
h) Price of crop will benefit from strong U.S. Dollar
i) Price of crop will benefit from weak U.S. Dollar
j) Price of crop will benefit from strong Euro
k) Price of crop will benefit from weak Euro
l) Price of crop will benefit from good overseas production
m) Price of crop will benefit from poor overseas production
n) Irrigation must be available
o) Extra labour must be available

Question 6. Are there any other conditions which must be considered when choosing to grow WHEAT?

Name: ______________________ Date: ________________

Question 7. What types of adaptive action would you take in order to grow WHEAT in a warmer climate?

Question 8. What types of adaptive action would you take in order to grow WHEAT in a wetter climate?

Oilseed Rape

Question 9. Which of the following conditions are considered in any way when deciding to grow OILSEED? Please circle all that are applicable.

a) Needs warmer weather
b) Needs cooler weather
c) Needs wetter weather
d) Needs current climate
e) Price of crop will benefit from strong pound
f) Price of crop will benefit from weak pound
g) Price of crop will benefit from strong U.S. Dollar
h) Price of crop will benefit from weak U.S. Dollar
i) Price of crop will benefit from good overseas production
j) Price of crop will benefit from poor overseas production
k) Irrigation must be available
l) Extra labour must be available

Question 10. Are there any other conditions which must be considered when choosing to grow OILSEED?

Question 11. What types of adaptive action would you take in order to grow OILSEED in a warmer climate?

Name: ______________________ Date: ________________

Question 12. What types of adaptive action would you take in order to grow OILSEED in a wetter climate?

Vegetables

Question 13. Which of the following conditions are considered in any way when deciding to grow VEGETABLES? Please circle all that are applicable.

a) Needs warmer weather
b) Needs cooler weather
c) Needs wetter weather
d) Needs current climate
e) Price of crop will benefit from strong pound
f) Price of crop will benefit from weak pound
g) Price of crop will benefit from strong U.S. Dollar
h) Price of crop will benefit from weak U.S. Dollar
i) Price of crop will benefit from good overseas production
j) Price of crop will benefit from poor overseas production
k) Irrigation must be available
l) Extra labour must be available

Question 14. Are there any other conditions which must be considered when choosing to grow VEGETABLES?

Question 15. What types of adaptive action would you take in order to grow VEGETABLES in a warmer climate?

Question 16. What types of adaptive action would you take in order to grow VEGETABLES in a wetter climate?

Name: ______________________ Date: ________________

Onions

Question 17. Which of the following conditions are considered in any way when deciding to grow ONIONS? Please circle all that are applicable.

a) Needs warmer weather
b) Needs cooler weather
c) Needs wetter weather
d) Needs current climate
e) Price of crop will benefit from strong pound
f) Price of crop will benefit from weak pound
g) Price of crop will benefit from strong U.S. Dollar
h) Price of crop will benefit from weak U.S. Dollar
i) Price of crop will benefit from good overseas production
j) Price of crop will benefit from poor overseas production
k) Irrigation must be available
l) Extra labour must be available

Question 18. Are there any other conditions which must be considered when choosing to grow ONIONS?

Question 19. What types of adaptive action would you take in order to grow ONIONS in a warmer climate?

Question 20. What types of adaptive action would you take in order to grow ONIONS in a wetter climate?

Name: ______________________ Date: ________________

Warmer Climate Crops

Question 21. Under what conditions would you consider growing warmer climate crops in the near future?

Question 22. What do you consider to be warmer climate crops?

Maize and Soya below can be replaced with any other crop that you would consider growing in a warmer climate.

Maize

Question 1. Which of the following conditions are considered in any way when deciding to grow MAIZE? Please circle all that are applicable.

a) New variety must be bred with a shorter time to harvest
b) Needs warmer weather
c) Needs cooler weather
d) Needs wetter weather
e) Needs current climate
f) Price of crop will benefit from strong pound
g) Price of crop will benefit from weak pound
h) Price of crop will benefit from strong U.S. Dollar
i) Price of crop will benefit from weak U.S. Dollar
j) Price of crop will benefit from good overseas production
k) Price of crop will benefit from poor overseas production
l) Irrigation must be available
m) Extra labour must be available

Question 2. Are there any other conditions which must be considered when choosing to grow MAIZE?

Question 3. What types of adaptive action would you take in order to grow MAIZE in a warmer climate?

Name: ______________________ Date: ________________

Question 4. What types of adaptive action would you take in order to grow MAIZE in a wetter climate?

Soya

Question 5. Which of the following conditions are considered in any way when deciding to grow SOYA? Please circle all that are applicable.

a) New variety must be bred with a shorter time to harvest

b) Needs warmer weather

c) Needs cooler weather

d) Needs wetter weather

e) Needs current climate

f) Price of crop will benefit from strong pound

g) Price of crop will benefit from weak pound

h) Price of crop will benefit from strong U.S. Dollar

i) Price of crop will benefit from weak U.S. Dollar

j) Price of crop will benefit from good overseas production

k) Price of crop will benefit from poor overseas production

l) Irrigation must be available

m) Extra labour must be available

Question 6. Are there any other conditions which must be considered when choosing to grow SOYA?

Question 7. What types of adaptive action would you take in order to grow SOYA in a warmer climate?

Name: ______________________ Date: ________________

Question 8. What types of adaptive action would you take in order to grow SOYA in a wetter climate?

Any other comments?

Any other feedback on this topic would be most welcome. If you would be willing to participate in further research, could you also mention this below.

Thank you for your help.

Appendix B

Content of CD-ROM

The CD-ROM contains all the files necessary to run the model and there is sufficient detail in the preceding chapters to enable a replication of the experiments that were conducted. However, there is also additional documentation on the CD-ROM. The contents include:

1. Source files for the model in the **AdaptiveDynamics/src/tutorial/experipd** directory, which can be run in either graphical or batch mode. However, the model can be run directly from executable files in this directory also. Please refer to the **README.txt** file on how to do this.
2. A **README.txt** file contains details on how to run the model, including the specific commands used and other details on the basis of the model.
3. API documentation is in the directory named **AdaptiveDynamics/src/doc**.
4. **RePast v.1.4.1** in the **RePast** directory, which is required if the model is to be run using source files. The RePast jar files in the **lib** directory, which is created when the files from the **repast-1.4.1.zip** file are extracted, all need to be included in the classpath to run RePast models. In later versions of RePast, only the repast.jar file needs to be included in the classpath. However, please refer to RePast documentation files for instructions on installation. There is also an additional Repast help document included.
5. **Jess v.5.2** is also required if the model is to be run using source files. The **jess** directory in the **Jess52** directory should be included in the classpath. Please refer to Jess documentation files for instructions on installation.

Appendix C

Rules in the knowledge base (Rulebase.clp)

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; Register Java classes for matching like deftemplates.
;; Bean-like properties become slots. Classes must support
;; addPropertyChangeListener. First argument is the 'deftemplate name'.
  (defclass env tutorial.experipd.JessBeans.Environment dynamic)
  (defclass econ tutorial.experipd.JessBeans.Economy dynamic)
  (defclass clim tutorial.experipd.JessBeans.Climate dynamic)
  (defclass adapt tutorial.experipd.JessBeans.Strategy dynamic)
  (defclass cap tutorial.experipd.JessBeans.Capital dynamic)

  (set-multithreaded-io TRUE)
  (set-fact-duplication TRUE)

  (defglobal ?*results* = (create$))
  (defglobal ?*advice* = (create$))
  ;;list of crops chosen by rules fired.
  (defglobal ?*adapt-advice* = (create$))
  ;;list of strategies fired in each scenario
  (defglobal ?*LI* = (create$))
  ;;Level 1 and 2 strategies disaggregated for analysis
  (defglobal ?*LII* = (create$))
  (defglobal ?*strategy-design* = (create$))
  ;;list of strategic designs as defined by Bennett
  (defglobal ?*warnings* = (create$))
  ;;list of warnings regarding resource use
  (defglobal ?*events* = (create$))
  ;;list of water shortage events
  (defglobal ?*AC* = (create$))
  ;;list of strategies resulting in Action Constraint dynamic
  (defglobal ?*AD* = (create$))
  ;;list of strategies resulting in Adaptive Drift dynamic
  (defglobal ?*SF* = (create$))
  ;;list of strategies resulting in Action Constraint dynamic
  (defglobal ?*B* = (create$))
  ;;list of strategies resulting in Step Function dynamic
  (defglobal ?*SP* = (create$))
  ;;list of strategies resulting in Buffering dynamic
```

```
(defglobal ?*RC* = (create$))
;;list of strategies resulting in Specialisation dynamic
(defglobal ?*LRC* = (create$))
;;list of strategies resulting in Local Resource Competition dynamic
(defglobal ?*IC* = (create$))
;;list of strategies resulting in Resource Competition dynamic

(defglobal ?*wheat-water* = 0) ;;irrigation requirements
(defglobal ?*osr-water* = 0)
(defglobal ?*veg-water* = 0)
(defglobal ?*pot-water* = 0)
(defglobal ?*soya-water* = 0)
(defglobal ?*oni-water* = 0)
(defglobal ?*peas-water* = 0)

(defglobal ?*action-constraint* = 0)
(defglobal ?*spec-of-pot* = 0)
(defglobal ?*resource-competition* = 0)
(defglobal ?*local-resource-competition* = 0)

(defglobal ?*incr-change* = 0)
(defglobal ?*buffering* = 0)
(defglobal ?*adapt-drift* = 0)
(defglobal ?*step-function* = 0)

(defglobal ?*id* = (fetch "ID"))
(defglobal ?*neighbour1* = (fetch "NEIGHBOUR1"))
(defglobal ?*neighbour2* = (fetch "NEIGHBOUR2"))
(defglobal ?*neighbour3* = (fetch "NEIGHBOUR3"))
(defglobal ?*neighbour4* = (fetch "NEIGHBOUR4"))

;;[Nix, 1999:15]
;;winter wheat
(defglobal ?*wheat-gmargin* = (fetch "WHEAT-GMARGIN"))
(defglobal ?*spring-wheat-gmargin* = (fetch "S-WHEAT-GMARGIN"))
(defglobal ?*osr-gmargin* = (fetch "OSR-GMARGIN"))
(defglobal ?*spring-osr-gmargin* = (fetch "S-OSR-GMARGIN"))
(defglobal ?*broc-gmargin* = (fetch "BROC-GMARGIN"))
(defglobal ?*pot-gmargin* = (fetch "POT-GMARGIN")) ;; early potatoes
(defglobal ?*soya-gmargin* = (fetch "SOYA-GMARGIN"))
;; includes oilseeds area aid payment + £25 more than osr/tonne - seed is expensive but less fertilizer is required
(defglobal ?*oni-gmargin* = (fetch "ONI-GMARGIN"))
(defglobal ?*maize-gmargin* = (fetch "MAIZE-GMARGIN"))
;; includes area payment of £275/ha (£104/acre)
(defglobal ?*pulses-gmargin* = (fetch "PULSES-GMARGIN"))
(defglobal ?*linseed-gmargin* = (fetch "LINSEED-GMARGIN"))
(defglobal ?*beans-gmargin* = 550)
(defglobal ?*navy-gmargin* = (fetch "NAVY-GMARGIN"))
;;no EU area aid payment
;;Gross margin includes area aid payment, and variable costs such as fertilizers and sprays. Price/tonne does not.

(defglobal ?*irrigation-value* = 1)
;;2000/ha
(defglobal ?*labour-cost* = 1)
```

```
(defglobal ?*hourly-wage* = 4.26)
;; Excluding overtime.  Wage of casuals is 3.21 excluding overtime, but
   not included here.
(defglobal ?*winter-cereal-hours* = 5.76) ;;[Nix, 1999:115]
(defglobal ?*spring-cereal-hours* = 4.88)
(defglobal ?*pot-hours* = 76.08)
(defglobal ?*peas-hours* = 8.64)
(defglobal ?*winter-beans-hours* = 4.96)
(defglobal ?*spring-beans-hours* = 5.12)
(defglobal ?*osr-hours* = 6.64)
(defglobal ?*oni-hours* = 48)
(defglobal ?*broc-hours* = 80)

(defglobal ?*wheat-profit* = 0)
(defglobal ?*veg-profit* = 0)
(defglobal ?*soya-profit* = 0)
(defglobal ?*osr-profit* = 0)
(defglobal ?*pot-profit* = 0)
(defglobal ?*oni-profit* = 0)
(defglobal ?*peas-profit* = 0)

(defglobal ?*max-main* = 0)
(defglobal ?*max-break* = 0)
(defglobal ?*year* = (fetch "YEAR"))

(defglobal ?*starting-capital* = (fetch "START-CAP"))

(defglobal ?*cwr* = 0)
(defglobal ?*iwr* = 0)
(defglobal ?*water-available* = (fetch "IRRIGATION"))
;; default 12 million gallon license available
(defglobal ?*irr-water* =0)
;; amount available
(defglobal ?*risk* = 0) ;; in terms of value of crop not grown.
(defglobal ?*av-water-shortage-events* = 0)
(defglobal ?*av-loss* = 0)
(defglobal ?*irr-req* = 0.0)

(defglobal ?*av-winter-prec* = 2.0);; UK precipitation and temp values
(defglobal ?*av-summer-prec* = 1.6)
(defglobal ?*av-spring-prec* = 1.6)
(defglobal ?*av-aut-prec* = 2.5)
(defglobal ?*av-ann-temp* = 10.1)
(defglobal ?*av-ann-prec* = 1.9)
(defglobal ?*min-aut-prec* = 2.5)
(defglobal ?*max-aut-prec* = 2.6)
(defglobal ?*min-summer-prec* = 1.6)
(defglobal ?*max-summer-prec* = 1.7)
(defglobal ?*min-spring-prec* = 1.6)
(defglobal ?*max-spring-prec* = 1.7)
(defglobal ?*prec-inc-rate* = 0)

(defglobal ?*numFields* = (fetch "NUM-FIELDS"))
(defglobal ?*field1* = (fetch "FIELD1"))
(defglobal ?*field2* = (fetch "FIELD2"))
(defglobal ?*field3* = (fetch "FIELD3"))
```

```
(defglobal ?*area1* = (fetch "AREA1"))
(defglobal ?*area2* = (fetch "AREA2"))
(defglobal ?*area3* = (fetch "AREA3"))
(defglobal ?*soil* = 0)
(defglobal ?*counter* = 1)

(defglobal ?*temp-wheat* = 0)
(defglobal ?*temp-pot* = 0)
(defglobal ?*temp-veg* = 0)
(defglobal ?*temp-osr* = 0)
(defglobal ?*temp-oni* = 0)
(defglobal ?*temp-maize* = 0)
(defglobal ?*temp-soya* = 0)
(defglobal ?*temp-pulses* = 0)

(defglobal ?*temp* = 0)
(defglobal ?*prec* = 0)
(defglobal ?*winter* = 0)
(defglobal ?*summer* = 0)
(defglobal ?*autumn* = 0)
(defglobal ?*spring* = 0)

(bind ?*wheat-prod*(new java.util.Hashtable))
(bind ?*wheat-prod* (fetch "WHEAT-PROD"))

(bind ?*pot-prod*(new java.util.Hashtable))
(bind ?*pot-prod* (fetch "POT-PROD"))

(bind ?*veg-prod*(new java.util.Hashtable))
(bind ?*veg-prod* (fetch "VEG-PROD"))

(bind ?*osr-prod*(new java.util.Hashtable))
(bind ?*osr-prod* (fetch "OSR-PROD"))

(bind ?*oni-prod*(new java.util.Hashtable))
(bind ?*oni-prod* (fetch "ONI-PROD"))

(bind ?*maize-prod*(new java.util.Hashtable))
(bind ?*maize-prod* (fetch "MAIZE-PROD"))

(bind ?*soya-prod*(new java.util.Hashtable))
(bind ?*soya-prod* (fetch "SOYA-PROD"))

(bind ?*pulses-prod*(new java.util.Hashtable))
(bind ?*pulses-prod* (fetch "PULSES-PROD"))

(bind ?*annTemp*(new java.util.Hashtable))
(bind ?*annTemp* (fetch "ANNTEMP"))
(bind ?*annPrec*(new java.util.Hashtable))
(bind ?*annPrec* (fetch "ANNPREC"))
(bind ?*djf* (new java.util.Hashtable))
(bind ?*djf* (fetch "DJF"))
(bind ?*jja* (new java.util.Hashtable))
(bind ?*jja* (fetch "JJA"))
(bind ?*son* (new java.util.Hashtable))
(bind ?*son* (fetch "SON"))
```

```
(bind ?*mam* (new java.util.Hashtable))
(bind ?*mam* (fetch "MAM"))
(bind ?*wheat-cir* (new java.util.Hashtable))
(bind ?*pot-cir* (new java.util.Hashtable))
(bind ?*broc-cir* (new java.util.Hashtable))
(bind ?*oni-cir* (new java.util.Hashtable))
(bind ?*peas-cir* (new java.util.Hashtable))

(bind ?*v* (new java.util.Vector)) ;; store area in a list until can be
  assigned a soil type for dynamic retrieval - not necessary in this ver-
  sion.

