Assessing the Impact of Climate Change upon Migration in Burkina Faso: An Agent-Based Modelling Approach

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Acronyms & Model Versions

ABM	Agent-Based Model
AMARC	Agent Migration Adaptation to Rainfall Change
CHANS	Complex Human and Natural System
CRU	Climate Research Unit
ECOWAS	Economic Community of West African States
EMIUB	Enquête Migration Insertion Urbaine au Burkina Faso
GCM	Global Climate Model
GIS	Geographical Information System
IOM	International Organization for Migration
IPCC	Intergovernmental Panel on Climate Change
ISSP	Institute Supérieur des Sciences de la Population
JAS	July-August-September
MARC	Migration Adaptation to Rainfall Change
MPPACC	Model of Private Proactive Adaptation to Climate Change
NDVI	Normalized Difference Vegetation Index
NELM	New Economics of Labour Migration
PACC	Proactive Adaptation to Climate Change
PMT	Protection Motivation Theory
RACC	Reactive Adaptation to Climate Change
RMSD	Root Mean Squared Deviation
SMARC	Simple Migration Adaptation to Climate Change
UNPD	United Nations Population Division
UNSD	United Nations Statistics Division

Model Versions

AMARC_Population	Simple demographic model with no migration decision-making.
AMARC1	Full migration decision-making neither birth nor death of agents.
AMARC2	Full migration decision-making and agent birth permitted.
AMARC3	Full migration decision-making and full demographic change.
AMARC3_Dry	Version of AMARC3 in which all model years are defined as dry.
AMARC3_Ave	Version of AMARC3 in which all model years are defined as average.
AMARC3_Wet	Version of AMARC3 in which all model years are defined as wet.
AMARC3_BirthDeath	Version of AMARC3 in which model population remains static due to equal birth and death rates.

Behavioural Attitude Weight Matrix Options

ppt.mp10	Current year rainfall and 1990-1999 EMIUB migration record.
ppt.mp30	Current year rainfall and 1970-1999 EMIUB migration record.
ppt3.mp10	Three year rainfall and 1990-1999 EMIUB migration record.
ppt3.mp30	Three year rainfall and 1970-1999 EMIUB migration record.

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ASSESSING THE IMPACT OF CLIMATE CHANGE UPON MIGRATION IN BURKINA FASO: AN AGENT-BASED MODELLING APPROACH

SUMMARY

The notion of environmental migration, and the associated desire to predict the likely scale of the phenomenon in the future, has frequented academic debate since the 1980s. Despite this, current estimates of the numbers of people likely to be displaced by environmental change by 2050 range from 150 million to 1 billion. By developing an agent-based model this research attempts to provide a rigorous means of quantifying the influence of future changes in climate (using rainfall as a proxy) upon migration trends within the context of Burkina Faso. Located in dryland West Africa, the population and economy of Burkina Faso are highly dependent upon rain-fed agriculture, placing them in a position of considerable vulnerability to future changes in rainfall. The conceptual basis behind the Agent Migration Adaptation to Rainfall Change (AMARC) model presented by this thesis is developed using contributions from the fields of climate adaptation and social psychology to focus upon three Theory of Planned Behaviour components of the migration decision: behavioural attitude; subjective norm; and perceived behavioural control. Rules of behaviour defined within the model are developed and parameterised using information gained from both retrospective migration data analysis and the responses of interviewees in focus groups conducted across Burkina Faso. Following a process of stringent model validation and testing the AMARC model is used to investigate the role of changes in rainfall variability upon past and future modelled migration. Although a relatively clear hierarchical impact of (from highest to lowest modelled migration) average, dry and wet rainfall conditions upon total modelled migration is identified, the individual flows of migrants that make up the total show unique and varied relationships with changes in rainfall. Furthermore, modelled internal and international migration flows show both similarities and differences when compared with relationships identified between rainfall and migration within existing literature.

Chapter 1

Introduction

1.1 Introduction

Despite widespread recognition that climate change is occurring, our capacity to accurately predict how it will affect the livelihoods of people is still limited. As a result, the impact of future climate change scenarios upon a human phenomenon such as migration is highly uncertain. In their First Assessment Report the Intergovernmental Panel on Climate Change (IPCC) identified migration and resettlement as potentially one of the most threatening short-term effects of climate change upon human settlements as a result of land degradation, flooding or drought (Tegart et al., 1990). However, seventeen years later the IPCC's Fourth Assessment Report suggests that current estimates of what they term 'environmental migrants' are still, at best, 'guesswork' (Wilbanks et al., 2007).

The element of guesswork involved in migrant forecasts can be inferred from the wide range of current estimates of global migration induced by climate change. Such estimates place numbers of displaced persons between 150-200 million (Stern, 2007) and 1 billion (ChristianAid, 2007) worldwide by 2050. Despite these attempts at quantification, there is a clear paucity of empirical information supporting the notion of environmental migration. Rather than taking into account the multiple and complex reasons behind migration, predictions of environmental migrant numbers are generally based upon the size of the populations living in at-risk regions and adopt a top-down approach that assumes all individuals will respond to the same stimuli in the same way. On this basis, most estimates do not account for the range of adaptation strategies available to affected communities, or their differing levels of vulnerability to change.

In their paper presenting a conceptual model to investigate migration as a possible adaptive response to risks associated with climate change, McLeman and Smit (2006) show that such a strategy has been employed by populations throughout history. In the face of any climate stress, ranging from slow-onset land degradation to the more rapid occurrence of periodic drought, a variety of adaptation strategies are generally available to affected individuals. As well as a range of in-situ adaptation options, some individuals may have the option of migrating to an alternative location. However, as per Black et al.'s (2011a) notion of 'trapped populations', the investment often required for long-distance travel may leave those more vulnerable to the impacts of climate change unable to invest in migration. As a result, individuals wishing to migrate in the face of change may be unable to do so while those with the capacity to relocate may choose not to do so. The potential value of previous attempts to quantify environmental migration is thus inhibited by their failure to adequately acknowledge such local and individual components of migration behaviour. Furthermore, with migration commonly undertaken worldwide for a variety of interconnected social, economic and political reasons, it is unlikely that such top-down approaches can successfully isolate environmental influences from the multitude of other factors that influence human migration.

It is evident therefore that a need exists for quantitative research into environmental migration on a smaller and more individual-centric scale. Some recent studies of the migration-climate nexus have sought to understand the process of migration by exploring the relationships of covariates to migratory and non-migratory outcomes by using such techniques as multi-level event-history analysis (Henry et al., 2004a). Although such local-scale approaches provide a more nuanced assessment of the triggers of migration than their global counterparts, they tend not to acknowledge the complex, non-linear and emergent processes inherently involved in the behavioural aspect of any social phenomena. By neglecting to explicitly resolve the individual decision-making process much of the past research on quantifying climate change migration is limited as a basis for social simulation for conditions outside those experienced in the past. In a changing climate this may restrict our ability to predict new flows of people and to simulate the impact of different policy responses on these flows.

An alternative approach is to investigate the rules of behaviour that govern how individuals respond to complex combinations of multi-level stimuli within different contexts and circumstances. By applying such rules to a computational model of migration decision-making, human responses to conditions outside those previously witnessed can be simulated. A technique well-suited to this style of rule-based predictive simulation is agent-based modelling, a class of computational models used to simulate the actions and interactions of autonomous agents. Although there is no universal agreement on the precise definition of an agent, most suggestions insist that a component's behaviour must be adaptive for it to be considered to have agency. From a practical modelling perspective, Wooldridge and Jennings (2002) described the key features common to most agents as autonomy, heterogeneity and activity with the potential for asynchronous updating and stochasticity. Through the interactions and feedbacks determined by user-defined rules, an agent can learn from their environment and past experience and adapt their behaviour accordingly. As a result, the impact of agent actions and interactions upon the model system as a whole may be observed.