(deffacts control-information
 (phase startup)
 (phase-sequence askables  insurance main  break crops adapt exit clear)
 ;;Elimination by Aspects Methodology [Gladwin, 1983] can be included
  here, with different phases for elimination of each set of variables,
  eg.elimination Questions-for-import-crops Questions-for-export-crops
  etc [see Chapter 6].
)

(defrule change-phase
(declare (salience -10))
 ?phase <- (phase ?current-phase)
 ?list <- (phase-sequence ?next-phase $?other-phases)
=>
 ;; (printout t "--------" crlf)
 ;; (printout t "----++++ phase change " ?current-phase " --> " ?next-
  phase crlf)
 ;; (printout t "++++++++" crlf)
  (retract ?phase ?list)
  (assert (phase ?next-phase))
  (assert (phase-sequence ?other-phases ?next-phase))
)

(defrule startup
 (not (startup))
 (phase startup)
 (cap (output ?output)(input ?input)(costIrrigation ?cost)(OBJECT ?cap))
 (env (soil ?soil) (OBJECT ?env))
=>
 (load-facts .//labour.txt)
 (load-facts .//irrigation.txt)
 (load-facts .//strategy.txt)
 (load-facts .//effects.txt)
 (set ?cap output 0.0)
 (set ?cap input 0.0)
 (store INPUT (get ?cap input))
 (store OUTPUT (get ?cap output))

 (if (= ?*water-available* 0)
 then
 (bind ?*water-available* (readline))
 )
 (if (= ?*irrigation-value* 0)
 then
```

```
    (bind ?*irrigation-value* (readline))
    else
    (bind ?cost (+ ?cost ?*irrigation-value*))
    )
    (if (= ?*labour-cost* 0)
    then
    (bind ?*labour-cost* (readline))
    )
    (call ?*v* setSize 10)

    (set ?env soil ?*field1*)
    (call ?*v* setElementAt (new jess.Value ?*area1* 4) ?*field1*)
    ;; use soil type as index
    (assert (env (soil ?*field1*)))

    (set ?env soil ?*field2*)
    (call ?*v* setElementAt (new jess.Value ?*area2* 4) ?*field2*)
    ;; use soil type as index
     (assert (env (soil ?*field2*)))

    (set ?env soil ?*field3*)
    (call ?*v* setElementAt (new jess.Value ?*area3* 4) ?*field3*)
    ;; use soil type as index
    (assert (env (soil ?*field3*)))

    (assert (startup))
  )

  (defrule Agent-Death
   (not (agent-death))
   (phase startup)
   (adapt (delayed ?del)(immediate ?immed)(multiplier ?multi)(sustained
     ?sust)(OBJECT ?adapt))
   ?f1 <- (clearJess)
   =>
    (bind ?*action-constraint* 0)
    (bind ?*spec-of-pot* 0)
    (bind ?*resource-competition* 0)
    (bind ?*local-resource-competition* 0)
    (bind ?*incr-change* 0)
    (bind ?*buffering* 0)
    (bind ?*adapt-drift* 0)
    (bind ?*step-function* 0)
    (set ?adapt delayed 0)
    (set ?adapt immediate 0)
    (set ?adapt sustained 0)
    (set ?adapt multiplier 0)
    (assert (agent-death))
    (assert (death))
    (retract ?f1)
  )

  (defrule Death1
     (death)
    ?f1 <- (effects mktst ? ?last&:(= ?last (- ?*year* 10)) ?*id*)
    =>
```

```
    (retract ?f1)
)
(defrule Death2
    (death)
   ?f2 <-(effects warning ? ?last&:(= ?last (- ?*year* 10)) ?*id*)
   =>
   (retract ?f2)
)
(defrule Death3
    (death)
   ?f3 <-(strategy-design ? ? ?last&:(= ?last (- ?*year* 10)) ?*id*)
   =>
   (retract ?f3)
)
(defrule Death4
    (death)
   ?f3 <-(effects ? ?*id*)
   =>
   (retract ?f3)
)
;;-----------------------------------------------
(defrule Ask-Remaining-Questions
 (not (asked))
 (phase askables)
 (irrigation ?irr-memory)
 (labour ?lab-memory)
 (clim  (weather ?annTemp)(prec ?prec) (autumn ?son) (winter ?djf) (spring
   ?mam) (summer ?jja) (OBJECT ?clim))
 (adapt   (irrigation ?irr)(labour ?lab)(immediate ?immed)(sustained
   ?sust)(delayed ?del)(multiplier ?multi)(buffer ?buff)(OBJECT ?adapt))
 (econ  (dollar ?dollar) (sterling ?sterling) (euro ?euro) (worldPrices
   ?worldprices) (OBJECT ?econ))
 =>
 (assert (asked))
 (bind ?*autumn* (call ?*son* get (new jess.Value ?*year* 4)))
 (bind ?son ?*autumn*)
 (store "SON-value" ?*autumn*)
 (set ?clim autumn (float ?son))

 (bind ?*spring* (call ?*mam* get (new jess.Value ?*year* 4)))
 (bind ?mam ?*spring*)
 (store "MAM-value" ?*spring*)
 (set ?clim spring (float ?mam))

 (bind ?*summer* (call ?*jja* get (new jess.Value ?*year* 4)))
 (bind ?jja ?*summer*)
 (store "JJA-value" ?*summer*)
 (set ?clim summer (float ?jja))

 (bind ?*winter* (call ?*djf* get (new jess.Value ?*year* 4)))
 (bind ?djf ?*winter*)
 (store "DJF-value" ?*winter*)
 (set ?clim winter (float ?djf))

 (bind ?*temp* (call ?*annTemp* get (new jess.Value ?*year* 4)))
 (bind ?annTemp ?*temp*)
```

```
   (store "TEMP-value" ?*temp*)
   (set ?clim weather (float ?annTemp))

   (bind ?*prec* (call ?*annPrec* get (new jess.Value ?*year* 4)))
   (bind ?annPrec ?*prec*)
   (store "PREC-value" ?*prec*)
   (set ?clim prec (float ?annPrec))

   (bind ?*temp-wheat* (call ?*wheat-prod* get (new jess.Value ?*year* 4)))
   (bind ?*temp-wheat* (integer ?*temp-wheat* ))
   (assert (econ (prodWheat ?*temp-wheat* )(OBJECT ?econ)))

   (bind ?*temp-pot* (call ?*pot-prod* get (new jess.Value ?*year* 4)))
   (bind ?*temp-pot* (integer ?*temp-pot* ))
   (assert (econ (prodPot ?*temp-pot* )(OBJECT ?econ)))

   (bind ?*temp-veg* (call ?*veg-prod* get (new jess.Value ?*year* 4)))
   (bind ?*temp-veg* (integer ?*temp-veg* ))
   (assert (econ (prodVeg ?*temp-veg* )(OBJECT ?econ)))

   (bind ?*temp-osr* (call ?*osr-prod* get (new jess.Value ?*year* 4)))
   (bind ?*temp-osr* (integer ?*temp-osr* ))
   (assert (econ (prodOsr ?*temp-osr* )(OBJECT ?econ)))

   (bind ?*temp-oni* (call ?*oni-prod* get (new jess.Value ?*year* 4)))
   (bind ?*temp-oni* (integer ?*temp-oni* ))
   (assert (econ (prodOni ?*temp-oni* )(OBJECT ?econ)))

   (bind ?*temp-soya* (call ?*soya-prod* get (new jess.Value ?*year* 4)))
   (bind ?*temp-soya* (integer ?*temp-soya* ))
   (assert (econ (prodSoya ?*temp-soya* )(OBJECT ?econ)))

 (if (= (fetch EURO) 0)
   then
 (assert (econ (euro 0)(OBJECT ?econ)))
 )

  (if (= (fetch EURO) 1)
   then
  (assert (econ (euro 1)(OBJECT ?econ)))
  )

 (if (= (fetch DOLLAR) 0)
   then
  (assert (econ (dollar 0)(OBJECT ?econ)))
  )

  (if (= (fetch DOLLAR) 1)
   then
  (assert (econ (dollar 1)(OBJECT ?econ)))
  )

 (if (= (fetch STERLING) 0)
  then
  (assert (econ (sterling 0)(OBJECT ?econ)))
  )
```

```

(if (= (fetch STERLING) 1)
 then
(assert (econ (sterling 1) (OBJECT ?econ)))
)

(if (= (fetch MTWP) 1)
 then
(assert (econ (worldPrices 1)(OBJECT ?econ)))
)

 (if (= (fetch MTWP) 0)
 then
 (assert (econ (worldPrices 0)(OBJECT ?econ)))
 )
(if (= ?*year* 1960)
then
  (if (eq ?irr-memory 0)
  then
  (bind ?irr 0)
  (set ?adapt irrigation ?irr)
  )

  (if (eq ?irr-memory 1)
  then
  (bind ?irr 1)
  (set ?adapt irrigation ?irr)
  )

  (if (eq ?lab-memory 0)
  then
  (bind ?lab 0)
  (set ?adapt labour ?lab)
  )

  (if (eq ?lab-memory 1)
  then
  (bind ?lab 1)
  (set ?adapt labour ?lab)
  )

 (assert (adapt   (irrigation ?irr)(labour ?lab)(immediate ?immed)(sus-
   tained ?sust)(multiplier ?multi)(buffer ?buff)(delayed ?del)(OBJECT
   ?adapt)))
;; assert vegetables, potatoes, cereals, including warmer climate crops,
   then break crops to fire them in the right order.
;; Then add restrictions on use of irrigation and capital. This is the
   order in which the rotation is decided
;; [see Chapter 4].))
(defrule The-End
 (not (end))
 (phase exit)
 ?f1 <-(env (OBJECT ?env))
 ?f2 <- (clim (OBJECT ?clim))
 ?f3 <- (econ (OBJECT ?econ))
```

```
 ?f4 <- (adapt (irrigation ?irr)(labour ?lab)(immediate ?immed)(sustained
   ?sust)(multiplier ?multi)(buffer ?buff)(delayed ?del)(design
   ?des)(OBJECT ?adapt))
 ?f5 <- (cap (input ?input)(output ?output)(OBJECT ?cap))
 =>
 (assert (irrigation ?irr ?*id*))
 (save-facts .//irrigation.txt irrigation)
 (assert (labour ?lab ?*id*))
 (save-facts .//labour.txt labour)
 (save-facts .//effects.txt effects)
 (store RESULTS ?*results*)
 (store CROPS ?*advice*)
 (store LI ?*LI*)
 (store LII ?*LII*)
 (store ADAPT  ?*adapt-advice*)
 (store DESIGN ?*strategy-design*)
 (store WARNINGS ?*warnings*)
 (store EVENTS ?*events*)
 (store ADLIST ?*AD*)
 (store ACLIST ?*AC*)
 (store SPLIST ?*SP*)
 (store BLIST ?*B*)
 (store ICLIST ?*IC*)
 (store SFLIST ?*SF*)
 (store RCLIST ?*RC*)
 (store LRCLIST ?*LRC*)
 (store AD ?*adapt-drift*)
 (store SP ?*spec-of-pot*)
 (store RC ?*resource-competition*)
 (store LRC ?*local-resource-competition*)

 (store AC ?*action-constraint*)
 (store IC ?*incr-change*)
 (store B ?*buffering*)
 (store SF ?*step-function*)
 (bind ?avail (- ?*water-available* ?*cwr*))
 (store REMAINING-WATER ?avail)
 (Calculate-Risk)
 (Calculate-Choices)
 (undefinstance ?econ);;to remove shadow facts
 (undefinstance ?clim)
 (undefinstance ?cap)
 (undefinstance ?adapt)
 (assert (end))
 (assert (phase clear))
;; (watch facts) ;; use for debugging
 (reset)
 (halt)
)

(defrule Clear-Strategy
 (phase clear)
 ?f1 <- (strategy ?)
 =>
 (retract ?f1)
 )
```

```

(defrule Clear-Water
 (phase clear)
 ?f1 <- (water ?)
 =>
 (retract ?f1)
)

(defrule Clear-IncLab
 (phase clear)
 ?f1 <- (increase-labour ?)
 =>
 (retract ?f1)
)

(defrule Clear-DecLab
 (phase clear)
 ?f1 <- (decrease-labour ?)
 =>
 (retract ?f1)
)

(defrule Clear-IAD
 (phase clear)
 ?f1 <- (iad)
 =>
 (retract ?f1)
)

(defrule Clear-Pref
 (phase clear)
 ?f1 <- (sceptic)
 =>
 (retract ?f1)
)

(defrule Clear-Labour-2
 (phase clear)
 ?f1 <- (labour ? ?)
 =>
 (retract ?f1)
)

(defrule Clear-Labour-1
 (phase clear)
 ?f1 <- (labour ?)
 =>
 (retract ?f1)
)

(defrule Clear-Irrigation-1
 (phase clear)
 ?f1 <- (irrigation ?)
 =>
 (retract ?f1)
)
```

```

 (defrule Clear-Irrigation-2
  (phase clear)
  ?f1 <- (irrigation ? ?)
  =>
  (retract ?f1)
 )

(defrule Clear-Break
 (phase clear)
 ?f1 <- (break-crop ?)
 =>
 (retract ?f1)
)

(defrule Clear-Main
 (phase clear)
 ?f1 <- (main-crop ?)
 =>
 (retract ?f1)
)