A major advantage of a complex systems approach such as agent-based modelling is the fact that the result of a series of individual interactions may be more than the sum of the parts. As a result, unforeseen, or emergent, properties may arise from the simulation process that could not have been predicted through a more linear analysis that did not allow for interaction between unique elements. For example, the rules of behaviour that govern one agent's actions may lead to behaviour that affects the context within which a second agent forms their decision. As a consequence, the rules of behaviour governing the second agent result in an outcome that is affected by the actions of the first. The crux of a successful agent-based model (ABM) lies in the formation of the rules of behaviour that govern agent-agent and agent-environment interactions and feedbacks. In simulating a process such as the impact of climate change upon migration, the rules of behaviour developed for the model must be evidence-based through extensive data analysis and fieldwork. Through the successful implementation of an agent-based modelling approach, the attitudes, controls and norms considered by individuals in their decision to migrate may be used as an investigative/predictive tool in identifying the likely scale of the influence of environmental and climatic change upon migration.

Rainfall is used as the sole proxy for climate variability and change within the context of the ABM produced by this research. The selection of rainfall as the only manifestation of changes in climate is made on the basis of the intimate link between rainfall and the livelihood choices made by communities in drought-prone regions of the world. Limiting climate change to this one component also reduces complexity in both model development and interpretation of simulation outputs. The geographical context within which the concept of agent-based modelling of rainfall-induced migration is applied is the country of Burkina Faso in landlocked West Africa. One of the poorest countries in the world, more than 80% of the population of Burkina Faso relies on subsistence agriculture.

Existing literature (Findley, 1994, Cordell et al., 1996, Henry et al., 2004a) suggests that the population of Burkina Faso has long been characterised by considerable mobility with long and short-term rainfall conditions thought to influence both temporary and permanent migrations. With a climate characterised by a south-north decreasing rainfall gradient and a population heavily reliant upon rain-fed subsistence agriculture, Burkina Faso presents an appropriate location for the consideration of the influence of changes in rainfall upon migration. For people living in a country such as Burkina Faso, migration presents one of the few adaptation strategies available to individuals and households in the face of the environmental stress resulting from changes in rainfall in West Africa. Over the past century, rainfall within Burkina Faso has been recorded as undergoing considerable change with both the 600 mm and 900 mm isohyets seen in Figure 1.1 to have moved consistently southwards between 1931 and 2000.

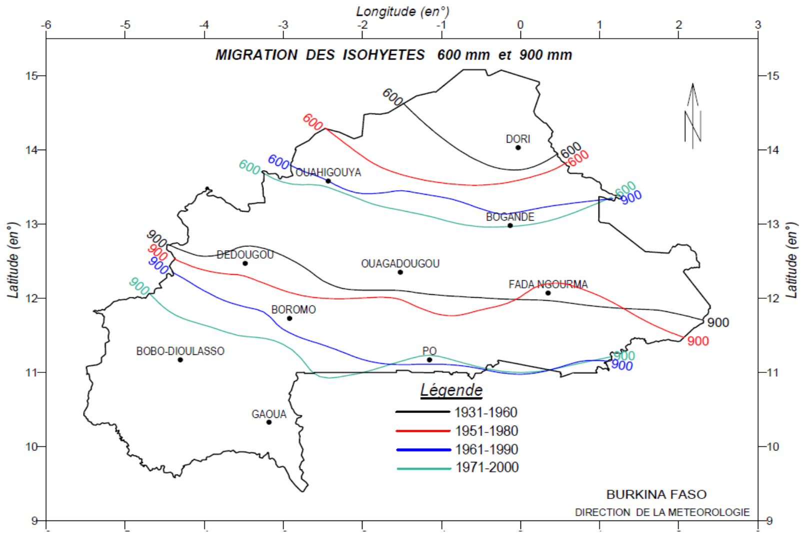

Figure 1.1: Spatial change of 600 mm and 900 mm isohyets between 1931 and 2000. Sourced from Direction de la Météo (2001).

The spatial change in isohyets seen in Figure 1.1 suggests a long-term change in mean rainfall conditions across Burkina Faso between 1931 and 2000. Such change can be assumed to have placed environmental stress upon communities across the country and is likely to have influenced migration across the region as a result of environmental change manifest through a gradual process of land degradation, particularly in the North. One of the primary causal mechanisms behind the longer-term process of land degradation is rainfall change. This research is intended to focus upon rainfall variability and the change in such variability witnessed and forecast over time. As such, the environmental stress placed upon communities affected by changes in rainfall variability will be manifest through short-term drought as opposed to longer term degradation of agricultural land.

1.2 Research Objectives

The objective of this research is therefore to investigate the role of changes in rainfall variability, as a proxy for changes in climatic variability, in the migration decisions of people in Burkina Faso through the application of an agent-based modelling approach. Although both Warner (2010) and Tacoli (2011) highlight the existence of controversy over whether migration should be deemed an adaptation strategy or an example of failure to adapt in the face of climate change, for the purposes of this thesis migration is deemed one of a range of adaptation options that may be available to individuals affected by climate change. The ABM presented in Chapter 5 has therefore been developed using existing theoretical advances in the fields of both human migration and climate change adaptation. These theoretical foundations are combined with advances in the field of social psychology to develop a conceptual basis for agent cognition within the model. Agents in the modelled environment of Burkina Faso interact with one another and their environment to develop intentions to adapt to changes in rainfall through migration. The likelihood of an agent migrating is affected by both their individual attributes and their placement in a social network within which changes in rainfall are communicated.

Although recurrent reference to the existence of the impact of climate change upon migration within IPCC publications (Tegart, et al., 1990, Wilbanks et al., 2007) suggests relatively widespread acceptance of the notion, further understanding is required in order for policy makers to propose useful adaptation measures that can alleviate the impact of such change upon the livelihoods of vulnerable communities worldwide. As such, the ABM developed by this thesis aims to contribute to the growing body of literature that has emerged surrounding the notion of environmental migration. Although developed with the intention of quantifying the influence of rainfall-related environmental change upon migration within and from Burkina Faso towards 2050, results from the ABM are also intended to provide greater understanding of the multiple and interacting components that contribute to the migration decisions of individuals. As such, the overall impact of changes in rainfall variability upon the national-scale flow of migrants within and from Burkina Faso will be broken down into smaller scale sub flows in order to investigate the trends in behaviour at regional scales that make up the more generalised national trend.

From the proposed analysis of complexity at varying scales, the value of quantifying global environmental migration forecast to occur in the future will be assessed. Previous research by Acosta-Michlik and Espaldon (2008) suggested that very few studies had represented models of human behaviour or cognition in assessing vulnerability to global environmental change. However, the authors found that social networks were an important source of adaptive capacity while cognition could be said to enable adaptation. The use of an agent-based modelling approach to considering the concept of environmental migration within and from Burkina Faso therefore incorporates both social networks and cognition in an effort to simulate the impact of rainfall variability upon migration decision-making.

1.3 Uncertainty

Inherently ‘wrong’ because by design they are a simplified view of the system being represented, models of any human or natural system suffer at the hands of considerable uncertainty. Such uncertainty is further increased when interactions between human and natural systems are additionally considered. An ABM intended to represent the interactions between human migrants and the climate conditions affecting them in the future therefore offers considerable potential for uncertainty. In any simulation that uses climate data, uncertainty results from the ambiguities in the extent and magnitude of the climate signals input into the model. This uncertainty is increased further when predictions of future climate are used, particularly when the proxy for climate is rainfall which shows considerable variation in both spatial and temporal terms. Furthermore, the basis upon which an individual’s attitude towards migration (or probability of migrating) is calculated involves a considerable degree of uncertainty. In modelling migration decision-making a number of assumptions must be made that categorise the migration decision into a format from which it can be expressed as a relatively simple algorithm. Creating such an algorithm permits the complexity of the migration decision to be defined by smaller components that require lower level assumptions and thus reduce uncertainty. Crucially therefore, the assumptions made in the development of a simulation of such a complex system are made at a lower level of analysis than have been undertaken in previous, more top-down, approaches to quantifying environmental migration and can act to reduce overall uncertainty. Furthermore, such assumptions can be subjected to a thorough process of sensitivity analysis in order to assess the range of impact that any adjustments to a relevant parameter may have on model outcomes.