(defrule Clear-Redundant-Strategies    ;;Important to improve performance
?f1 <- (strategy-design ? ? ?year&:(<= ?year (- ?*year* 30)) ?)
=>
(retract ?f1)
)

(defrule Clear-Redundant-Neg-Strategies
?f1 <- (strategy-design neg ? ? ? ?year&:(<= ?year (- ?*year* 30)) ?)
=>
(retract ?f1)
)

(defrule Clear-Buffering-StepFunction-Strategies
?f1 <- (strategy-design buffering ? ? ? ?year&:(<= ?year (- ?*year* 40)) ?)
=>
(retract ?f1)
)

(defrule Clear-Redundant-Warnings
?f1 <- (effects ? ? ?year&:(<= ?year (- ?*year* 40)) ?)
=>
(retract ?f1)
)


----------------------------------

(deffunction Calculate-Risk()
  (bind ?*risk* 0.0)
  (if (> ?*av-water-shortage-events* 0)
  then
  (bind ?*av-loss* (/ ?*av-loss* ?*av-water-shortage-events*))
  ;; to get average from total loss
```

```
    (bind ?*risk* (* ?*av-water-shortage-events* ?*av-loss*))
    )
  ;;  (printout t "Risk is equal to " ?*risk* crlf)
    (store "RISK-value" ?*risk*)
)

(deffunction Calculate-Water-Needed(?area ?cir)
   (bind ?*irr-req* 0.0)
   (bind ?*irr-req* (+ ?*irr-req* ?cir))  ;; mm/1 ha
   (bind ?*irr-req* (* ?*irr-req* 0.04))  ;; inch/ha
   (bind ?*irr-req* (/ ?*irr-req* 2.47))   ;; inch/acre
   (bind ?*irr-req* (* ?*irr-req* 22622)) ;; gallons/acre
   (bind ?area (* ?area 2.47))            ;; to convert area from hectares to acres
   (bind ?*irr-req* (* ?*irr-req* ?area))  ;; gallons/whole area in acres
   (bind ?*irr-req* (integer ?*irr-req*))
)

(deffunction Calculate-Labour-Cost(?area ?lab-hrs)
   (bind ?*labour-cost* 0.0)
   (bind ?*labour-cost* (+ ?*labour-cost* (* ?area ?lab-hrs)))
   (bind ?*labour-cost* (* ?*labour-cost* ?*hourly-wage*))
)

(deffunction Calculate-Profitability (?gmargin ?area ?labour-cost)
   (bind ?*profit* 0.0)
   (bind ?*profit* (* ?gmargin ?area))
   (bind ?*profit* (- ?*profit* ?labour-cost))
   ;; Variable costs (fertiliser) - fixed costs (labour).
   ;; Other fixed costs, such as machinery and rent should be included in an expanded version.
)

(deffunction Calculate-Choices ()
   (bind ?*max-main* (max ?*wheat-profit* ?*veg-profit*  ?*oni-profit*))
   (bind ?*max-break* (max ?*soya-profit* ?*osr-profit* ?*pot-profit* ?*veg-profit*  ?*oni-profit*))
   (store "MAX-MAIN" ?*max-main*)
   (store "MAX-BREAK" ?*max-break*)
   (bind ?*min-water* (min ?*soya-water* ?*osr-water* ?*veg-water* ?*pot-water*))
)

---------------------------------

(defrule Grow-Oilseed_Rape
   (not (break-crop oilseed))
   (phase break)
   (not (effects mktst G_Osr  ?year1&:(= ?year1 (- ?*year* 10)) ?id&~?*id*))
   (env  (soil ?soil&:(= ?soil 5)) (OBJECT ?env))
   ;; light soil is better for wet climate for drainage, heavy soil for warmer weather to retain moisture
   (econ (prodOsr 1) (OBJECT ?econ))
   ;; Poor overseas production of oilseed
```

```
    (clim (weather ?temp)(prec ?prec&:(> ?prec ?*av-ann-prec*)) (OBJECT ?clim))
    ;; Wetter weather
    (cap  (input ?input) (output ?output) (OBJECT ?cap))
    (adapt  (delayed ?del) (OBJECT ?adapt))
=>
    (assert (break-crop oilseed))
    (bind ?index ?soil)
    (bind ?area 100);;(call ?*v* elementAt ?index) for possibility dynamic retrieval of area as described in Chapter 8.
    ;;100ha is amount currently grown by the domain expert
    (bind ?*labour-cost* (Calculate-Labour-Cost ?area ?*osr-hours*))
    (bind ?*osr-profit* (Calculate-Profitability ?*osr-gmargin* ?area ?*labour-cost*))
    (bind ?*osr-cir* (fetch "OSR-CIR"))
    (bind ?*cir* (call ?*osr-cir* get (new jess.Value ?*year* 4)))
    (if (neq ?*cir* nil)
    then
    (bind ?*water-needed* 0)
    ;;  (printout t "CIR is " ?*cir* crlf)
    (bind ?*water-needed* (Calculate-Water-Needed ?area ?*cir*))
    ;;  (printout t "Irrigation required for oilseed to be planted on all suitable land available is " ?*water-needed* " gallons." crlf)
    )
    (bind ?*osr-water* ?*water-needed*)
    (bind ?*cwr* (+ ?*cwr* ?*water-needed*))
    ;;  (printout t "Total crop water requirements are " ?*cwr* " gallons" crlf)
    (if (> ?*cwr* ?*water-available*)
    then
    (bind ?*events* (create$ OsrWet ?*events*))
    ;;(printout t "There is not enough water available to irrigate a oilseed crop." crlf)
    (bind ?*av-water-shortage-events* (+ ?*av-water-shortage-events* 1))
    (bind ?*av-loss* (+ ?*av-loss* ?*osr-profit*))
    (bind ?*cwr* (- ?*cwr* ?*water-needed*))
    else
    ;;(printout t "There is enough water to irrigate a oilseed crop." crlf)
    (printout t "**** Grow Oilseed Rape as a break crop. ****" crlf crlf)
    (bind ?*results* (create$ Grow Oilseed Rape as a break crop. ?*results*))
    (bind ?*advice* (create$ Osr ?*advice*))
    (set ?cap input (+ ?input ?*labour-cost*))
    ;;(printout t "The potential profitability (variable costs - fixed costs) of osr is £" ?*osr-profit* crlf)
    (set ?cap output (+ ?output ?*osr-profit*))
    (bind ?*advice* (create$ ?*osr-profit* ?*advice*))
    (bind ?*advice* (create$ ?*water-needed* ?*advice*))
    (bind ?*advice* (create$ ?*labour-cost* ?*advice*))
    (bind ?*adapt-advice* (create$ OsrWet ?*adapt-advice*))
    (store INPUT (get ?cap input))
    (store OUTPUT (get ?cap output))
    (set ?adapt delayed (+ ?del 1))
    (store DELAYED (get ?adapt delayed))
    (assert (strategy-design del G_Osr ?*year* ?id*))
    (save-facts .//strategy.txt strategy-design)
```

```
  )
)
;;-----------------------------------------------------------------
;;****************** DOMESTIC CROPS **********************

(defrule Grow-Vegetables
   (not (main-crop vegetables))
   (not (main wheat))
   (phase insurance)
   (not (effects mktst G_Veg ?year1&:(= ?year1 (- ?*year* 10)) ?id&~?*id*))
   (env  (soil ?soil&:(= ?soil 5)) (OBJECT ?env))
   (clim (name ?n) (weather ?w&:(>= ?w ?*av-ann-temp*)) (OBJECT ?clim))
   ;; Poor overseas production is the deciding issue.
   (econ (prodVeg 1) (OBJECT ?econ))
   (adapt  (irrigation 1)(OBJECT ?adapt))
   (adapt  (labour 1) (delayed ?del)(multiplier ?multi)(OBJECT ?adapt))
   (cap  (input ?input) (output ?output) (OBJECT ?cap))
=>
   (assert (main-crop vegetables))
   (bind ?index ?soil)
   (bind ?area 100) ;; grown as main crop
   (bind ?*labour-cost* (Calculate-Labour-Cost ?area ?*broc-hours*))
   (bind ?*veg-profit* (Calculate-Profitability ?*broc-gmargin* ?area
    ?*labour-cost*))
   (bind ?*broc-cir* (fetch "BROC-CIR"))
   (bind ?*cir* (call ?*broc-cir* get (new jess.Value ?*year* 4)))
   (if (neq ?*cir* nil)
   then
   (bind ?*water-needed* 0);;  (printout t "Broc CIR is " ?*cir* crlf)
   (bind ?*water-needed* (Calculate-Water-Needed ?area ?*cir*))
;;  (printout t "Irrigation required for veg (broc) to be planted on all
    suitable land available is " ?*water-needed* " gallons." crlf)
   )
   (bind ?*veg-water* ?*water-needed*)
   (bind ?*cwr* (+ ?*cwr* ?*water-needed*))
;;  (printout t "Total crop water requirements are " ?*cwr* " gallons"
    crlf)
   (if (> ?*cwr* ?*water-available*)
   then
   (bind ?*events* (create$ Veg ?*events*))
;;  (printout t "There is not enough water available to irrigate a veg
    (broc) crop." crlf)
   (bind ?*av-water-shortage-events* (+ ?*av-water-shortage-events* 1))
   (bind ?*av-loss* (+ ?*av-loss* ?*veg-profit*))
   (bind ?*cwr* (- ?*cwr* ?*water-needed*))
   else
   ;;(printout t "There is enough water to irrigate a veg (broc) crop."
    crlf)
   (set ?cap input (+ ?input ?*labour-cost*))
   (printout t "**** Vegetables are another main crop option, but irriga-
    tion and a large labour force are essential. ****" crlf crlf)
   (bind ?*results* (create$ Vegetables are another main crop option, but
    irrigation and a large labour force are essential.  ?*results*))
   (assert (main veg))
   (assert (vegetables))
;;  (printout t ?*av-water-shortage-events* ", " ?*av-loss* crlf)
```

```
;;  (printout t "The potential profitability (variable costs - fixed costs) of veg is £" ?*veg-profit* crlf)
  (set ?cap output (+ ?output ?*veg-profit*))
  (bind ?*advice* (create$ Veg ?*advice*))
  (bind ?*advice* (create$ ?*veg-profit* ?*advice*))
  (bind ?*advice* (create$ ?*water-needed* ?*advice*))
  (bind ?*advice* (create$ ?*labour-cost* ?*advice*))
  (bind ?*adapt-advice* (create$ Veg ?*adapt-advice*))
  (store INPUT (get ?cap input))
  (store OUTPUT (get ?cap output))
  (set ?adapt delayed (+ ?del 1))
  (set ?adapt multiplier (+ ?multi 1))
  (store MULTI (get ?adapt multiplier))
  (assert (strategy-design del G_Veg ?*year* ?*id*))
  (assert (strategy-design multi G_Veg ?*year* ?*id*))
  (save-facts .//strategy.txt strategy-design)
  )
)

(defrule Grow-Onions-after-Potatoes
  (not (break-crop onions))
  (phase insurance)
  (effects ? G_Pot ?year1&:(= ?year1 (- ?*year* 10)) ?*id*)
  ;;check to see if potatoes were grown in the previous timestep
  (not (effects mktst G_Oni ?year1&:(= ?year1 (- ?*year* 10)) ?id&~?*id*))
  ;;no multiplier effects because same machinery can be used as for pota-toes.
  (clim (weather ?w&:(>= ?w ?*av-ann-temp*))(OBJECT ?clim))
  (env (soil ?soil&:(= ?soil 2)) (OBJECT ?env))
   ;; med-heavy soil
  (econ (prodOni 1) (OBJECT ?econ))  ;;  "Poor Overseas Production"
  (adapt (irrigation 1) (delayed ?del)(multiplier ?multi)(OBJECT ?adapt))
  (adapt  (labour 1) (delayed ?del)(multiplier ?multi)(OBJECT ?adapt))
  (cap (input ?input) (output ?output) (OBJECT ?cap))
=>
  (assert (break-crop onions))
  (bind ?index ?soil)
  (bind ?area 40)
  (bind ?*labour-cost* (Calculate-Labour-Cost ?area ?*oni-hours*))
  (bind ?*oni-profit* (Calculate-Profitability ?*oni-gmargin* ?area ?*labour-cost*))
  (bind ?*oni-cir* (fetch "ONI-CIR"))
  (bind ?*cir* (call ?*oni-cir* get (new jess.Value ?*year* 4)))
  (if (neq ?*cir* nil)
  then
  (bind ?*water-needed* 0)
  ;;  (printout t "CIR is " ?*cir* crlf)
  (bind ?*water-needed* (Calculate-Water-Needed ?area ?*cir*))
   ;;  (printout t "Irrigation required for onions to be planted on all suitable land available is " ?*water-needed* " gallons." crlf)
  )
  (bind ?*veg-water* ?*water-needed*)
  (bind ?*cwr* (+ ?*cwr* ?*water-needed*))
  ;;  (printout t "Total crop water requirements are " ?*cwr* " gallons" crlf)
  (if (> ?*cwr* ?*water-available*)
```

```
    then
    (bind ?*events* (create$ Oni ?*events*))
    ;;  (printout t "There is not enough water available to irrigate a onion crop." crlf)
    (bind ?*av-water-shortage-events* (+ ?*av-water-shortage-events* 1))
    (bind ?*av-loss* (+ ?*av-loss* ?*oni-profit*))
    (bind ?*cwr* (- ?*cwr* ?*water-needed*))
    else
    ;;  (printout t "There is enough water to irrigate a onion crop." crlf)
    (printout t "**** Grow Onions as a break crop, with irrigation.  Onions can grow on heavy land,since the sit on top of the soil.
    Since potatoes are being grown, the same machinery can be utilised, with the addition of a specialized drill and topper.
    Irrigation is needed. ****" crlf crlf)
    (bind ?*results* (create$ Grow Onions as a break crop, with irrigation. Onions can grow on heavy land,since the sit on top of the soil.
    Since potatoes are being grown, the same machinery can be utilised, with the addition of a specialized drill and topper.
    Irrigation is needed. ?*results*))
    (assert (effects oni ?*id*))
    (set ?cap input (+ ?input ?*labour-cost*))
    ;;  (printout t "The potential profitability (variable costs - fixed costs) of oni is £" ?*oni-profit* crlf)
    (set ?cap output (+ ?output ?*oni-profit*))
    (bind ?*advice* (create$ Oni ?*advice*))
    (bind ?*advice* (create$ ?*oni-profit* ?*advice*))
    (bind ?*advice* (create$ ?*water-needed* ?*advice*))
    (bind ?*advice* (create$ ?*labour-cost* ?*advice*))
    (bind ?*adapt-advice* (create$ Oni-after-Pot ?*adapt-advice*))
    (store INPUT (get ?cap input))
    (store OUTPUT (get ?cap output))
    (set ?adapt delayed (+ ?del 1))
    (store DELAYED (get ?adapt delayed))
    ;;(set ?adapt multiplier (+ ?multi 1))
    ;;(store MULTI (get ?adapt multiplier))
    (assert (strategy-design del G_Oni ?*year* ?*id*))
    ;;  (assert (strategy-design multi G_Oni ?*year* ?*id*))
    (save-facts .//strategy.txt strategy-design)
    )
)

(defrule Grow-Onions-After-Onions
    (not (break-crop onions))
    (phase insurance)
    (effects oni ?*id*)
    ;;check whether onions where successfully chosen in the previous timestep.
    (not (effects mktst G_Oni ?year1&:(= ?year1 (- ?*year* 10)) ?id&~?*id*))
     ;;no multiplier effects because the same machinery can be used as for potatoes.
    (clim (weather ?w&:(>= ?w ?*av-ann-temp*))(OBJECT ?clim))
    (env (soil ?soil&:(= ?soil 2)) (OBJECT ?env))
     ;; heavy or med-heavy soil
    (econ (prodOni 1) (OBJECT ?econ))
    ;;  Poor overseas production of onions
```

```
    (adapt (irrigation 1) (delayed ?del)(multiplier ?multi)(OBJECT ?adapt))
    (adapt  (labour 1) (delayed ?del)(multiplier ?multi)(OBJECT ?adapt))
    (cap (input ?input) (output ?output) (OBJECT ?cap))
=>
    (assert (break-crop onions))
    (bind ?index ?soil)
    (bind ?area 40)
    (bind ?*labour-cost* (Calculate-Labour-Cost ?area ?*oni-hours*))
    (bind ?*oni-profit* (Calculate-Profitability ?*oni-gmargin* ?area ?*labour-cost*))
    (bind ?*oni-cir* (fetch "ONI-CIR"))
    (bind ?*cir* (call ?*oni-cir* get (new jess.Value ?*year* 4)))
    (if (neq ?*cir* nil)
    then
    (bind ?*water-needed* 0)
    ;;  (printout t "CIR is " ?*cir* crlf)
    (bind ?*water-needed* (Calculate-Water-Needed ?area ?*cir*))
    ;;  (printout t "Irrigation required for onions to be planted on all suitable land available is " ?*water-needed* " gallons." crlf)
    )
    (bind ?*veg-water* ?*water-needed*)
    (bind ?*cwr* (+ ?*cwr* ?*water-needed*))
    ;;  (printout t "Total crop water requirements are " ?*cwr* " gallons" crlf)
    (if (> ?*cwr* ?*water-available*)
    then
    (bind ?*events* (create$ Oni ?*events*))
    ;; (printout t "There is not enough water available to irrigate a onion crop." crlf)
    (bind ?*av-water-shortage-events* (+ ?*av-water-shortage-events* 1))
    (bind ?*av-loss* (+ ?*av-loss* ?*oni-profit*))
    (bind ?*cwr* (- ?*cwr* ?*water-needed*))
    else
    ;;  (printout t "There is enough water to irrigate a onion crop." crlf)
    (printout t "**** Grow Onions as a break crop, with irrigation.  Onions can grow on heavy land,since the sit on top of the soil.
    Since potatoes are being grown, the same machinery can be utilised, with the addition of a specialized drill and topper.
    Irrigation is needed. ****" crlf crlf)
    (bind ?*results* (create$ Grow Onions as a break crop, with irrigation. Onions can grow on heavy land,since the sit on top of the soil.
    Since potatoes are being grown, the same machinery can be utilised, with the addition of a specialized drill and topper.
    Irrigation is needed. ?*results*))
    (set ?cap input (+ ?input ?*labour-cost*))
    ;;  (printout t "The potential profitability (variable costs - fixed costs) of oni is £" ?*oni-profit* crlf)
    (set ?cap output (+ ?output ?*oni-profit*))
    (bind ?*advice* (create$ Oni ?*advice*))
    (bind ?*advice* (create$ ?*oni-profit* ?*advice*))
    (bind ?*advice* (create$ ?*water-needed* ?*advice*))
    (bind ?*advice* (create$ ?*labour-cost* ?*advice*))
    (bind ?*adapt-advice* (create$ Oni-after-Oni ?*adapt-advice*))
    (store INPUT (get ?cap input))
    (store OUTPUT (get ?cap output))
    (set ?adapt delayed (+ ?del 1))
```

```
   (store DELAYED (get ?adapt delayed))
   ;;      (set ?adapt multiplier (+ ?multi 1))
   ;;(store MULTI (get ?adapt multiplier))
   (assert (strategy-design del G_Oni ?*year* ?*id*))
   ;;  (assert (strategy-design multi G_Oni ?*year* ?*id*))
   (save-facts .//strategy.txt strategy-design)
   )
 )

;;------------------------------------------------------------------
;;***************** DOMESTIC CROP **********************

(defrule Grow-Potatoes1
  (not (break-crop potatoes))
  (phase insurance)
  (not (effects mktst G_Pot ?year1&:(= ?year1 (- ?*year* 10)) ?id&~?*id*))
  (env  (soil ?soil&:(= ?soil 5)) (OBJECT ?env))
  (clim (name ?n) (weather ?w&:(>= ?w ?*av-ann-temp*))(OBJECT ?clim))
  (adapt  (irrigation 1)(OBJECT ?adapt))
  (adapt (labour 1) (delayed ?del)(multiplier ?multi)(OBJECT ?adapt))
  (cap  (input ?input) (output ?output) (OBJECT ?cap))
=>
  (assert (break-crop potatoes))
  (bind ?index ?soil)
  (bind ?area 40);;(call ?*v* elementAt ?index))
  (bind ?*labour-cost* (Calculate-Labour-Cost ?area ?*pot-hours*))
  (bind ?*pot-profit* (Calculate-Profitability ?*pot-gmargin* ?area ?*labour-cost*))
  (bind ?*pot-cir* (fetch "POT-CIR"))
  (bind ?*cir* (call ?*pot-cir* get (new jess.Value ?*year* 4)))
  (if (neq ?*cir* nil)
  then
  (bind ?*water-needed* 0);
  ;;  (printout t "Pot CIR is " ?*cir* crlf)
  (bind ?*water-needed* (Calculate-Water-Needed ?area ?*cir*))
  ;;  (printout t "Irrigation required for potatoes to be planted on all suitable land available is " ?*water-needed* " gallons." crlf)
  )
  (bind ?*pot-water* ?*water-needed*)
  (bind ?*cwr* (+ ?*cwr* ?*water-needed*))
  ;;  (printout t "Total crop water requirements are " ?*cwr* " gallons" crlf)
  (if (> ?*cwr* ?*water-available*)
  then
  (bind ?*events* (create$ Pot ?*events*))
  ;;  (printout t "There is not enough water available to irrigate a potato crop." crlf)
  (bind ?*av-water-shortage-events* (+ ?*av-water-shortage-events* 1))
  (bind ?*av-loss* (+ ?*av-loss* ?*pot-profit*))
  (bind ?*cwr* (- ?*cwr* ?*water-needed*))
  else
  (printout t "**** Grow Potatoes as a break crop, with irrigation.  Irrigation is needed to grow potatoes successfully on a light soil.
  Extra labour  is needed.  Overseas production  is not a consideration as potatoes in the U.K. are grown for the home market. ****" crlf crlf)
```

```
  (bind ?*results* (create$ Grow Potatoes as a break crop, with irriga-
   tion.  Irrigation is needed to grow potatoes successfully on a light
   soil.
  Extra labour  is needed.  Overseas production  is not a consideration as
   potatoes in the U.K. are grown for the home market. ?*results*))
  (assert (potatoes))
  ;;  (printout t "There is enough water to irrigate a potato crop." crlf)
  (set ?cap input (+ ?input ?*labour-cost*))
  ;;  (printout t ?*av-water-shortage-events* ", " ?*av-loss* crlf)
  ;;  (printout t "The potential profitability (variable costs - fixed
   costs) of potatoes is £" ?*pot-profit* crlf)
  (set ?cap output (+ ?output ?*pot-profit*))
     (bind ?*advice* (create$ Pot ?*advice*))
  (bind ?*advice* (create$ ?*pot-profit* ?*advice*))
  (bind ?*advice* (create$ ?*water-needed* ?*advice*))
  (bind ?*advice* (create$ ?*labour-cost* ?*advice*))
  (bind ?*adapt-advice* (create$ Pot ?*adapt-advice*))
  (store INPUT (get ?cap input))
  (store OUTPUT (get ?cap output))
  (set ?adapt delayed (+ ?del 1))
  (store DELAYED (get ?adapt delayed))
  (set ?adapt multiplier (+ ?multi 1))
  (store MULTI (get ?adapt multiplier))
  (assert (strategy-design del G_Pot ?*year* ?*id*))
  (assert (strategy-design multi G_Pot ?*year* ?*id*))
  (save-facts .//strategy.txt strategy-design)
  )
)

;;------------------------------------------------------------
;; Soya rule which is fired when new-crops-warmer-climate is activated.
(defrule Grow-Soya-as-Warmer-Climate-Crop-after-Peas
  (not (sceptic))
  (not (break-crop soya))
  (phase crops)
  (effects ? G_Peas ?year1&:(>= ?year1 (- ?*year* 30)) ?*id*)
  ;;if past knowledge and experience of growing legumes, no multiplier
   effects (see Chapter 9).
  (not (effects mktst G_Soya ?year1&:(= ?year1 (- ?*year* 10))
   ?id&~?*id*))
  (strategy new-variety-warmer-climate)
  (env  (soil ?soil&:(= ?soil 2)) (OBJECT ?env))
  ;;med-heavy
  (cap  (input ?input) (output ?output) (OBJECT ?cap))
  (adapt  (delayed ?del)(multiplier ?multi) (OBJECT ?adapt))
=>
  (assert (break-crop soya))
  (bind ?index ?soil)
  (bind ?area 70);;area of peas and beans currently grown
  (bind ?*labour-cost* (Calculate-Labour-Cost ?area ?*winter-cereal-
   hours*))
  (bind ?*soya-profit* (Calculate-Profitability ?*soya-gmargin* ?area
   ?*labour-cost*))
  (bind ?*soya-cir* (fetch "SOYA-CIR"))
  (bind ?*cir* (call ?*soya-cir* get (new jess.Value ?*year* 4)))
  (if (neq ?*cir* nil)
```

```
  then
  (bind ?*water-needed* 0);;  (printout t "Soya CIR is " ?*cir* crlf)
  (bind ?*water-needed* (Calculate-Water-Needed ?area ?*cir*))
  ;;  (printout t "Irrigation required for soya to be planted on all suitable land available is " ?*water-needed* " gallons." crlf)
  )
  (bind ?*soya-water* ?*water-needed*)
  (bind ?*cwr* (+ ?*cwr* ?*water-needed*))
  ;;  (printout t "Total crop water requirements are " ?*cwr* " gallons" crlf)
  (if (> ?*cwr* ?*water-available*)
  then
  (bind ?*events* (create$ SoyaWCC ?*events*))
  ;;  (printout t "There is not enough water available to irrigate an soya crop." crlf)
  (bind ?*av-water-shortage-events* (+ ?*av-water-shortage-events* 1))
  (bind ?*av-loss* (+ ?*av-loss* ?*soya-profit*))
  (bind ?*cwr* (- ?*cwr* ?*water-needed*))
   else
  (printout t "**** Grow Soya, or other warmer climate crops. Irrigation may be needed.*****" crlf)
  (bind ?*results* (create$ Grow Soya-wcc, or other warmer climate crops. Irrigation may be needed. ?*results*))
  (assert (soya))
  (assert  (effects soya ?*id*))
  ;;  (printout t "There is enough water to irrigate an soya crop." crlf crlf)
  (set ?cap input (+ ?input ?*labour-cost*))
  ;;  (printout t ?*av-water-shortage-events* ", " ?*av-loss* crlf)
  ;;  (printout t "The potential profitability (variable costs - fixed costs) of soya is £" ?*soya-profit* crlf)
  (set ?cap output (+ ?output ?*soya-profit*))
     (bind ?*advice* (create$ SoyaWCC ?*advice*))
  (bind ?*advice* (create$ ?*soya-profit* ?*advice*))
  (bind ?*advice* (create$ ?*water-needed* ?*advice*))
  (bind ?*advice* (create$ ?*labour-cost* ?*advice*))
  (bind ?*adapt-advice* (create$ SoyaWCCLII ?*adapt-advice*))
  (bind ?*LII* (create$ SoyaWCC ?*LII*))
  (store INPUT (get ?cap input))
  (store OUTPUT (get ?cap output))
  (set ?adapt delayed (+ ?del 1))
  (store DELAYED (get ?adapt delayed))
  ;; (set ?adapt multiplier (+ ?multi 1))
  ;; (store MULTI (get ?adapt multiplier))
  (assert (strategy-design del G_SoyaWCC ?*year* ?*id*))
  ;; (assert (strategy-design multi G_SoyaWCC ?*year* ?*id*))
  (save-facts .//strategy.txt strategy-design)
  )
)

;; Soya rule for which overseas production is more of a driver than the activation of new-crops-warmer-climate
;; fact, as above.
(defrule Grow-Soya-after-Peas ;;poor soya crop in the U.S. is consideration when becoming a new competitor,
  (not (sceptic))
```

```
    (not (break-crop soya))
    (phase break)
    (effects ? G_Peas ?year1&:(>= ?year1 (- ?*year* 30)) ?*id*)
    ;;if past knowledge and experience of growing legumes, no multiplier effects (see Chapter 9).
    (not (effects mktst G_Soya ?year1&:(= ?year1 (- ?*year* 10)) ?id&~?*id*))
    (env (soil ?soil&:(= ?soil 2)) (OBJECT ?env)) ;;med-heavy
    (clim (name ?n) (weather ?w&:(> ?w ?*av-ann-temp*)) (OBJECT ?clim))
    ;; (econ (sterling ?sterling)(OBJECT ?econ))
    (econ (prodSoya 1) (OBJECT ?econ)) ;; Poor overseas production - (e.g. poor soya crop in the U.S.)
    (cap (input ?input) (output ?output) (OBJECT ?cap))
    (adapt(delayed ?del)(multiplier ?multi) (OBJECT ?adapt))
 =>
    (assert (break-crop soya))
    (bind ?index ?soil)
    (bind ?area 70);;area of peas and beans currently grown
    (bind ?*labour-cost* (Calculate-Labour-Cost ?area ?*winter-cereal-hours*))
    (bind ?*soya-profit* (Calculate-Profitability ?*soya-gmargin* ?area ?*labour-cost*))
    (bind ?*soya-cir* (fetch "SOYA-CIR"))
    (bind ?*cir* (call ?*soya-cir* get (new jess.Value ?*year* 4)))
    (if (neq ?*cir* nil)
    then
    (bind ?*water-needed* 0);;  (printout t "Soya CIR is " ?*cir* crlf)
    (bind ?*water-needed* (Calculate-Water-Needed ?area ?*cir*))
    ;;  (printout t "Irrigation required for soya to be planted on all suitable land available is " ?*water-needed* " gallons." crlf)
    )
    (bind ?*soya-water* ?*water-needed*)
    (bind ?*cwr* (+ ?*cwr* ?*water-needed*))
    ;;  (printout t "Total crop water requirements are " ?*cwr* " gallons" crlf)
    (if (> ?*cwr* ?*water-available*)
    then
    (bind ?*events* (create$ SoyaWCC ?*events*))
    ;;  (printout t "There is not enough water available to irrigate an soya crop." crlf)
    (bind ?*av-water-shortage-events* (+ ?*av-water-shortage-events* 1))
    (bind ?*av-loss* (+ ?*av-loss* ?*soya-profit*))
    (bind ?*cwr* (- ?*cwr* ?*water-needed*))
    else
    (printout t "**** Grow Soya, or other warmer climate crops. Irrigation may be needed.*****" crlf)
    (bind ?*results* (create$ Grow Soya, or other warmer climate crops. Irrigation may be needed. ?*results*))
    ;;  (printout t "There is enough water to irrigate an soya crop." crlf)
    (assert (soya))
    (assert  (effects soya ?*id*))
    (set ?cap input (+ ?input ?*labour-cost*))
   ;;  (printout t ?*av-water-shortage-events* ", " ?*av-loss* crlf)
 ;;  (printout t "The potential profitability (variable costs - fixed costs) of soya is £" ?*soya-profit* crlf)
     (set ?cap output (+ ?output ?*soya-profit*))
```