In order to manage the extent of the uncertainty incorporated into the ABM presented by this thesis the notion of simplicity of design promoted by An (2011) in the field of complex human and natural systems (CHANS) is adopted. By researching theoretical advances made in the fields of migration decision-making, climate change adaptation and social psychology a conceptual model of migration decision-making was constructed. The conceptual model was then tested and further informed by a period of fieldwork in Burkina Faso during which thirty focus group interviews were undertaken across the country. Finally, survey data collected in 2000 was used to parameterise the ABM. Due to the nature of a model as a representation of a complex phenomenon, the outcome of any simulation can only be a descriptive output. As a result, any explanatory power is significantly constrained by the assumptions made during the process of model development. On this basis, the assumptions involved in the process of model construction were kept to a minimum and empirical parameterisation sought wherever possible.

1.4 Summary

When developed on the basis of observed empirical data that reflects a real-world situation, agent-based modelling provides a realistic and promising opportunity to integrate the multiple variables involved in migration decision-making and manipulate them in order to obtain simulations of future migration patterns. The influence of the unique responses and attitudes of individuals towards changes in rainfall variability, as a proxy for climatic variability and change, are of considerable importance in identifying the livelihood impact they perceive and the importance of this impact in their current and future existence. By developing and testing an ABM intended to investigate the role of changes in rainfall variability in the migration decision-making of Burkinabé people this research aims to quantify the likely influence of future changes in rainfall variability upon migration within and from Burkina Faso towards 2050. In achieving this goal, the ABM is anticipated to provide insight into the degree of complexity manifest within the context of a national-scale simulation of environmental migration.

Chapter 2 of this thesis provides a brief introduction to the significant body of literature that has led to this research. The convergence of the fields of climate change and migration through consideration of climate impacts and human adaptation is described before turning to the growth of the concept of environmental migration. Following a summary of the literature that highlights the nexus between climate change and migration the chapter turns to publications relevant to the case study location, Burkina Faso. Finally, previous approaches to conceptualising migration decision-making and applications of agent-based modelling within related fields are documented.

Permitting further investigation into the literature surrounding previous models of migration and climate change, Chapter 3 outlines the process of developing a conceptual model of Migration Adaptation to Rainfall Change (MARC) upon which the ABM is based. Through consideration of reactive and proactive responses to climate stimuli and following significant contribution from the theory of planned behaviour, the full conceptual model (MARC) and its simplified version for appropriate ABM construction (SMARC) are described.

The methods and resources used by this research are documented in detail in Chapter 4. By drawing upon the extensive retrospective migration histories dataset made available to the project and the information gained during a two month period of fieldwork in Burkina Faso, the general approach used to construct the modelled rules of agent behaviour is described. Furthermore, the processes of validating and testing the agent-based model and of interpreting the rainfall data are outlined.

Chapter 5 describes the process of constructing the Agent Migration Adaptation to Rainfall Change (AMARC) model. Following the construction of a basic model that depicts a simplistic form of demographic change within Burkina Faso, agents within the model are endowed with the capacity to undertake migration decisions on the basis of appropriate stimuli. With each agent forming intentions towards migratory behaviour as a result of their individual context and circumstances, the process of translating each component of the SMARC conceptual model into the ABM is documented in detail.

Following construction of the AMARC model, Chapter 6 outlines the extensive process of model validation and testing. The chapter describes how well the modelled migration flows simulated by two versions of the model, AMARC1 and AMARC2, correlate with relevant migration history data used for validation purposes. On the basis of these findings, the AMARC models are deemed to be an appropriate tool from which to investigate the role of changes in rainfall variability in historical migration decisions and to simulate future trends in migration as a result of different rainfall scenarios.

Using a final version of the validated ABM (AMARC3), the process of investigating the role of changes in rainfall variability in the modelled migration decision is documented in Chapter 7. Within the 1970 to 1999 initial model timeframe, multiple and varied relationships between rainfall and modelled migration are identified at a variety of scales of analysis. The impact of rainfall upon modelled departures and arrivals from each zone are considered during dry, average and wet conditions using both an artificial scenario approach and an analysis of historically dry, average and wet years between 1970 and 1999.

Building upon the findings presented from analysis of model outputs that simulated migration flows between 1970 and 1999, Chapter 8 uses a range of future scenarios of changes in rainfall variability to further test the impact of changing rainfall conditions upon modelled migration. In parallel with the different rainfall scenarios, the additional impact of future scenarios of demographic change upon modelled flows is investigated. On the basis of the nature of modelled migrant flows seen under each combination of rainfall and demographic scenario tested, the potential for emergent outcomes is assessed. The final chapter of the thesis, Chapter 9, outlines the research that has been undertaken before documenting the conclusions, possible implications and recommendations for further work within the field.

Chapter 2

Literature Review

2.1 Introduction

In recent years the issues of climate change and human migration have independently attracted significant debate in both academic and non-academic publications. Since the late 1970s/early 1980s when global warming came to the forefront of international politics, the predicted scale of future climate change has been widely contested. Similarly, migration and its perceived impacts upon origin and, more commonly, destination locations have long been high on political agendas worldwide. Literature on global climate change has more recently expanded beyond debate surrounding the scientific basis of change to include significant consideration of the impacts of future climate upon environments and societies worldwide. One of the many impacts discussed within the literature is the potential for increased flows of migrants from those areas most affected by climate change to destinations of relative economic wealth. Born out of this discussion, a new area of research has been developed that focuses upon the existence and, more recently, scale of these future flows of "environmental migrants". This chapter provides a summary of the literature that has contributed to developments in the field of environmental migration and led to the use of an agent-based modelling approach to quantifying the influence of environmental change on migration in the context of Burkina Faso.

2.2 Climate Change, Environmental Stress and Migration

Although the precise role of its causal mechanisms is still contested, climate change has become widely accepted as a challenge that communities around the world will face in the relatively near future. Although uncertainty remains as to the precise nature and extent of future changes in climate, scientific evidence presented by the IPCC (Boko et al., 2007) suggests that significant future climate change is inevitable. Within the longer term notion of climate change lies climate variability, the dynamic variations in climate seen on seasonal, decadal and longer timescales. Both climate variability and change can be considered to affect human populations through environmental stressors, expected to pose significant challenges for society in terms of their effect on development and livelihoods, settlement options, food production and disease (Kniveton et al. 2011).

As part of a paper identifying the governance challenges of global environmental change and migration, Warner (2010) discussed whether or not migration in the face of environmental change could be considered adaptation. On the basis of available evidence Warner suggested that, while some forms of environmentally induced migration may be adaptive, other forms of forced migration and displacement may indicate a failure of the social-ecological system to adapt. In agreement with this finding, Brown (2008) stated that migration was, and always had been an important mechanism to deal with climate stress. However, Brown noted that migration was not typically the first adaptive response households took when confronted by climate stress but was utilised when other means of adaptation were insufficient. Migration can therefore be thought of as existing on a difficult to define spectrum of movement ranging from forced displacement to voluntary relocation, and is documented as both a viable proactive adaptation strategy in the face of risks posed by climate change (Berkes et al., 2003) and an indication of the failure of the social-ecological system to adapt.