```
      (bind ?*advice* (create$ Soya ?*advice*))

   (bind ?*advice* (create$ ?*soya-profit* ?*advice*))
   (bind ?*advice* (create$ ?*water-needed* ?*advice*))
   (bind ?*advice* (create$ ?*labour-cost* ?*advice*))
   (bind ?*adapt-advice* (create$ SoyaLII ?*adapt-advice*))
   (bind ?*LII* (create$ Soya ?*LII*))
   (store INPUT (get ?cap input))
   (store OUTPUT (get ?cap output))
   (set ?adapt delayed (+ ?del 1))
   (store DELAYED (get ?adapt delayed))
   ;; (set ?adapt multiplier (+ ?multi 1))
   ;; (store MULTI (get ?adapt multiplier))
    (assert (strategy-design del G_Soya ?*year* ?*id*))
   ;; (assert (strategy-design multi G_Soya ?*year* ?*id*))
    (save-facts .//strategy.txt strategy-design)
 )
 )

(defrule Grow-Soya-After-Soya
;;poor soya crop in the U.S. is consideration when becoming a new competitor,
   (not (sceptic))
   (not (break-crop soya))
   (effects soya ?*id*)
   (phase break)
   (not (effects mktst G_Soya ?year1&:(= ?year1 (- ?*year* 10)) ?id&~?*id*))
   (env (soil ?soil&:(= ?soil 2)) (OBJECT ?env)) ;;med-heavy
   (clim (name ?n) (weather ?w&:(> ?w ?*av-ann-temp*)) (OBJECT ?clim))
   (econ (prodSoya 1) (OBJECT ?econ))
   ;;Poor Overseas Production - Poor Soya crop in the U.S.
   (cap (input ?input) (output ?output) (OBJECT ?cap))
   (adapt(delayed ?del)(multiplier ?multi) (OBJECT ?adapt))
=>
   (assert (break-crop soya))
   (bind ?index ?soil)
   (bind ?area 70);;(call ?*v* elementAt ?index)) area of peas and beans currently grown
  (bind ?*labour-cost* (Calculate-Labour-Cost ?area ?*winter-cereal-hours*))
  (bind ?*soya-profit* (Calculate-Profitability ?*soya-gmargin* ?area ?*labour-cost*))
   (bind ?*soya-cir* (fetch "SOYA-CIR"))
   (bind ?*cir* (call ?*soya-cir* get (new jess.Value ?*year* 4)))
   (if (neq ?*cir* nil)
   then
   (bind ?*water-needed* 0);; (printout t "Soya CIR is " ?*cir* crlf)
   (bind ?*water-needed* (Calculate-Water-Needed ?area ?*cir*))
   ;; (printout t "Irrigation required for soya to be planted on all suitable land available is " ?*water-needed* " gallons." crlf)
   )
   (bind ?*soya-water* ?*water-needed*)
   (bind ?*cwr* (+ ?*cwr* ?*water-needed*))
   ;; (printout t "Total crop water requirements are " ?*cwr* " gallons" crlf)
```

```
    (if (> ?*cwr* ?*water-available*)
    then
    (bind ?*events* (create$ SoyaWCC ?*events*))
    ;;  (printout t "There is not enough water available to irrigate an soya crop." crlf)
    (bind ?*av-water-shortage-events* (+ ?*av-water-shortage-events* 1))
    (bind ?*av-loss* (+ ?*av-loss* ?*soya-profit*))
    (bind ?*cwr* (- ?*cwr* ?*water-needed*))
    else
    (printout t "**** Grow Soya, or other warmer climate crops. Irrigation may be needed.*****" crlf)
    (bind ?*results* (create$ Grow Soya, or other warmer climate crops. Irrigation may be needed. ?*results*))
    ;;  (printout t "There is enough water to irrigate an soya crop." crlf)
    (assert (soya))
    (set ?cap input (+ ?input ?*labour-cost*))
    ;;  (printout t ?*av-water-shortage-events* ", " ?*av-loss* crlf)
    ;;  (printout t "The potential profitability (variable costs - fixed costs) of soya is £" ?*soya-profit* crlf)
    (set ?cap output (+ ?output ?*soya-profit*))
     (bind ?*advice* (create$ Soya ?*advice*))
    (bind ?*advice* (create$ ?*soya-profit* ?*advice*))
    (bind ?*advice* (create$ ?*water-needed* ?*advice*))
    (bind ?*advice* (create$ ?*labour-cost* ?*advice*))
    (bind ?*adapt-advice* (create$ SoyaLII-after-soya ?*adapt-advice*))
    (bind ?*LII* (create$ Soya ?*LII*))
    (store INPUT (get ?cap input))
    (store OUTPUT (get ?cap output))
    (set ?adapt delayed (+ ?del 1))
    (store DELAYED (get ?adapt delayed))
    ;; (set ?adapt multiplier (+ ?multi 1))
    ;; (store MULTI (get ?adapt multiplier))
    (assert (strategy-design del G_Soya ?*year* ?*id*))
    ;; (assert (strategy-design multi G_Soya ?*year* ?*id*))
    (save-facts .//strategy.txt strategy-design)
  )
  )

(defrule Grow-Wheat
    (not (main veg))
    (not (main-crop wheat))
    (phase main)
   (not (effects mktst G_Wheat ?year1&:(= ?year1 (- ?*year* 10)) ?id&~?*id*))
   ;;mark-sat by another agent, and this agent should therefore do something different.
    (econ (prodWheat ?wheat)  (OBJECT ?econ))
    (clim (weather ?climate) (OBJECT ?clim) )
    (cap (input ?input) (output ?output) (OBJECT ?cap))
    (adapt (delayed ?del)(OBJECT ?adapt))
=>
   (bind ?area 250);;(max(call ?*v* elementAt 2)(call ?*v* elementAt 5)));;for rotation/varying field types
   (bind ?*labour-cost* (Calculate-Labour-Cost ?area ?*winter-cereal-hours*))
```

```
(bind ?*wheat-profit* (Calculate-Profitability ?*wheat-gmargin* ?area
 ?*labour-cost*))
 (bind ?*wheat-cir* (fetch "WHEAT-CIR"))
 (bind ?*cir* (call ?*wheat-cir* get (new jess.Value ?*year* 4)))
 (if (neq ?*cir* nil)
 then
 (bind ?*water-needed* 0)
 ;;  (printout t "CIR is " ?*cir* crlf)
 (bind ?*water-needed* (Calculate-Water-Needed ?area ?*cir*))
 ;;  (printout t "Irrigation required for wheat to be planted on all suit-
  able land available is " ?*water-needed* " gallons." crlf)
 )
 (bind ?*wheat-water* ?*water-needed*)
 (bind ?*cwr* (+ ?*cwr* ?*water-needed*))
 ;;  (printout t "Total crop water requirements are " ?*cwr* " gallons"
  crlf)
 (if (> ?*cwr* ?*water-available*)
 then
 (bind ?*events* (create$ Wheat ?*events*))
 ;;  (printout t "There is not enough water available to irrigate a wheat
  crop." crlf)
 (bind ?*av-water-shortage-events* (+ ?*av-water-shortage-events* 1))
 (bind ?*av-loss* (+ ?*av-loss* ?*wheat-profit*))
 (bind ?*cwr* (- ?*cwr* ?*water-needed*))
  else
  ;;  (printout t "There is enough water to irrigate a wheat crop." crlf)
 (set ?cap input (+ ?input ?*labour-cost*))
 (assert (main wheat))
 (assert (main-crop wheat))
 (printout t "**** Grow Wheat as a main crop. ****" crlf crlf)
 (bind ?*results* (create$ Grow Wheat as a main crop. ?*results*))
 (printout t "The potential profitability of wheat (variable costs -
  fixed costs) is £" ?*wheat-profit* " and this can be grown on any soil
  type" crlf)
 (set ?cap output (+ ?output ?*wheat-profit*))
 (bind ?*advice* (create$ Wheat ?*advice*))
 (bind ?*advice* (create$ ?*wheat-profit* ?*advice*))
 (bind ?*advice* (create$ ?*water-needed* ?*advice*))
 (bind ?*advice* (create$ ?*labour-cost* ?*advice*))
 (bind ?*adapt-advice* (create$ Wheat ?*adapt-advice*))
 (store INPUT (get ?cap input))
 (store OUTPUT (get ?cap output))
 (set ?adapt delayed (+ ?del 1))
 (store DELAYED (get ?adapt delayed))
 (assert (strategy-design del G_Wheat ?*year* ?*id*))
 (save-facts .//strategy.txt strategy-design)
)
)


(defrule Grow-Peas
    (not (break-crop peas))
    (phase break)
 (not (effects mktst G_Peas  ?year1&:(= ?year1 (- ?*year* 10))
  ?id&~?*id*))
    (econ (prodSoya 1) (OBJECT ?econ))  ;;  "Poor Overseas Production"
```

```
    (cap  (input ?input) (output ?output) (OBJECT ?cap))
    (adapt  (delayed ?del) (OBJECT ?adapt))
  =>
    (assert (break-crop peas))
    (bind ?area 70)
    (bind ?*labour-cost* (Calculate-Labour-Cost ?area ?*peas-hours*))
   (bind ?*peas-profit* (Calculate-Profitability ?*pulses-gmargin* ?area ?*labour-cost*))
    (bind ?*peas-cir* (fetch "PEAS-CIR"))
    (bind ?*cir* (call ?*peas-cir* get (new jess.Value ?*year* 4)))
    (if (neq ?*cir* nil)
    then
    (bind ?*water-needed* 0)
    ;;  (printout t "CIR is " ?*cir* crlf)
    (bind ?*water-needed* (Calculate-Water-Needed ?area ?*cir*))
    ;;  (printout t "Irrigation required for peas to be planted on all suitable land available is " ?*water-needed* " gallons." crlf)
    )
    (bind ?*peas-water* ?*water-needed*)
    (bind ?*cwr* (+ ?*cwr* ?*water-needed*))
   ;;  (printout t "Total crop water requirements are " ?*cwr* " gallons" crlf)
    (if (> ?*cwr* ?*water-available*)
    then
    (bind ?*events* (create$ Peas ?*events*))
  ;;  (printout t "There is not enough water available to irrigate peas." crlf)
    (bind ?*av-water-shortage-events* (+ ?*av-water-shortage-events* 1))
    (bind ?*av-loss* (+ ?*av-loss* ?*peas-profit*))   ;;   ?area
    (bind ?*cwr* (- ?*cwr* ?*water-needed*))
     else
    ;;  (printout t "There is enough water to irrigate peas." crlf)
    (printout t "**** Grow Peas as a break crop. ****" crlf crlf)
    (bind ?*advice* (create$ Peas ?*advice*))
    (bind ?*results* (create$ Grow Peas as a break crop. ?*results*))
    ;; (set ?cap output (+ ?output (* ?*peas-gmargin* ?area)))
    (set ?cap input (+ ?input ?*labour-cost*))
    ;;  (printout t "The potential profitability (variable costs - fixed costs) of peas is £" ?*peas-profit* crlf)
    (set ?cap output (+ ?output ?*peas-profit*))
    (bind ?*advice* (create$ ?*peas-profit* ?*advice*))
    (bind ?*advice* (create$ ?*water-needed* ?*advice*))
    (bind ?*advice* (create$ ?*labour-cost* ?*advice*))
    (bind ?*adapt-advice* (create$ Peas ?*adapt-advice*))
    (store INPUT (get ?cap input))
    (store OUTPUT (get ?cap output))
    (set ?adapt delayed (+ ?del 1))
    (store DELAYED (get ?adapt delayed))
    (assert (strategy-design del G_Peas ?*year* ?*id*))
    (save-facts .//strategy.txt strategy-design)
   )
  )

(defrule Grow-Peas2
    (not (break-crop peas))
    (phase break)
```

```
    (not (effects warning G_Soya ?year1&:(= ?year1 (- ?*year* 10)) ?any))
    ;;production of soya is low/not specialised in by other agents.
    (econ (prodSoya 1) (OBJECT ?econ))  ;;  Poor Overseas Production
    (cap  (input ?input) (output ?output) (OBJECT ?cap))
    (adapt  (delayed ?del) (OBJECT ?adapt))
  =>
    (assert (break-crop peas))
    (bind ?area 70);(call ?*v* elementAt ?index))
    (bind ?*labour-cost* (Calculate-Labour-Cost ?area ?*peas-hours*))
   (bind ?*peas-profit* (Calculate-Profitability ?*pulses-gmargin* ?area ?*labour-cost*))
    (bind ?*peas-cir* (fetch "PEAS-CIR"))
    (bind ?*cir* (call ?*peas-cir* get (new jess.Value ?*year* 4)))
    (if (neq ?*cir* nil)
    then
    (bind ?*water-needed* 0)      ;;  (printout t "CIR is " ?*cir* crlf)
    (bind ?*water-needed* (Calculate-Water-Needed ?area ?*cir*))
    ;;  (printout t "Irrigation required for peas to be planted on all suitable land available is " ?*water-needed* " gallons." crlf)
    )
    (bind ?*peas-water* ?*water-needed*)
    (bind ?*cwr* (+ ?*cwr* ?*water-needed*))
   ;;  (printout t "Total crop water requirements are " ?*cwr* " gallons" crlf)
    (if (> ?*cwr* ?*water-available*)
    then
    (bind ?*events* (create$ Peas ?*events*))
    ;;  (printout t "There is not enough water available to irrigate peas." crlf)
    (bind ?*av-water-shortage-events* (+ ?*av-water-shortage-events* 1))
    (bind ?*av-loss* (+ ?*av-loss* ?*peas-profit*))
    (bind ?*cwr* (- ?*cwr* ?*water-needed*))
    else
    ;;  (printout t "There is enough water to irrigate peas." crlf)
    (printout t "**** Grow Peas as a break crop. ****" crlf crlf)
    (bind ?*advice* (create$ Peas ?*advice*))
    (bind ?*results* (create$ Grow Peas as a break crop. ?*results*))
    (set ?cap input (+ ?input ?*labour-cost*))
    ;;  (printout t "The potential profitability (variable costs - fixed costs) of peas is £" ?*peas-profit* crlf)
    (set ?cap output (+ ?output ?*peas-profit*))
    (bind ?*advice* (create$ ?*peas-profit* ?*advice*))
    (bind ?*advice* (create$ ?*water-needed* ?*advice*))
    (bind ?*advice* (create$ ?*labour-cost* ?*advice*))
    (bind ?*adapt-advice* (create$ PeasLowSoya ?*adapt-advice*))
    (store INPUT (get ?cap input))
    (store OUTPUT (get ?cap output))
    (set ?adapt delayed (+ ?del 1))
    (store DELAYED (get ?adapt delayed))
    (assert (strategy-design del G_Peas ?*year* ?*id*))
    (save-facts .//strategy.txt strategy-design)
   )
  )