The contrasting viewpoints evident in the debate surrounding migration as a form of adaptation identify a commonly perceived dichotomy within the climate migration literature. However, debate surrounding this difference of opinions largely ignores the interplay of economic pushes and pulls which place migration decisions further from a survival mechanism and more towards an aspirational action. Despite apparent contention surrounding the idea the IPCC Fourth Assessment Report (2007) describes migration as one of the emerging range of livelihood adaptation practices observed in response to climate stresses. Consideration of migration as an adaptation strategy is supported by the work of Downing et al. (1997) and Smithers and Smit (1997), both of whom however suggested that, at that time, the nature and processes of human adaptation to climate were poorly understood and rarely investigated directly. More recent investigations by Pandey (2003), Adger et al. (2005), and McLeman and Smit (2006) have further supported the structural notion that migration has been employed as an adaptation strategy to both historical and contemporary climate stress.

Despite frequent references to migration as an adaptation strategy and not as evidence of a failure to adapt, Tacoli (2009) proposed that migration is commonly perceived to be problematic with most policies attempting to influence the volume, direction and types of movement rather than accommodating new flows and supporting migrants in their efforts to broaden household income in times of agricultural shortage. Such a negative perception of climate migrants as helpless individuals undertaking a last resort adaptation strategy may have contributed to the long-running debate over the existence of environmental refugees. Described by Myers and Kent (1995) as individuals who perceive themselves to have no alternative but to migrate and seek sanctuary from the environmental problems facing their homeland, the term "environmental refugee" lacks a precise legal definition. Although potentially reducing the value and legitimacy of procedures put in place for legally defined refugees, environmental refugees have now been the focus of numerous articles and reports ranging from the work of El Hinnawi (1985) to more recent articles by such proponents as Connisbee and Simms (2003).

As well as being criticised from a political perspective for its potentially adverse effects upon the legal rights of refugees, the notion of environmental refugees has also come under attack from a conceptual standpoint. Black (1998, 2001) proposed that forced displacement is multi-causal, making the role of environmental change difficult or even conceptually impossible to determine. Moreover, Black suggested that discussions around environmental refugees threaten to skew understanding of forced displacement towards proximal causes rather than focusing upon the underlying political, economic and social drivers. Despite widespread support for this argument within the social sciences (Kibreab, 1997, Castles, 2002) the notion of environmentally displaced communities has risen on the political agenda and become the focus of numerous reports released by government bodies such as HM Treasury (Stern, 2007) and the Norwegian Refugee Council (Kolmannskog, 2008) and non-government organisations such as Friends of the Earth (2007) and Christian Aid (2007).

These reports have usefully highlighted the potential for changes in climate (manifested through environmental change) to contribute to the displacement of vulnerable communities. In addition, many such reports have attempted to quantify the level of displacement occurring worldwide as a result of such challenges. Resulting estimates of the numbers of people likely to be displaced range from 150-200 million to 1 billion migrants induced by climate change alone by 2050 (Stern, 2007, Jacobson, 1988, Myers, 1997, Myers, 2002). In a recent paper reviewing the wealth of literature relating to the numbers of people reported as displaced by environmental changes, Gemenne (2011) suggested that future predictions of such migrants had been largely based upon previous reports that estimated current and past migrant numbers and were themselves subject to considerable limitations. As a result, Gemenne went on to report that such studies suffered from a combination of weak or inexistent methodologies and a tendency to use large numbers to raise awareness of environmental issues rather than report scientifically-derived evidence. Numerous authors (Tacoli, 2009, O'Brien et al., 2007, Piguet, 2008) have since suggested that predictions of such magnitude could however lead to inappropriate policy responses being developed that will do little to protect the rights of those most vulnerable to climate change.

2.3 Describing the Nexus

A number of studies have sought to derive evidence for a link between environmental change and migration, of which climate variability and change can be considered one aspect. The recent European Union funded Environmental Change and Forced Migration Scenarios (EACH-FOR) project (Jäger et al., 2009) undertook fieldwork or desk studies in 23 case study areas. The two year study concluded that migration induced by environmental hazards and degradation is mainly internal and seldom international; that it is often the young that migrate, with older people staying in places of origin even in the face of severe environmental stress; and that while temporary and seasonal migration was often found to be a means to cope with the effects of environmental impacts such as droughts or floods, there was evidence of recent changes in traditional patterns of migration due to rapidly changing socio-economic and environmental conditions.

Other past studies have found examples of both increased (Halliday, 2006, Munshi, 2003), and decreased (Henry et al., 2004a, Findley, 1994, Halliday, 2006, Kniveton et al., 2008) international flows in response to increased environmental stress. These apparently contradictory findings point to a complex relationship between migration and the environment and one in which the direction of the response is determined by the social and economic conditions within which the community, households or individuals find themselves. At first glance, the limiting factor to some environmental stresses and shocks initiating international migration appears to be the various capitals required to migrate. In Burkina Faso, Henry et al. (2004a) showed that food scarcity during drought was found to lead to increased prices forcing people to spend more money on their basic needs rather than on long-distance migration. Similarly, Halliday (2006) found that, in El Salvador, migration was more likely for wealthier households than poorer ones which were liquidity-constrained. However, Halliday also found that international migration from El Salvador was reduced for wealthier and poorer households alike following earthquakes, suggesting that the relative magnitude of an environmental stressor is also an important determinant. In short therefore, evidence exists in the modern literature for both an increase and decrease in international migration as a result of environmental stress. On the basis of this evidence the magnitude of the stressor and economic, social and psychological contexts of the exposed population are seen to contribute in determining whether the migratory response is positive (increased flow) or negative (decreased flow). As such, while citing a range of locations worldwide in which empirical evidence has been seen to have some effect on income, income variability and migration, Lilleør and Van den Broek (2011) suggested that the effects of a changing climate will not have direct effects on income but a reduced-form effect driven by changes in crop yields, their threshold levels, available crop choices and adaptive strategies.

Whether the sign of a change in migration flows is positive or negative, it is likely to have some form of impact on both the origin and destination locations involved. Amongst a range of other means of classification, migration can be generally categorised as either internal or international. Movement of people across international boundaries may be either overseas migration or movement within a continental region. Compared to overseas moves which require significant capital investment (Massey et al., 1993), regional migration is a common phenomenon in a number of locations. One example of this is West Africa where a long history of migration across national borders reflects freedom of movement within the Economic Community of West African States (ECOWAS) (Cordell et al., 1996). As well as considering migration in the context of continental landmasses such as West Africa, the significant vulnerability of the inhabitants of small island states to environmental stresses and shocks has been highlighted (Mimura et al., 2007). Avery (2003) for example reported that over 10,000 people were evacuated from Montserrat in 1995 due to the imminent eruption of the volcano on the island. While this movement was, for the majority of people, temporary, and relates to an environmental event that is not related to climate change, it nonetheless provides an example of forced overseas displacement from a small island state. Similar fears have been raised for the populations of some Pacific Ocean small island states such as Tuvalu, Kiribati, Tokelau and the Marshall Islands due to potential dangerous manifestations of climate change in the form of raised sea levels and increased storm surge intensities (Adger et al., 2007).

Although international migration may be more commonly pertinent to both political and media publications, the number of people migrating internally worldwide is thought to vastly outnumber that of people moving internationally. The United Nations Population Division's Human Development Report 2009 (UNDP, 2009) conservatively estimated that, while there were then 214 million international migrants worldwide, there were at the same time about 740 million internal migrants. Seasonal and circular internal migration is a crucial livelihood strategy for many households in rural areas of the developing world, providing both a means of income diversification and a reduction in consumption requirements in the source region (Cordell et al., 1996). While the literature points to differences between migrants in terms of their different regions and countries of origin, their destinations and the duration of migration, there is broad agreement in the literature that internal short-distance migration in developing countries often intensifies following major droughts or famines (Pederson, 1995, Shipton, 1990, Findley, 1994, Ezra, 2001, Perch-Nielsen, 2004).

Migration in response to environmental variability and change is however not restricted to developing countries. In the case of Hurricane Katrina, the impacts of hurricane force winds resulted in significant demographic changes on the Gulf coast of the USA. Places within the affected area that were characterised as having greater social vulnerability (illustrated by greater proportions of disadvantaged populations, housing damage and, to a lesser extent, greater population density) were found to be more likely to experience outmigration (Elliott and Pais, 2006, Falk et al., 2006, Landry et al., 2007, Myers et al., 2008). However, in accordance with the high level of complexity associated with such migration it is interesting to note that, in the case of Hurricane Katrina, initially as many as 70,000, mainly poorer, black residents of New Orleans were unable to leave (Landry et al., 2007). Over time however it appears that it is these same residents who have also been least able to return (Black et al., 2008).

2.4 Burkina Faso

Characterised by low rainfall, high evaporation and subsequently limited soil moisture and biomass production, drylands cover over 40% of the Earth's land surface and are currently occupied by approximately a third of the world's population (Thomas, 2011). As one of the poorest countries in the world, the population and economy of the dryland country of Burkina Faso largely depend upon rain-fed agriculture and cattle-raising, making many communities throughout the country sensitive to changes in climate. While accepting that large uncertainty relating to the magnitude and even sign of changes in rainfall under different climate change scenarios in the future remains, the latest IPCC report (Boko et al., 2007) suggested that projected reductions in yield in some African countries could be as much as 50 per cent by 2020 as a result of climate variability and change. With small-scale farmers being the most likely to be affected the impact of this reduction in yield upon human settlements is expected to be significant.

Burkina Faso is described by Cordell et al. (1996) as having a historically mobile population as a result of both its location within a dryland environment and its past position within the economic priorities of colonial France. In this context, the impact of changes in climate, whether manifested through slow-onset land degradation or periodic drought, upon migration in Burkina Faso is of considerable academic interest. A significant body of literature therefore focuses upon climate change adaptation, migration and natural resource management within the context of Burkina Faso. In their paper investigating the costs and risks of coping with drought, Roncoli et al. (2001) showed that livelihood diversification, including migration and non-farm work, was a critical dimension of adaptation to the agro-ecological and socio-economic impacts of drought across Burkina Faso. Furthermore, using survey data collected from north-eastern Burkina Faso in 2000 and 2002, Konseiga (2006) identified migration, particularly to neighbouring Côte d'Ivoire, as a unique survival strategy in a region confronted with severe scarcity of natural resources. Migration and other forms of household income diversification are therefore considered to be commonly adopted livelihood strategies in Burkina Faso. Wouterse and Taylor (2008) found that the impact of emigration from rural households varied both by migrant destination and production activity. Econometric evidence from their research revealed no evidence of either positive or negative effects of continental migration on agricultural or livestock activities in the home location but found that inter-continental migration stimulated livestock production, likely due to the significantly larger remittances generated.

Despite the relative ease with which continental and, more specifically, internal migration may be undertaken, Gray (2002) highlighted the potential problems that may occur as a result of rural-rural migration within Burkina Faso. Focussing on the south-western region of the country, an area of both extensive immigration and fast-paced socioeconomic change, Gray identified the range of issues relating to environmental policy, land rights and conflict that result from natural resource management under conditions of significant immigration. While local farmers were seen by Gray to be attempting to expel migrant farmers from land in the southwest by accusing the latter of unsound environmental practice, the migrant farmers were intentionally not leaving land fallow through fear that their local hosts would take unused land from them. Gray therefore proposed that projects and policies applied in the region should focus on conflict resolution and reconciliation when attempting to restructure the allocation of natural resources in changing communities.

While policies relating to rural issues resulting from migration patterns are relatively few, the long-witnessed flow of migrants from rural to urban locations across the developing world has spawned numerous theories, policies and research within that arena. Byerlee (1974) stated that rural-urban migration accounted for over half the growth of most African cities at that time, leading to what the author described as, “wide-spread concern that the rates of rural-urban migration should be slowed”. In response to policies oriented around attempting to reduce rates of urbanisation occurring in many large cities of the developing world, Beauchemin and Schoumaker (2005) used Burkina Faso as the case study location for an investigation into whether the notion of improving the quality of life in rural areas and secondary towns could reduce out-migration to cities. They concluded that, contrary to policy expectations, most components of rural development either have no effect on migration or even encourage internal migration to cities in Burkina Faso.

Internal migration is often differentiated in migration literature as to whether it is rural to rural, rural to urban, urban to rural or urban to urban in nature. Accordingly, a number of studies have attempted to distinguish any relationship between the environment and migration within these conceptual boundaries. Using econometric analysis, Barrios et al. (2006) found that climatic change, as proxied by a general decline in rainfall, has acted to encourage urbanisation in sub-Saharan Africa, particularly after decolonisation, likely due to the lifting of legislation prohibiting free internal movement of native Africans. Interestingly however, Barrios et al. suggested that analysis of their cross-country panel dataset showed that a similar influence of climate change upon urbanisation was not seen elsewhere in the developing world. Using multi-level event history analysis to investigate the nature of the first out-migration of individuals from villages, Henry et al. (2004a) confirmed the existence of one of the most consistent findings of migration studies (Lututala, 1995, Todaro, 1997): a strong positive relationship between level of education and migration, particularly to urban areas. They also found that urban areas represent 14% of the destinations of first migration among both men and women. Importantly however, in terms of the impact of rainfall variables, the authors found that the risk of leaving the village for the first time varied significantly across destinations. While the odds of men living in a poor agro-climatic region migrating to another village were three times greater than for those living in areas with higher average rainfall, the relationship between rainfall and the risk of migrating to urban areas was found by Henry et al. (2004a) to be much less consistent.

With respect to first out-migration to international destinations, Henry et al. (2004a) stated that individuals living in wetter areas were far more likely to leave their village for a foreign country, purported by the authors to be perhaps due to the need for people from wetter regions in the south of the country to travel beyond the nation's border with Côte d'Ivoire in order to find better watered areas. As well as investigating the impact of an individual's agro-climatic region of origin upon the risk of first out-migration, Henry et al. examined the impact of the rainfall of the three preceding years upon propensity to migrate. They found that the odds of males migrating were 60% higher if the rainfall conditions were unfavourable than if they were normal. As such, the authors suggested that both a poor agro-climatic situation and short-term unfavourable rainfall conditions tended to push men to leave for other rural areas. However, in direct contrast to the findings of Barrios et al. (2006), Henry et al. (2004a) found that overall both men and women were more likely to migrate to urban and international destinations if recent rainfall conditions had been favourable. Drawing upon findings of both Nelson (1983) and Findley (1994), the authors proposed that such migrants tended to wait for good economic conditions in the preceding years before migration as the cost of migration may need to be met by a production surplus.

A second paper produced by Henry but with a different team of co-authors (Henry et al., 2004b) tested the influence of environmental changes on all migration in Burkina Faso. The authors found that, from the age of 20, people from areas with unfavourable land degradation and climatic conditions migrated less out of their first residence than individuals from areas with favourable conditions. However, those that did migrate from a rural area were seen to settle more often in an area with more favourable environmental conditions, a finding supported by previous work by the lead author (Henry et al., 2003). Henry et al. (2004b) also found that the definition of environmental conditions, whether considered in terms of the land degradation associated with a long-term change in climate or shorter term variability in rainfall, affected the proportion of people migrating. The authors proposed that permanent migrations within and from Burkina Faso were likely to be more influenced by slow-acting processes such as land degradation than by episodic events such as droughts. However, the authors went on to suggest that, while land degradation progressively made livelihood strategies based on farming unsustainable, numerous coping strategies, of which short-term migration could be considered one, could be employed to make agropastoralism sustainable in semi-arid regions affected by climate variability.