;;-----------------------------------------------------------------

```

```
;; ADAPTATON STRATEGIES
(defrule Increase-Irrigation-Veg "Immediate/Sustained-Effect"
   (not (strategy irrigation-veg))
   (phase crops)
   (not (effects warning +IrrVeg ?year1&:(= ?year1 (- ?*year* 10)) ?*id*))
   (vegetables)
   (adapt (immediate ?immed)(sustained ?sust) (OBJECT ?adapt))
   (cap  (input ?input) (output ?output) (OBJECT ?cap))
=>
   (printout t "Invest in a cooperative ditch system(veg), or any other
    source of irrigation, if this strategy is feasible.
  There is a need to invest in irrigation, and this is a low risk strategy,
    as the effects are immediate and continuous        (sustained).
  Capital available to invest in this strategy is " ?output crlf crlf)
   (bind ?*results* (create$ Invest in a cooperative ditch system for vege-
    tables, or any other source of irrigation, if this strategy is feasible.
  There is a need to invest in irrigation, and this is a low risk strategy,
    as the effects are immediate, continuous          and sustained.
    ?*results*))
   (set ?adapt immediate (+ ?immed 1))  ;; if quick return and relatively
    certain to produce results = low risk p284.
   (set ?adapt sustained (+ ?sust 1))    ;; strategies which produce contin-
    ual flow of returns
  ;;once initiated = variable risk (continuous input of capital) [Bennett,
    1976:284].
   (set ?adapt irrigation 1)
   (bind ?*adapt-advice* (create$ IrrLII-Veg ?*adapt-advice*))
   (bind ?*LII* (create$ Irr-Veg ?*LII*))
   (assert (strategy irrigation-veg))
   (store IMMED (get ?adapt immediate))
   (store SUST (get ?adapt sustained))
   (assert (strategy-design immed +IrrVeg ?*year* ?*id*))
   (assert (strategy-design sust +IrrVeg ?*year* ?*id*))
   (save-facts .//strategy.txt strategy-design)
)

(defrule Increase-Irrigation-Pot "Immediate/Sustained-Effect"
   (not (strategy irrigation-pot))
   (phase crops)
   (not (effects warning +IrrPot ?year1&:(= ?year1 (- ?*year* 10)) ?*id*))
   (potatoes)
   (adapt (immediate ?immed)(sustained ?sust) (OBJECT ?adapt))
   (cap  (input ?input) (output ?output) (OBJECT ?cap))
=>
   (printout t "Invest in a cooperative ditch system(pot), or any other
    source of irrigation, if this strategy is feasible.
  There is a need to invest in irrigation, and this is a low risk strategy,
    as the effects are immediate and continuous
   (sustained).
  Capital available to invest in this strategy is " ?output crlf crlf)
  (bind ?*results* (create$ Invest in a cooperative ditch system for pota-
    toes, or any other source of irrigation, if this strategy is feasible.
  There is a need to invest in irrigation, and this is a low risk strategy,
    as the effects are immediate, continuous and
  sustained. ?*results*))
```

```
    (set ?adapt immediate (+ ?immed 1))  ;; if quick return and relatively
    certain to produce results = low risk p284.
    (set ?adapt sustained (+ ?sust 1))   ;; strategies which produce contin-
    ual flow of returns
   ;;once initiated = variable risk (continuous input of capital) [Bennett,
    1976:284].
    (set ?adapt irrigation 1)
    (bind ?*adapt-advice* (create$ IrrLII-Pot ?*adapt-advice*))
     (bind ?*LII* (create$ Irr-Pot ?*LII*))
    (assert (strategy irrigation-pot))
    (store IMMED (get ?adapt immediate))
    (store SUST (get ?adapt sustained))
    (assert (strategy-design immed +IrrPot ?*year* ?*id*))
    (assert (strategy-design sust +IrrPot ?*year* ?*id*))
    (save-facts .//strategy.txt strategy-design)
)

(defrule Add-Water-Dry-Autumn "Immediate/Sustained-Effect"
    (not (water dry-autumn))
    (phase crops)
    (not (effects warning +IrrDryAut ?year1&:(= ?year1 (- ?*year* 10))
    ?*id*))
    (clim (autumn ?b&:(< ?b ?*min-aut-prec*)) (OBJECT ?clim))
    (adapt (immediate ?immed)(sustained ?sust) (OBJECT ?adapt))
    (cap  (input ?input) (output ?output) (OBJECT ?cap))
=>
    (printout t "Invest in a cooperative ditch system(dry autumn), or any
    other source of irrigation, if this strategy is feasible,since autumn
    rainfall is falling below minimum requirements.  This is a strategy
   with immediate effect. Capital available to invest in this strategy is "
    ?output crlf)
    (bind ?*results* (create$ Invest in a cooperative ditch system due to
    dry autumns, or any other source of irrigation, if this strategy
   is feasible,since autumn rainfall is falling below minimum requirements.
    This is a strategy with immediate effect. ?*results*))
    (assert (water dry-autumn))
    (set ?adapt immediate (+ ?immed 1))
    (set ?adapt sustained (+ ?sust 1))
    (set ?adapt irrigation 1)
    (bind ?*adapt-advice* (create$ +WDryAutLII ?*adapt-advice*))
    (bind ?*LII* (create$ +WDryAut ?*LII*))
    (store IMMED (get ?adapt immediate))
    (store SUST (get ?adapt sustained))
    (assert (strategy-design immed +IrrDryAut ?*year* ?*id*))
    (assert (strategy-design sust +IrrDryAut ?*year* ?*id*))
    (save-facts .//strategy.txt strategy-design)
)

(defrule Add-Water-Dry-Spring "Immediate/Sustained-Effect"
    (not (water dry-spring))
    (phase crops)
   (not (effects warning +IrrDrySpr ?year1&:(= ?year1 (- ?*year* 10))
    ?*id*))
    (clim (spring ?c&:(< ?c ?*min-spring-prec*))(OBJECT ?clim))
    (adapt (immediate ?immed) (sustained ?sust)(OBJECT ?adapt))
    (cap  (input ?input) (output ?output) (OBJECT ?cap))
```

```
=>
  (printout t "Invest in a cooperative ditch system(dry spring), or any
   other source of irrigation, if this strategy is feasible,
  since spring rainfall is falling below minimum requirements. This is a
   strategy with immediate effect.
  Capital available to invest in this strategy is " ?output crlf)
   (bind ?*results* (create$ Invest in a cooperative ditch system due to
   dry springs, or any other source of irrigation, if this strategy is fea-
   sible,
  since spring rainfall is falling below minimum requirements. This is a
   strategy with immediate effect. ?*results*))
  (assert (water dry-spring))
  (set ?adapt immediate (+ ?immed 1))
  (set ?adapt sustained (+ ?sust 1))
  (set ?adapt irrigation 1)
  (bind ?*adapt-advice* (create$ +WDrySprLII ?*adapt-advice*))
  (bind ?*LII* (create$ +WDrySpr ?*LII*))
  (store IMMED (get ?adapt immediate))
  (store SUST (get ?adapt sustained))
  (assert (strategy-design immed +IrrDrySpr ?*year* ?*id*))
  (assert (strategy-design sust +IrrDrySpr ?*year* ?*id*))
  (save-facts .//strategy.txt strategy-design)
)

(defrule  Can-Increase-Labour-Veg "Immediate-Effect"
  (not (increase-labour-veg))
  (phase crops)
  (not (effects warning +LabVeg ?year1&:(= ?year1 (- ?*year* 10)) ?*id*))
  (vegetables)
  (adapt(labour 1) (immediate ?immed) (OBJECT ?adapt))
=>
  (printout t "Invest in labour (veg) - this is a low risk strategy, as the
   effects are immediate and continuous. " crlf crlf)
 (bind ?*results* (create$ Invest in labour for vegetables - this is a low
   risk strategy, as the effects are immediate and continuous.
   ?*results*))
  (set ?adapt immediate (+ ?immed 1))
  (set ?adapt labour 1)
  (bind ?*adapt-advice* (create$ +LabLI-Veg ?*adapt-advice*))
  (bind ?*LI* (create$ +Lab-Veg ?*LI*))
  (store IMMED (get ?adapt immediate))
  (assert (increase-labour-veg))
  (assert (strategy-design immed +LabVeg ?*year* ?*id*))
  (save-facts .//strategy.txt strategy-design)
)

(defrule  Can-Increase-Labour-Pot "Immediate-Effect"
  (not (increase-labour-pot))
  (phase crops)
  (not (effects warning +LabPot ?year1&:(= ?year1 (- ?*year* 10)) ?*id*))
  (potatoes)
  (adapt(labour 1) (immediate ?immed) (OBJECT ?adapt))
  (cap  (input ?input) (output ?output) (OBJECT ?cap))
=>
  (printout t "Invest in labour(pot) - this is a low risk strategy, as the
   effects are immediate and continuous. " crlf crlf)
```

```
     (bind ?*results* (create$ Invest in labour for potatoes - this is a low risk strategy, as the effects are immediate and continuous. ?*results*))
   (set ?adapt immediate (+ ?immed 1))
   (set ?adapt labour 1)
   (bind ?*adapt-advice* (create$ +LabLI-Pot ?*adapt-advice*))
   (bind ?*LI* (create$ +Lab-Pot ?*LI*))
   (store IMMED (get ?adapt immediate))
   (assert (increase-labour-pot))
   (assert (strategy-design immed +LabPot ?*year* ?*id*))
   (save-facts .//strategy.txt strategy-design)
)

(defrule Labour-Overuse-Pot "Immediate-Effect"
   (not (labour-overuse-pot))
   (labour 0 ?*id*)
   (effects warning +LabPot  ?year1&:(= ?year1 (- ?*year* 10)) ?*id*)
=>
   (bind ?*adapt-advice* (create$ +Lab-Overuse-Pot ?*adapt-advice*))
   (assert (labour-overuse-pot))
)

(defrule Labour-Overuse-Veg "Immediate-Effect"
   (not (labour-overuse-veg))
   (labour 0 ?*id*)
   (effects warning +LabVeg  ?year1&:(= ?year1 (- ?*year* 10)) ?*id*)
=>
   (bind ?*adapt-advice* (create$ +Lab-Overuse-Veg ?*adapt-advice*))
   (assert (labour-overuse-veg))
)

(defrule Labour-Check "Immediate-Effect"
   (not (labour-check))
   (labour 0 ?*id*)
   (not (effects warning +LabPot  ?year1&:(= ?year1 (- ?*year* 10)) ?*id*))
   (not (effects warning +LabVeg  ?year1&:(= ?year1 (- ?*year* 10)) ?*id*))
   (adapt  (labour ?lab) (immediate ?immed) (OBJECT ?adapt))
   (cap  (input ?input) (output ?output) (OBJECT ?cap))
=>
  (printout t "Invest in labour - this is a low risk strategy, as the effects are immediate and continuous. " crlf crlf)
  (bind ?*results* (create$ Invest in labour - this is a low risk strategy, as the effects are immediate and continuous. ?*results*))
   (set ?adapt immediate (+ ?immed 1))
   (set ?adapt labour 1)
   (assert (labour 1 ?*id*))
   (save-facts .//labour.txt labour)
   (bind ?*adapt-advice* (create$ +LabCheckLI ?*adapt-advice*))
   (bind ?*LI* (create$ +LabCheck ?*LI*))
   (store IMMED (get ?adapt immediate))
   (assert (labour-check))
   (assert (strategy-design immed +LabCheck ?*year* ?*id*))
   (save-facts .//strategy.txt strategy-design)
)

(defrule  Can-Decrease-Labour "Immediate-Effect"
```

```
  (phase crops)
  (not (decrease-labour))
  (not (vegetables))
  (not (potatoes))
  (labour 1 ?*id*)
  (adapt  (labour ?lab) (immediate ?immed) (OBJECT ?adapt))
  (cap  (input ?input) (output ?output) (OBJECT ?cap))
=>
  (printout t "There is a need to decrease amount of labour working on the
   land; this is a low risk strategy, as the effects are immediate and con-
   tinuous.
  Current capital available is £" ?output  " and cost of labour is £"
   ?*labour-cost* crlf crlf)
  (bind ?*results* (create$ There is a need to decrease amount of labour
   working on the land - this is a low risk strategy, as the effects are
   immediate and continuous. ?*results*))
  (set ?adapt immediate (- ?immed 1))
  (set ?adapt labour 0)
  (assert (labour 0 ?*id*))
  (save-facts .//labour.txt labour)
  (bind ?*adapt-advice* (create$ RemLabLI ?*adapt-advice*))
  (bind ?*LI* (create$ RemLab ?*LI*))
  (store IMMED (get ?adapt immediate))
  (assert (decrease-labour))
)

(defrule New-Crops-Wet-Spring "Delayed-Effect"
  (not (sceptic))
  (not (strategy new-variety-wet-spring))
  (phase crops)
  (not (effects mktst NCWetSpr  ?year1&:(= ?year1 (- ?*year* 10))
   ?id&~?*id*))
  (clim (spring ?prec&:(> ?prec ?*min-spring-prec*)) (OBJECT ?clim))
  ;;  autumns are too wet.
  (adapt (delayed ?del) (multiplier ?multi)(OBJECT ?adapt))
  (cap  (input ?input) (output ?output) (OBJECT ?cap))
=>
  (printout t "It may be advisable to look to new crops at this time, as
   spring precipitation levels are too high to main current cropping pat-
   terns.
  There is enough capital to invest in new inputs and this is a low risk
   strategy, if it is relatively certain to produce results.
  Capital remaining to invest in this new strategy is £" ?output ". This is
   a strategy with delayed effect." crlf crlf)
  (bind ?*results* (create$ It may be advisable to look to new crops at
   this time, as spring precipitation levels are too high to main current
   cropping patterns.
  There is enough capital to invest in new inputs and this is a low risk
   strategy, if it is relatively certain to produce results. ?*results*))
  (set ?adapt delayed (+ ?del 1))
  (set ?adapt multiplier (+ ?multi 1))
  ;; introduction of new technology due to failure of previous technologi-
   cal inputs [Bennett, 1976:285]
  (assert  (strategy new-variety-wet-spring))
  (bind ?*adapt-advice* (create$ NCWetSprLII ?*adapt-advice*))
  (bind ?*LII* (create$ +NCWetSpr ?*LII*))
```

```
    (store DELAYED (get ?adapt delayed))
    (store MULTI (get ?adapt multiplier))
    (assert (strategy-design del NCWetSpr ?*year* ?*id*))
    (assert (strategy-design multi NCWetSpr ?*year* ?*id*))
    (save-facts .//strategy.txt strategy-design)
)