2.5 Conceptualising Migration Behaviour

As part of the United Nations Framework Convention on Climate Change, the Cancun Adaptation Framework (UNFCCC, 2011) urges all parties to develop “measures to enhance understanding, coordination and cooperation with regard to climate change induced displacement, migration and planned relocation, where appropriate, at the national, regional and international levels”. While this statement mirrors policy makers’ concerns regarding the social implications of climate change, there is growing consensus that climate change cannot, in most cases, be isolated from other macro level economic, political, social and demographic drivers of migration (Castles, 2002, Piguet, 2010, Jónsson, 2010, Black et al., 2011a). Furthermore, it is also recognised that migration behaviour is determined by a host of micro-level factors including access to the variety of capitals needed to migrate, the viability of alternative livelihood strategies, the extent of institutional barriers to migration (Black et al., 2011b) and, as a socially mediated process (Massey et al., 1998), the behaviour of others through the formation of attitudes towards migration and access to migration networks.

A popular basis from which the number of people displaced by environmental changes are derived is Myers and Kent’s (1995) estimate of at least 25 million ‘environmental refugees’ at that time. Although reports such as the Stern Review (Stern, 2007) reuse estimates of future numbers (150-200 million by 2050) gained from the methodology employed by Myers and Kent, and further developed by Myers (1997, 2002, 2005), authors such as McGregor (1993), Kibreab (1997) and Black (1998, 2001) have disputed the method used to estimate these numbers. In reality, they propose that migration responses are the result of a far more complex combination of multiple pressures and opportunities that shape the behavioural decisions of individuals. Previous approaches to understanding such behavioural decisions have not successfully isolated environmental influences from the multitude of other structural transformations that influence migration at the individual or household level. Despite the simplistic approach most often used to model the numbers of migrants resulting from changes in climate, vast bodies of literature are available that document developments in both migration decision-making (DaVanzo, 1981, De Jong & Gardner, 1981, Judson, 1990, De Jong, 2000, Konseiga, 2006) and the computational advances made in the fields of psychology and neuroscience (Busemeyer, 2008, Sun, 2004, 2008).

Bardsley and Hugo (2010) suggested that thresholds of climate change, manifested through natural resource conditions and environmental hazards, will be reached by communities. After such a threshold is exceeded, Bardsley and Hugo proposed that migration will become a vital component of an effective adaptation response. By incorporating the actions of individuals into the climate change adaptation discourse, Grothmann and Patt (2005) considered human cognition in the adaptation process. In their analysis, Grothmann and Patt incorporated the perception of climate change as a risk through an appraisal of how harmful potential impacts might be to things of value to an actor, relative to an appraisal of how harmful and urgent other problems or challenges in their life were. On top of this, Grothmann and Patt also considered the fact that the adaptation strategy employed by an individual or group is not just controlled by the objective ability or capacity of the actors in terms of available options resulting from access to resources. As such they gave equal importance to the subjective or perceived ability of the agent to adapt and, in contrast to many previous studies, therefore weighed the importance of climate risks against the influence of other problems and challenges involved in the adaptation process.

From the conceptual standpoint that adaptations to climate change are local adjustments to deal with changing conditions, and using data on Swedish private individual forest owners, Blennow and Persson (2009) tested the consequences of strength of beliefs in successful adaptation. They found that an individual's strength of beliefs, or perceptions, of both the occurrence of climate change and their own adaptive capacity were crucial factors for explaining observed differences in adaptation behaviour between Swedish forest owners. The power of beliefs upon adaptive behaviour supports the Model of Private Proactive Adaptation to Climate Change (MPPACC) presented by Grothmann and Patt (2005) and its application of cognitive aspects such as perceptions of risks and actions in explaining adaptive behaviour to a long-term phenomenon such as climate change.

Outside the realm of climate adaptation but continuing to consider actions from a cognitive perspective, Tabor and Milfont (2011) described migration as a major change in an individual's behaviour for which little is known about contributory motives during the pre-departure period. Using the example of British migrants to New Zealand, Tabor and Milfont described a Migration Change Model that incorporates four stages: pre-contemplation; contemplation; action and; acculturation. Within these four stages, the authors turn to ideas of intrapersonal factors and familial connections, factors affecting individuals and society, stress and coping, psychological adjustment and sociological adaptation. Although Tabor and Milfont referred to a process where contemplation leads to the formation of a decision and therefore action, Lu (1999) contrastingly focused on the notion of whether or not people move when they say they will. Using data drawn from the American Housing Survey, Lu concluded that a substantial number of people do not realise their intention to move and many move unexpectedly. Furthermore, Lu found that the extent to which individuals act consistently with their intentions also differs along with attributes such as age, education and gender.

As a further contribution to our understanding of migration decision-making, De Jong (2000) posited that expectations, along with family norms about migration, are major predictors of intentions to move. Such intentions were described by the author as a proximate determinant of migration behaviour. In the context of Thailand, De Jong found that a different set of expectations, household demographic indicators, and migrant capital factors were significant determinants of migration intentions for both men and women. Although clearly different studies, a common theme seen to run through the work of authors such as Lu (1999), De Jong (2000) and Tabor and Milfont (2011) is the identification of the unique nature of the migration decision undertaken by individuals with different attributes of, for example, age, gender, location and access to capital that define the cognitive bounds within which the development of an intention towards migration is being formulated and subsequently realised.

While numerous authors within the social sciences have been working on advances in the field of conceptualising the migration decision, a significant but largely separate body of work has focussed on addressing more general decision-making procedures undertaken by individuals. Advances in this discipline have generally originated from the fields of psychology, economics and mathematics with such advances as the theory of riskless choices, the theory of risky choices and the theory of games and statistical decision functions (Edwards, 1954). Busemeyer and Johnson (2008) proposed that the field of decision-making had been largely dominated by utility theory-based research that focused on ranking individual preferences (Fishburn, 1970) or simple heuristic rule models that attempted to explain how people make decisions (Payne et al., 1993). Busemeyer and Johnson (2008) suggested that the additional complexity contributed by computational models of decision-making was initially met with reluctance. However, a steady progression away from simple and intuitive models based around the principle of maximising expected value have led the field towards a complex system approach that embraces the potential for complexity introduced by computational approaches. Such complex systems can be described as composed of networked heterogeneous parts that interact in a non-linear fashion to generate emergent outcomes that are not obvious from the properties of the individual parts.

Such systems are described by Sokolova and Fernández Caballero (2012) as characterised by a high number of entities and a high degree of interactions. The migration decisions undertaken by a population affected by climate stress within an active social network are thus considered by this research to be a prime example of a complex system suited to a computational approach.

In an article addressing theoretical modelling of how humans make decisions in a rich, interactive environment, Sanfey (2007) stated that most experimental studies of decision-making examined choices with clearly defined probabilities and outcomes. However, the author suggested that, given the highly complex social environments within which most decisions are made, many of our most important decisions are at least partly dependent upon the associated choices of others. Sanfey described the emergence of an interdisciplinary subject area that aims to examine decision-making at different levels of analysis by combining the formal mathematical approach of economics and the role of brain function into the field of neuroeconomics. Through this interdisciplinary approach researchers have attempted to gain a more detailed picture of social decision-making. Furthermore, incorporating the analytical and processing power of computational approaches permits greater levels of complexity to be modelled and allows the potential to capture robust trends in human choice behaviour to be realised (Busemeyer and Johnson, 2008).

2.6 Agent-Based Models

Past studies of migration and climate have generally incorporated environmental factors into the explanation of migration motives as an isolated component. In the same way that earlier theories of migration stressed the sole importance of economic concerns (Todaro, 1969, Borjas, 1989), the multiple and complex impact of environmental change upon existing shock and stress components that impact individual livelihoods has been largely ignored. Born out of efforts to incorporate greater complexity in modelling and understanding of behavioural interactions, Moss and Edmonds (2005) reported that agent-based models were a computational approach capable of being used to support good social science. In later agreement, Sun (2008) described the agent-based approach as a potentially important research methodology in its increasing application to the social sciences. In the context of migration decision-making in the face of rainfall change, an agent-based model (ABM) can be characterised, verified, assessed and validated against data before then being used to predict future changes in modelled flows.

In a recent paper, An (2012) suggested that agent-based modelling has, "a fundamental philosophy of methodological individualism, which advocates a focus on the uniqueness of individuals and interactions among them". Also described by Bonabeau (2002) as a mindset more than a technology, the mindset of agent-based modelling requires describing a system from the perspective of its constituent parts. As such, in an ABM, a system is modelled as a collection of autonomous decision-making entities that individually assess their situation and make decisions on the basis of a series of predefined rules. Originally developed for use within commercial industries, the appeal of agent-based models to social science were described by Epstein (2005) as having come about through their potential to facilitate generative explanations of the complex interactions evident in human systems through the unforeseen interaction of multiple agents. In the context of financially-oriented business applications, Bonabeau (2002) described agent-based modelling methods and techniques as well suited to simulating human systems. In doing so the author identified the primary advantage of agent-based models to be their ability to capture emergent phenomena. Described by Gilbert (1995) as that which cannot be predicted from knowledge of the properties of the agents, except as a result of simulation, emergent behaviour was proposed by Gilbert to be an unstable and uninteresting feature of complex systems. However, significant value was described by the author as coming from the way that "micro" level individual features of agents and their environment could interact to produce global-level "macro" properties that emerge from the micro-level behaviour. In simple terms, Bonabeau (2002) suggests that uncomplicated individual rules within an ABM can lead to coherent group behaviour that, as a result of small changes in those rules within the complex system, can have a dramatic impact upon emergent group behaviour.

Bonabeau (2002) goes on to report that it is best to use ABM when: the interactions between agents are complex, non-linear, discontinuous or discrete; space is crucial and agent's positions are not fixed; the population is heterogeneous; the topology of interactions is heterogeneous and complex; and the agents exhibit complex behaviour. As a socially mediated spatial process between heterogeneous individuals between whom unique interactions occur, the migration decision under changing rainfall conditions can be identified as an appropriate subject upon which an agent-based methodology can be applied. On this basis, rainfall migration as a group system may be described from the perspective of the migrants themselves as they respond to complex combinations of multi-level stimuli.

While agent-based models present a valuable tool for application in the social sciences, they are not without issue. Bonabeau (2002) identifies the need to build a model at the right level of description to serve the specific purpose sought as an issue common to all modelling techniques with ABM being no exception. Finding the correct level of representation and complexity to appropriately model the system in question is described by Bonabeau as an art more than a science. A further issue with agent-based models arises as a result of the human agents being modelled. Bonabeau describes the potentially irrational behaviour, subjective choices, and complex psychology of human actors as ‘soft factors’ that are difficult to quantify, calibrate and justify. However, it is also these components of modelling human decision makers that make ABM the most suitable simulation option.

The issues identified by Bonabeau (2002) shape the need for careful construction of the rules of behaviour that shape the development of an ABM that human decisions. As noted by Gimblett (2002), the process of understanding how human decisions are made and then put into practice can never be exaggerated. As such, the data collection for agent-based modelling is often very time-consuming and sometimes considered to be a drawback of the approach. The level of data available for the construction of an ABM therefore plays a large part in shaping its development. With reference to modelling the human decision within an ABM in the context of readily available data, An (2012) noted that agents in related models tend to be assigned attributes on the basis of real data. Although aggregate distributions and histograms (from a higher level population) may also be used, their overuse may limit the strength of the model by reducing the vital heterogeneity of agents to averaged values and creating the potential for hidden or implicit attribute conflicts.

In the presence of ample data, An (2012) described the process of developing empirical or heuristic rules derived from empirical data or observations following often complex data manipulation. In such a context, empirical probabilities of a particular action being undertaken may be derived from data by categorising each agent ‘types’. However, some theoretical influence is required in order to define these types. As such, an empirical or heuristic approach is rarely used in isolation but combined with more theoretical or process-based notions as psychosocial and cognitive models or institution-based models. Although comprehensive data on the subject of focus is advantageous, An points out that the deeper question of why decisions made as a result of, for example, probabilistic tendencies are truly being made from the perspective of actual motivations, incentives and preferences.

In the absence of such comprehensive data, the literature reveals that an agent-based modeller retains a number of options in addition to the direct application of accepted theory. An (2012) outlined the application of experience- or preference-based decision models that represent more of a ‘rule of thumb’ that can be inductively derived from smaller quantities of both quantitative and qualitative data, direct observations, ethnographic histories or ‘facts’ abstracted from real-world studies. In modelling human-environment interactions, An reported that most decision rules are derived in this manner unless there are historically documented analogues available. Further building upon this approach is participatory agent-based modelling, described by An as a variant in the family of experience- or preference-based decision models. In such an approach, real people directly tell the modeller what they would do under certain conditions so that stakeholders themselves are involved in the process of describing contexts, soliciting decisions, running the model and envisioning scenarios resulting from the corresponding decisions. A final data-scarce approach to model development described by An is the use of assumption and/or calibration-based rules. Such hypothetical rules can be used in the absence of adequate data or theory and can be temporarily accepted into a model in order to make it operational before they are manipulated in order to perform calibration or sensitivity testing. However, such an approach is problematic in the sense that calibration-based rules may easily result in erroneous outcomes where errors act to cancel one another out, giving rise to problematic calibration outcomes. Although assumption and/or calibration-based rules should therefore be used sparingly and with caution, they present a viable option to contribute to ABM development in an instance of partial data scarcity. In fact, most agent-based modellers will draw upon several techniques related to theory-, empirical-, experience- and assumption-based approaches in the construction of an ABM of human decisions.

One of the crucial components of agent-based models that set them apart from other computational simulation approaches is the capacity for interaction effects such as networking to play a part in agent behaviour. In parallel with the concept of emergent outcomes, Sumpter (2006) noted that self-organisation between agents, in this case animals, allows simple repeated interactions between individuals to produce complex adaptive patterns at group level. On this basis Sumpter argued that the key to understanding collective behaviour lies in identifying the principles of the behavioural algorithms followed by individuals and how information flows between them. Although Sumpter applied principles such as positive feedback, response thresholds and individual integrity to animals, such notions can be readily applied to the emergence of group dynamics in human decision-making. In the context of social insects, emergent coordination is described by Susi and Ziemke (2001) as being explained by stigmergy, where individuals can affect the behaviour of others (and their own) through artefacts in their environment. However, Susi and Ziemke suggested that such artefacts clearly also play a strong role in collective human behaviour. The authors therefore proposed that the numerous crossovers between animal and human collective behaviour can be addressed through the notion of agent-environment interaction and the use of stigmergy as a common ground. With recent areas of application ranging from freight transport markets (Baindur & Viegas, 2011) to disease hotspots for red colobus monkeys (Bonnell et al., 2010) the opportunities for crossover between model procedures and approaches is vast and growing. However, at present, the greatest potential for overlap with modelling human decision-making appears to come from the field of collective animal behaviour described by Sumpter (2006).

2.7 Applying Agent-Based Models to Migration Behaviour

Described in a report by Buchanan (2009) as the social science analogue of the computational simulations now routinely used elsewhere in science to explore complex nonlinear processes such as the global climate, agent-based models are seen to have numerous applications within the social sciences. As a result of the adaptive behaviour with which agents can be endowed, Buchanan proposed that market behaviour could be predicted by allowing it to emerge from the properties and interactions of agents without any presupposition of the outcome. In support of this notion, Farmer and Foley (2009) suggested that agent-based models presented a potential way to model the financial economy as a complex system. However, they went on to refer to the difficulty of accurately specifying how agents behave, a process whereby rules are often created on the basis of, “common sense and guesswork, which is only sometimes sufficient to mimic real behaviour”. In conclusion, Farmer and Foley (2009) stated that, in order to make an ABM useful, the developer must proceed with model development in a systematic manner that avoids arbitrary assumptions by grounding and testing each part of the model against reality and only introducing additional complexity where it is needed.