(defrule New-Crops-Wet-Autumn "Delayed-Effect"
    (not (sceptic))
    (not (strategy new-variety-wet-autumn))
    (phase crops)
    (not (effects mktst NCWetAut ?year1&:(= ?year1 (- ?*year* 10)) ?id&~?*id*))
    (clim (autumn ?prec&:(> ?prec ?*min-aut-prec*)) (OBJECT ?clim))
    ;;  autumns are too wet.
    (adapt (delayed ?del)(multiplier ?multi) (OBJECT ?adapt))
    (cap  (input ?input) (output ?output) (OBJECT ?cap))
=>
    (printout t "It may be advisable to look to new crops at this time, as autumn precipitation levels are too high to main current cropping patterns.
    There is enough capital to invest in new inputs and this is a low risk strategy, if it is relatively certain to produce results. Capital remaining to invest in this new strategy is £" ?output ".
    This is a strategy with delayed effect." crlf crlf)
      (bind ?*results* (create$ It may be advisable to look to new crops at this time, as autumn precipitation levels are too high to main current cropping patterns.
    There is enough capital to invest in new inputs and this is a low risk strategy, if it is relatively certain to produce results. ?*results*))
    (set ?adapt delayed (+ ?del 1))
    ;; introduction of new technology due to failure of previous technological inputs [Bennett, 1976:285].
    (assert  (strategy new-variety-wet-autumn))
    (bind ?*adapt-advice* (create$ NCWetAutLII ?*adapt-advice*))
    (bind ?*LII* (create$ NCWetAut ?*LII*))
    (store DELAYED (get ?adapt delayed))
    (set ?adapt multiplier (+ ?multi 1))
    (store MULTI (get ?adapt multiplier))
    (assert (strategy-design del NCWetAut ?*year* ?*id*))
    (assert (strategy-design multi NCWetAut ?*year* ?*id*))
    (save-facts .//strategy.txt strategy-design)
)

(defrule New-Crops-Dry-Spring "Delayed-Effect"
    (not (sceptic))
    (not (strategy new-variety-dry-spring))
    (phase crops)
    (clim (spring ?prec&:(< ?prec ?*min-spring-prec*)) (OBJECT ?clim))
    (adapt (delayed ?del)(multiplier ?multi) (OBJECT ?adapt))
    (cap  (input ?input) (output ?output) (OBJECT ?cap))
=>
    (printout t "It may be advisable to look to new crops at this time, as spring precipitation levels are too low to main current cropping patterns.
```

```
There is enough capital to invest in new inputs and this is a low risk strategy, if it is relatively certain to produce results.
Capital remaining to invest in this new strategy is £" ?output ".
This is a strategy with delayed effect." crlf crlf)
 (bind ?*results* (create$ It may be advisable to look to new crops at this time, as spring precipitation levels are too low to main current cropping patterns.
There is enough capital to invest in new inputs and this is a low risk strategy, if it is relatively certain to produce results.  This is a strategy with delayed effect. ?*results*))
(set ?adapt delayed (+ ?del 1))
(set ?adapt multiplier (+ ?multi 1))
;; introduction of new technology due to failure of previous technological inputs [Bennett, 1976:285]
(assert  (strategy new-variety-dry-spring))
(bind ?*adapt-advice* (create$ NCDrySprLII ?*adapt-advice*))
(bind ?*LII* (create$ NCDrySpr ?*LII*))
(store DELAYED (get ?adapt delayed))
(store MULTI (get ?adapt multiplier))
(assert (strategy-design del NCDrySpr ?*year* ?*id*))
(assert (strategy-design multi NCDrySpr ?*year* ?*id*))
(save-facts .//strategy.txt strategy-design)
)

(defrule New-Crops-Dry-Autumn "Delayed-Effect"
 (not (sceptic))
 (not (strategy new-variety-dry-aut))
 (phase crops)
 (clim (autumn ?prec&:(< ?prec ?*min-aut-prec*)) (OBJECT ?clim))
 (adapt (delayed ?del) (multiplier ?multi)(OBJECT ?adapt))
 (cap  (input ?input) (output ?output) (OBJECT ?cap))
=>
 (printout t "It may be advisable to look to new crops at this time, as autumn precipitation levels are too low to main current cropping patterns.
There is enough capital to invest in new inputs and this is a low risk strategy, if it is relatively certain to produce results.
Capital remaining to invest in this new strategy is £" ?output ".
This is a strategy with delayed effect." crlf crlf)
 (bind ?*results* (create$ It may be advisable to look to new crops at this time, as autumn precipitation levels are too low to main current cropping patterns.
There is enough capital to invest in new inputs and this is a low risk strategy, if it is relatively certain to produce results. This is a strategy with delayed effect. ?*results*))
(set ?adapt delayed (+ ?del 1))
(set ?adapt multiplier (+ ?multi 1))
;; introduction of new technology due to failure of previous technological inputs [Bennett, 1976:285]
(assert  (strategy new-variety-dry-aut))
(bind ?*adapt-advice* (create$ NCDryAutLII ?*adapt-advice*))
(bind ?*LII* (create$ NCDryAut ?*LII*))
(store DELAYED (get ?adapt delayed))
(store MULTI (get ?adapt multiplier))
(assert (strategy-design del NCDryAut ?*year* ?*id*))
(assert (strategy-design multi NCDryAut ?*year* ?*id*))
```

```
    (save-facts .//strategy.txt strategy-design)
)

(defrule New-Crops-Dry-Summer "Delayed-Effect"
    (not (sceptic))
    (not (strategy new-variety-dry-summer))
    (phase crops)
   (not (effects mktst NCDrySum ?year1&:(= ?year1 (- ?*year* 10)) ?id&~?*id*))
    (clim (summer ?prec&:(< ?prec ?*min-summer-prec*)) (OBJECT ?clim))
    (adapt(delayed ?del)(multiplier ?multi) (OBJECT ?adapt))
    (cap  (input ?input) (output ?output) (OBJECT ?cap))
=>
    (printout t "It may be advisable to look to new crops at this time, as summer precipitation levels are too low to main current cropping patterns.
   There is enough capital to invest in new inputs and this is a low risk strategy, if it is relatively certain to produce results.
   Capital remaining to invest in this new strategy is £" ?output ".
   This is a strategy with delayed effect." crlf crlf)
    (bind ?*results* (create$ It may be advisable to look to new crops at this time, as summer precipitation levels are too low to main current cropping patterns.
   There is enough capital to invest in new inputs and this is a low risk strategy, if it is relatively certain to produce results. This is a strategy with delayed effect. ?*results*))
    (set ?adapt delayed (+ ?del 1))
    (set ?adapt multiplier (+ ?multi 1))
   ;; introduction of new technology due to failure of previous technological inputs [Bennett,1976:285]
    (assert  (strategy new-variety-dry-summer))
    (bind ?*adapt-advice* (create$ NCDrySumLII ?*adapt-advice*))
    (bind ?*LII* (create$ NCDrySum ?*LII*))
    (store DELAYED (get ?adapt delayed))
    (store MULTI (get ?adapt multiplier))
    (assert (strategy-design del NCDrySum ?*year* ?*id*))
    (assert (strategy-design multi NCDrySum ?*year* ?*id*))
    (save-facts .//strategy.txt strategy-design)
)

(defrule New-Crops-Wet-Summer "Delayed-Effect"
    (not (sceptic))
    (not (strategy new-variety-wet-summer))
    (phase crops)
   (not (effects mktst NCWetSum ?year1&:(= ?year1 (- ?*year* 10)) ?id&~?*id*))
    (clim (summer ?prec&:(> ?prec ?*max-summer-prec*)) (OBJECT ?clim))
    (adapt (delayed ?del)(multiplier ?multi) (OBJECT ?adapt))
    (cap  (input ?input) (output ?output) (OBJECT ?cap))
=>
    (printout t "It may be advisable to look to new crops at this time, as summer precipitation levels are too high to main current cropping patterns.
   This is a low risk strategy, if it is relatively certain to produce results.
   Capital remaining to invest in this new strategy is £" ?output  ".
```

```
  This is a strategy with delayed effect." crlf crlf)
  (bind ?*results* (create$ It may be advisable to look to new crops at this time, as summer precipitation levels are too high to main current cropping patterns.
  This is a low risk strategy, if it is relatively certain to produce results.
  This is a strategy with delayed effect.?*results*))
  (set ?adapt delayed (+ ?del 1))
  (set ?adapt multiplier (+ ?multi 1))
 ;; introduction of new technology due to failure of previous technological inputs [Bennett,1976:285]
  (assert  (strategy new-variety-wet-summer))
  (bind ?*adapt-advice* (create$ NCWetSumLII ?*adapt-advice*))
  (bind ?*LII* (create$ NCWetSum ?*LII*))
  (store DELAYED (get ?adapt delayed))
  (store MULTI (get ?adapt multiplier))
  (assert (strategy-design del NCWetSum ?*year* ?*id*))
  (assert (strategy-design multi NCWetSum ?*year* ?*id*))
  (save-facts .//strategy.txt strategy-design)
)

(defrule New-Crops-Wetter-Climate "Delayed-Effect"
  (not (sceptic))
  (not (strategy new-variety-wetter-climate))
  (phase crops)
  (not (effects mktst NCWetClim  ?year1&:(= ?year1 (- ?*year* 10)) ?id&~?*id*))
  (clim (weather ?prec&:(> ?prec ?*av-ann-prec*)) (OBJECT ?clim))
  (adapt (delayed ?del)(multiplier ?multi) (OBJECT ?adapt))
  (cap  (input ?input) (output ?output) (OBJECT ?cap))
=>
  (printout t "It may be advisable to look to new crops at this time, as average annual precipitation levels have increased.
  This is a low risk strategy, if it is relatively certain to produce results.  Capital remaining to invest in this new strategy is £" ?output ". This is a strategy with delayed effect." crlf crlf)
  (bind ?*results* (create$ It may be advisable to look to new crops at this time, as average annual precipitation levels have increased.
  This is a low risk strategy, if it is relatively certain to produce results.  This is a strategy with delayed effect.?*results*))
  (set ?adapt delayed (+ ?del 1))
  (set ?adapt multiplier (+ ?multi 1))
  ;; introduction of new technology due to failure of previous technological inputs [Bennett,1976:285]
  (assert  (strategy new-variety-wetter-climate))
  (bind ?*adapt-advice* (create$ NCWetClimLII ?*adapt-advice*))
  (bind ?*LII* (create$ NCWetClim ?*LII*))
  (store DELAYED (get ?adapt delayed))
  (store MULTI (get ?adapt multiplier))
  (assert (strategy-design del NCWetClim ?*year* ?*id*))
  (assert (strategy-design multi NCWetClim ?*year* ?*id*))
  (save-facts .//strategy.txt strategy-design)
)

(defrule New-Crops-Warmer-Climate "Delayed-Effect"
  (not (sceptic))
```

```
   (not (strategy new-variety-warmer-climate))
   (phase crops)
  (not (effects mktst NCWarmClim  ?year1&:(= ?year1 (- ?*year* 10))
    ?id&~?*id*))
   (clim (weather ?temp&:(> ?temp ?*av-ann-temp*)) (OBJECT ?clim))
   (adapt (delayed ?del)(multiplier ?multi) (OBJECT ?adapt))
   (cap  (input ?input) (output ?output) (OBJECT ?cap))
=>
   (printout t "It may be advisable to look to new crops at this time, as
    average annual temperature levels have increased.
   This is a low risk strategy, if it is relatively certain to produce
    results.
   Capital remaining to invest in this new strategy is £" ?output  ".
   This is a strategy with delayed effect." crlf crlf)
  (bind ?*results* (create$ It may be advisable to look to new crops at
    this time, as average annual temperature levels have increased.
 This is a low risk strategy, if it is relatively certain to produce
    results.  This is a strategy with delayed effect. ?*results*))
  (set ?adapt delayed (+ ?del 1))
  (set ?adapt multiplier (+ ?multi 1))
  ;; introduction of new technology due to failure of previous technologi-
    cal inputs [Bennett,1976:285]
   (assert  (strategy new-variety-warmer-climate))
   (bind ?*adapt-advice* (create$ NCWarmClimLII ?*adapt-advice*))
   (bind ?*LII* (create$ NCWarmClim ?*LII*))
   (store DELAYED (get ?adapt delayed))
   (store MULTI (get ?adapt multiplier))
   (assert (strategy-design del NCWarmClim ?*year* ?*id*))
   (assert (strategy-design multi NCWarmClim ?*year* ?*id*))
   (save-facts .//strategy.txt strategy-design)
)

(defrule Spring-Variety "Delayed-Effect"
    (not (strategy new-spring-sow-date))
    (phase crops)
    (clim (autumn ?prec&:(> ?prec ?*av-aut-prec*)) (OBJECT ?clim))
    ;;  autumns are too wet.
    (adapt (delayed ?del) (OBJECT ?adapt))
=>
   (printout t "Change to Spring crop varieties, as the autumn season is
   now producing too much rainfall to continue with those varieties grown
   in the past.  This is a low risk strategy, if it is relatively certain
   to produce results. The advantage of growing a spring variety is that
   spring crops are cheap to feed and  keep clean. This is a strategy with
   delayed effect." crlf crlf)
  (bind ?*results* (create$ Change to Spring crop varieties, as the autumn
   season is now producing too much rainfall to continue with those varie-
   ties grown in the past. This is a low risk strategy, if it is relatively
   certain to produce results.  The advantage of growing a spring variety
   is that spring crops are cheap to feed and  keep clean. This is a strat-
   egy with delayed effect. ?*results*))
  (set ?adapt delayed (+ ?del 1))
  (assert  (strategy new-spring-sow-date))
  (bind ?*adapt-advice* (create$ SprVarLI ?*adapt-advice*))
  (bind ?*LI* (create$ SprVar ?*LI*))
  (store DELAYED (get ?adapt delayed))
```

```
)

;;diff between these and new-crop-wet-aut-spr is that sceptic will invoke these also
(defrule Winter-Variety "Delayed-Effect"
  (not (strategy new-winter-sow-date))
  (phase crops)
  (clim (spring ?prec&:(= ?prec ?*av-spring-prec*)) (OBJECT ?clim))
 ;; springs are too dry.
  (adapt (delayed ?del) (OBJECT ?adapt))
=>
  (printout t "Grow Winter crop varieties, as the spring season is too dry to grow Spring varieties.  This is a low risk strategy, if it is relatively certain to produce results.  The advantage of growing a winter variety is that they tend to produce high yields.  This is a strategy with delayed effect." crlf crlf)
   (bind ?*results* (create$ Grow Winter crop varieties, as the spring season is too dry to grow Spring varieties.  This is a low risk strategy, if it is relatively certain to produce results.  The advantage of growing a winter variety is that they tend to produce high yields. This is a strategy with delayed effect. ?*results*))
  (set ?adapt delayed (+ ?del 1))
  (assert  (strategy new-winter-sow-date))
  (bind ?*adapt-advice* (create$ WinVarLI ?*adapt-advice*))
  (bind ?*LI* (create$ WinVar ?*LI*))
  (store DELAYED (get ?adapt delayed))
)

************************************************************************
;; Bennett's framework

(defrule Incremental-Change
  (phase adapt)
  ?f1 <- (strategy-design immed ?y ?*year* ?*id*)
  ?f2 <- (strategy-design immed ?y ?year1&:(= ?year1 (- ?*year* 10)) ?*id*)
 ;; strategies are repeated in at least 2 consecutive decades.
=>
 (printout t "Incremental change. Strategies are being taken to serve immediate ends of profit or output.
 Are future costs and long-range planning for change in the whole system being considered?
  Strategy chosen is " ?y  crlf crlf)
  ;;  (bind ?*results* (create$ Incremental change. Strategies are being taken to serve immediate ends of profit or output.
  ;;Are future costs and long-range planning for change in the whole system being considered? ?*results*))
  (bind ?*strategy-design* (create$  ?y IncChg* ?*strategy-design*))
  (bind ?*IC* (create$  ?y IncChg* ?*IC*))
  (bind ?*incr-change* (+ ?*incr-change* 1))
)

(defrule Buffering ;;invokes warnings that might are referred to by Bennett as a step function (see below).
  (phase adapt)
  ?f1 <- (strategy-design neg ?a ?y ?z ?*year* ?*id*)
```

```
  ?f2 <- (strategy-design neg ?b ?y ?z ?year1&:(= ?year1 (- ?*year* 10)) ?*id*)
  ;; negative strategies are repeated in at least 2 consecutive decades.
=>
  ;; (printout t "Buffering - A negative strategy is persisting because other factors encourage it to do so, in spite of ;;the danger.
  ;;This could be due to vested interests, which are one kind of buffering mechnism of particular importance in all   ;;growth-oriented
 systems where gain  is large and the risk of loss is correspondingly felt to be severe.
  ;; The negative strategy is " ?y " which is being used in " ?z crlf crlf)
  (assert (strategy-design buffering ?a ?y ?z  ?*year* ?*id*))
  (assert (strategy-design buffering ?b ?y ?z  ?year1 ?*id*))
  (assert (effects warning ?y  ?*year* ?*id*))
  ;; this agent is consuming resources dangerously, so other agents will be prompted to avoid them.
  (bind ?*warnings* (create$ warn ?y ?*warnings*))
  (bind ?*buffering* (+ ?*buffering* 1))
  (bind ?*strategy-design* (create$  ?y ?z Buf* ?*strategy-design*))
  (bind ?*B* (create$ ?y ?z Buf* ?*B*))
)

(defrule Step-Function
(not-invoked)
  (phase adapt)
  ?f2 <- (strategy-design buffering ? ?y ?z  ?*year* ?*id*)
  ?f1 <- (strategy-design buffering ? ?y ?z ?year1&:(= ?year1 (- ?*year* 10)) ?*id*)
 ;; negative strategies are repeated in at least 2 consecutive decades.
=>
  (printout t "Step-function. A demand for control may be triggered due to the existence of the buffering mechanism that has been invoked, because other factors are encouraging it to do so.  The negative
 strategies which belong to the buffering mechanism are " ?x ", " ?y " and " ?z crlf crlf)
  (assert (effects warning ?y ?*year* ?*id*))
  (bind ?*warnings* (create$ warn ?y ?*warnings*))
  (bind ?*step-function* (+ ?*step-function* 1))
  (bind ?*strategy-design* (create$ ?y ?z StpFn* ?*strategy-design*))
  (bind ?*SF* (create$ ?y ?z StpFn* ?*SF*))
)

(defrule Resource-Competition
;;movement towards a pattern of accommodation, where resources are allocated to particular groups.
  (phase adapt)
  ;; need to pass this agent the playerList and add a condition to this rule meaning that it can only match with the players in the von Neumann neighbourhoood.
 ?f1 <- (strategy-design del ?b ?*year* ?*id*)
 ?f2 <- (strategy-design del ?d&~?b ?*year*  ?id&~?*id*)
 ?f3 <- (strategy-design del ?b ?year2&:(= ?year2 (- ?*year* 20)) ?*id*)
 ?f4 <- (strategy-design del ?d ?year2&:(= ?year2 (- ?*year* 20)) ?id)
 ?f5 <- (strategy-design del ?b ?year1&:(= ?year1 (- ?*year* 10)) ?*id*)
 ?f6 <- (strategy-design del ?d ?year1&:(= ?year1 (- ?*year* 10)) ?id)
```

```
  ;;del effects since strategies need to be produce related i.e. crops, rather than local resources since competitive non-local as well as local neighbours
   =>
  ;;types can be the same but strategy needs to be different hence strategies are complementary rather than the same, though in theory they could be.
  (printout t "Resource competition. The competition for resources is proceeding cyclically, as strategies have attained a
  steady/homeostatic rhythm, whereby there is a movement towards a particular allocation of resources to particular
  groups. The strategies chosen are " ?b " and " ?d " the effects of which are delayed." crlf crlf)
   (bind ?*strategy-design* (create$ ?b  ?d RC* ?*strategy-design* ))
   (bind ?*RC* (create$ ?b ?d ?*id* ?id ?*year* ?year2 ?year1 RC* ?*RC* ))
   (bind ?*resource-competition* (+ ?*resource-competition* 1))
   )

;;these rules (Local-Copying N1-N4) are simply for reporting purposes
(defrule Local-Copying-N1
;;movement towards a pattern of accommodation, where resources are allocated to particular groups.
   (phase adapt)
   ;; local copying of players in the von Neumann neighbourhood. Agent is matched with agents in the playerList.
  ?f1 <- (strategy-design ? ?b ?*year* ?*id*)
  ?f2 <- (strategy-design ? ?b ?*year*  ?*neighbour1*)
  ?f6 <- (strategy-design ? ?b ?year2&:(= ?year2 (- ?*year* 20)) ?*id*)
  ?f7 <- (strategy-design ? ?b ?year2&:(= ?year2 (- ?*year* 20)) ?*neighbour1*)
   ;; strategies are the same, when achieving local resource competition since copying peers.
  ?f11 <- (strategy-design ? ?b ?year1&:(= ?year1 (- ?*year* 10)) ?*id*)
  ?f12 <- (strategy-design ? ?b ?year1&:(= ?year1 (- ?*year* 10)) ?*neighbour1*)
   =>
   (printout t "Peer-to-peer copying with neighbour 1. Aligned strategies are " ?b crlf crlf)
   (bind ?*strategy-design* (create$ ?b LRC* ?*strategy-design* ))
  ;; (bind ?*LRC* (create$ ?b  ?*id* ?*neighbour1* ?*year* ?year2 ?year1 LRC* ?*LRC* ))
   (bind ?*local-resource-competition* (+ ?*local-resource-competition* 1))
  )

(defrule Local-Copying-N2
;;movement towards a pattern of accommodation, where resources are allocated to particular groups.
   (phase adapt)
   ;; local copying of players in the von Neumann neighbourhood. Agent is matched with agents in the playerList.
  ?f1 <- (strategy-design ? ?b ?*year* ?*id*)
  ?f2 <- (strategy-design ? ?b ?*year*  ?*neighbour2*)
  ?f3 <- (strategy-design ? ?b ?year2&:(= ?year2 (- ?*year* 20)) ?*id*)
  ?f4 <- (strategy-design ? ?b ?year2&:(= ?year2 (- ?*year* 20)) ?*neighbour2*)
```

```
;; strategies are the same, when achieving local resource competition since copying peers.
?f5 <- (strategy-design ? ?b ?year1&:(= ?year1 (- ?*year* 10)) ?*id*)
?f6 <- (strategy-design ? ?b ?year1&:(= ?year1 (- ?*year* 10)) ?*neighbour2*)
=>
(printout t "Peer-to-peer copying with neighbour 2. Aligned strategies are " ?b crlf crlf)
(bind ?*strategy-design* (create$ ?b  LRC* ?*strategy-design* ))
(bind ?*LRC* (create$ ?b ?*id* ?*neighbour2* ?*year* ?year2 ?year1 LRC* ?*LRC* ))
(bind ?*local-resource-competition* (+ ?*local-resource-competition* 1))
)

(defrule Local-Copying-N3 ;;movement towards a pattern of accommodation, where resources are allocated to particular groups.
(phase adapt)
;; local copying of players in the von Neumann neighbourhood. Agent is matched with agents in the playerList.
?f1 <- (strategy-design ? ?b ?*year* ?*id*)
?f2 <- (strategy-design ? ?b ?*year*  ?*neighbour3*)
?f3 <- (strategy-design ? ?b ?year2&:(= ?year2 (- ?*year* 20)) ?*id*)
?f4 <- (strategy-design ? ?b ?year2&:(= ?year2 (- ?*year* 20)) ?*neighbour3*)
;; strategies are the same, when achieving local resource competition since copying peers.
?f5 <- (strategy-design ? ?b ?year1&:(= ?year1 (- ?*year* 10)) ?*id*)
?f6 <- (strategy-design ? ?b ?year1&:(= ?year1 (- ?*year* 10)) ?*neighbour3*)
=>
(printout t "Peer-to-peer copying with neighbour 3. Aligned strategies are " ?b crlf crlf)
(bind ?*strategy-design* (create$ ?b  ?b LRC* ?*strategy-design* ))
(bind ?*LRC* (create$ ?b  ?b ?*id* ?*neighbour3* ?*year* ?year2 ?year1 LRC* ?*LRC* ))
(bind ?*local-resource-competition* (+ ?*local-resource-competition* 1))
)

(defrule Local-Copying-N4 ;;movement towards a pattern of accommodation, where resources are allocated to particular groups.
(phase adapt)
;; local copying of players in the von Neumann neighbourhood. Agent is matched with agents in the playerList.
?f1 <- (strategy-design ? ?b ?*year* ?*id*)
?f2 <- (strategy-design ? ?b ?*year*  ?*neighbour4*)
?f3 <- (strategy-design ? ?b ?year2&:(= ?year2 (- ?*year* 20)) ?*id*)
?f4 <- (strategy-design ? ?b ?year2&:(= ?year2 (- ?*year* 20)) ?*neighbour4*)
;; strategies are the same, when achieving local resource competition since copying peers.
?f5 <- (strategy-design ? ?b ?year1&:(= ?year1 (- ?*year* 10)) ?*id*)
?f6 <- (strategy-design ? ?b ?year1&:(= ?year1 (- ?*year* 10)) ?*neighbour4*)
=>
(printout t "Peer-to-peer copying with neighbour 4. Aligned strategies are " ?b crlf crlf)
```

```
  (bind ?*strategy-design* (create$ ?b LRC* ?*strategy-design* ))
  (bind ?*LRC* (create$ ?b ?*id* ?*neighbour4* ?*year* ?year2 ?year1 LRC*
  ?*LRC* ))
  (bind ?*local-resource-competition* (+ ?*local-resource-competition*
  1))
 )

(defrule Spec-of-Potential
  (phase adapt)
  ?f2 <- (strategy-design ?a ?y ?*year* ?*id*)
  ?f1 <- (strategy-design ?b ?y ?year1&:(= ?year1 (- ?*year* 20)) ?*id*)
  ;; strategies are repeated in at least 3 consecutive decades.
  ?f3 <- (strategy-design ?c ?y ?year2&:(= ?year2 (- ?*year* 10)) ?*id*)
  ;; strategies are repeated in at least 3 consecutive decades.
  =>
 (printout t "Specialisation of potential. There is an increasingly
  focused use of particular resources over long periods of time.
  The specialization of the use of this resource results in particular
  productive regimes.
  The resource that is being specialized is " ?y " and this has " ?a ", "?b
  " and " ?c " effects." crlf crlf)
  (bind ?*strategy-design* (create$  ?y SpecPot* ?*strategy-design*))
  (bind ?*SP* (create$ ?y SpecPot* ?*SP*))
  (assert (strategy-design neg ?b ?y SP ?year1 ?*id*))
  (assert (strategy-design neg ?a ?y SP ?*year* ?*id*))
  (assert (strategy-design neg ?c ?y SP ?year2 ?*id*))
  (assert (effects mktst ?y ?*year* ?*id* ))
  ;; this agent is specialising for this niche in the market allowing
  other agents to target other niches.
  (bind ?*warnings* (create$ mktst ?y ?*warnings*))
  (bind ?*spec-of-pot* (+ ?*spec-of-pot* 1))
 )

(defrule Adaptational-Drift  ;;movement/vector of decisions and adjust-
  ments in a certain direction due to preservation
;;of cultural style, e.g.vicious circle effect
  (phase adapt)
  ?f1 <- (strategy-design ?a ?y ?*year* ?*id*) ;;?x
  ?f2 <- (strategy-design ?b ?y ?year1&:(= ?year1 (- ?*year* 10)) ?*id*)
;; strategies are repeated in at least 2 consecutive decades.
=>
  (printout t "Adaptive Drift. There is a movement/vector of decisions and
  adjustments in a certain direction.
Type of strategy chosen is " ?y " and the effects of this are " ?a " and "
  ?b crlf crlf)
  (assert (design adapt-drift))
  (bind ?*strategy-design* (create$  ?y AD* ?*strategy-design*))
  (bind ?*AD* (create$ ?y AD* ?*AD*))
  (assert (strategy-design neg ?b ?y AD ?year1 ?*id*))
  (assert (strategy-design neg ?a ?y AD ?*year* ?*id*))
  (bind ?*adapt-drift* (+ ?*adapt-drift* 1))
)

(defrule Action-Constraint   ;; similar to resource competition, but here
  increased no of variables, increases constraint.
  (phase adapt)
```

```
    ?f1 <- (strategy-design multi ?a ?*year* ?*id*)
    ?f2 <- (strategy-design multi ?b&~?a ?*year* ?*id*)
    ?f3 <- (strategy-design multi ?a ?year1&:(= ?year1 (- ?*year* 10)) ?*id*)
    ?f4 <- (strategy-design multi ?b ?year1&:(= ?year1 (- ?*year* 10)) ?*id*)
;; more than 1 strategy is repeated in at least 2 consecutive decades in a cycle.
=>
  (printout t "Action constraint - The number of variables in the long-term strategy have increased to the point
  that they are limiting or controlling future decisions and changes.
  There is a tension between the desire to alter the pattern and the impossibility of doing so due to the
   binding power of decisions produced by a very heavy investment.
   The strategies are " ?a " and " ?b " and they have multiple hidden costs." crlf crlf)
    (bind ?*strategy-design* (create$  ?a ?b ActCon* ?*strategy-design*));;multi
    (bind ?*AC* (create$  ?a ?b ActCon* ?*AC*));;multi
    (assert (strategy-design neg multi ?a AC ?year1 ?*id*))
    (assert (strategy-design neg multi ?a AC ?*year* ?*id*))
    (assert (strategy-design neg multi ?b AC ?year1 ?*id*))
    (assert (strategy-design neg multi ?b AC ?*year* ?*id*))
    (assert (effects mktst ?a  ?*year* ?*id*))
    (assert (effects mktst ?b  ?*year* ?*id*))
    (bind ?*warnings* (create$ mktst ?a ?*warnings*))
    (bind ?*warnings* (create$ mktst ?b ?*warnings*))
    (bind ?*action-constraint* (+ ?*action-constraint* 1))
)
```