In partial agreement with Farmer and Foley’s (2009) assertion regarding complexity of model design, papers by Acosta-Michlik and Espaldon (2008) and An (2011) highlighted the challenge of developing behavioural models that allowed a simple representation of the complexity involved in coupled human-environment, or human and natural systems, models. An described such complexities as being manifest through various components such as heterogeneity, non-linearity, feedback loops and emergence, with humans playing a crucial part in affecting such complex components and giving rise to changes in the environment which may, in turn, affect future human decisions and behaviour. A decade prior to the widespread acknowledgement of complexity issues within the field (Acosta-Michlik and Espaldon, 2008, Farmer and Foley, 2009, An, 2011) Janssen and de Vries (1998) constructed one of the first multi-agent models of adaptive responses to climate change. The aim of the model was to assess the impact of different perspectives (of how the world functions and of how it should be managed) upon how different forms of adaptive behaviour could be included into models of global change under circumstances where agents were capable of learning from their observations. The authors tentatively concluded that their model enabled a more explicit treatment of the notions of societal change and scientific surprise events (such as changing evidence of the nature of the radiative forcing associated with chlorofluorocarbons) than other modelling approaches in the field at that time.

In their paper that acknowledged challenges relating to model complexity, Acosta-Michlik and Espaldon (2008) presented an ABM of the behaviour of farmers in three villages in the Philippines in order to assess the factors that contributed to their vulnerability to global environmental change. In a previous article, Acosta-Michlik and Rounsevell (2005) had proposed a framework that explicitly modelled human adaptive behaviour. Within this framework, vulnerability to global environmental change was described as a function of exposure, sensitivity and adaptive capacity, but also cognition (Ziervogel et al., 2005, Grothmann and Patt, 2005, Acosta-Michlik, 2005). On this basis, Acosta-Michlik and Espaldon (2008) promoted the notion of cognition as enabling adaptation through such agent-level processes as perception and evaluation of risks, identification and assessment of options, the ability to make decisions and take actions and to modify and update behaviour on the basis of the outcome of these actions. On top of social and economic capacity to respond to environmental changes, Acosta-Michlik and Espaldon therefore proposed that adaptive decisions and actions could be either constrained or promoted by cognitive processes. As a tool that can be used to analyse and simplify a complex problem, such as the constantly changing human and natural systems that play a part in shaping adaptive behaviour in response to global environmental change, the authors promoted the value of agent-based modelling.

As the basis for their ABM Acosta-Michlik and Espaldon (2008) developed an intervulnerability framework, the cognitive component of which was developed from the “consumat approach” created by Jager et al. (2000) and further developed by Acosta-Michlik (2005) to study the interactions between a multitude of consumer agents and their environments through consideration of driving forces at both the collective (macro) and individual (micro) levels. Involving four cognitive strategies: deliberation; social comparison; repetition; and imitation, the “consumat approach” was adapted by Acosta-Michlik and Espaldon (2008) to suit Philippine farming communities through four cognitive processes: observation; interaction; social comparison; and income maximisation. Through application of the ABM developed in their paper, Acosta-Michlik and Espaldon found that lack of money and information were the most important reasons for failure to apply available technical adaptation measures, particularly among traditional and subsistence farmers. Furthermore, the authors found that social networks were an important source of adaptive capacity. In conclusion, the authors found that agent-based models were a useful policy tool for simulating the effects of different adaptation options because they allowed representation not only of the dynamic changes in climate and markets but also the dynamic adaptive process of different communities to the impacts of change.

Referring to such human-environment interactions in the context of coupled human and natural systems (CHANS), An (2011) used complexity theory and its application to review various decision models used in relevant agent-based simulations. Focussing on understanding complex adaptive systems, complexity theory was described by An as usually encompassing heterogeneous subsystems or autonomous entities which often feature nonlinear relationships and multiple interactions. In the paper, An (2011) suggested that agent-based models modelling human decisions or behaviour within the realm of CHANS and its associated complexity, ranged from highly empirically-based examples (derived through trend extrapolation, regression analysis, expert knowledge) to those that were more mechanistic or process-based (econometric or psychosocial). An concluded that without greater understanding of human decision-making it was very difficult to appreciate complexity at multiple dimensions or scales in order to achieve in-depth and dynamic coupling of the natural and human systems. Furthermore, in agreement with Farmer and Foley (2009), An (2011) suggested that, until there is greater process-based understanding of human decision-making in the context of natural systems, agent-based modellers should avoid unnecessary complexity through the inclusion of large numbers of trivial details.

As a result of the comprehensive review of CHANS agent-based modelling approaches, An (2011) proposed that a protocol similar to those promoted by Grimm et al. (2005, 2006) for ecology and Hare and Deadman (2004) for environmental management was required to formalise model development. Such a demand was described by An (2012) as resulting from significant growth in the use of ABM within different branches of the social sciences, including modelling migration. The reported rise in the application of agent-based models to the field of migration studies has come about as a result of assertions by authors such as Edwards (2008) and Kniveton et al (2008). In a paper assessing the computational tools that can be used in predicting and assessing forced migration, Edwards (2008) suggested that computational models, and more specifically agent-based models, possessed considerable potential for predicting when and where groups of individuals might flee given some displacement generating event, particularly in the context of otherwise counter-intuitive flight.

A useful example of an ABM developed to model migration comes from Naivinit et al. (2010) who presented a participatory approach to constructing an ABM of rice production and labour migrations in one village of northeast Thailand. Consisting of three interacting entities (water, rice, and household), daily decisions were undertaken by the household element that could result in labour migration of individuals. Used to deepen the understanding of local farmers on the nature of interrelations between labour migration and rice production, the model focussed upon the possible economic gain to be made from migration rather than the cognitive process that leads individuals to migrate in response to stimuli. As an economically driven model, climate stress could be considered to have an implicit impact upon migration as manifest through, for example, a reduction in yield. However, by focussing upon economic stimuli alone and avoiding a full representation of migration decision-making, Naivinit et al.'s model has limited potential to extrapolate the impact of climate stress upon migration. Furthermore, the model is not suited to the realm of quantifying the influence of environmental change upon migration as a result of its development for just one Thai village.

Perhaps more relevant to the research presented by this thesis, Silveira et al. (2006) described an ABM constructed to analyse the phenomenon of rural-urban migration within the context of an economy in the early stages of industrialisation. Simulations using the model developed by the authors showed some emergent properties common to those often seen in developing countries: transitional dynamics characterised by continuous growth of the urban population, followed by the equalisation of expected wages between rural and urban sectors, as per the equilibrium condition proposed by Harris and Todaro (1970). However, like the model of Naivinit et al. (2010), Silveira et al.'s (2006) model did not adopt an approach whereby migration was considered from the context of the full psychosocial decision itself but used what the authors described to be a "statistical mechanics" approach. As such, agents were modelled to take their decision to migrate or not based upon a consideration of only the differential of expected wages between their present sector and the sector they intended to go to.

Although described by Piguet (2010) as having been used in migration studies as early as the 1970s through Schelling's (1978) examination of the segregation process leading to intra-urban migration, applications of agent-based modelling within the field are seen to have been few, and rather disparate. Furthermore, most have considered agents to act largely on the basis of wage differentials with little or no consideration of cognitive aspects such as the bounded rationality of actors (Kant and Thiriot, 2006). Piguet (2010) went on to suggest that only very tentative studies had, at that time, used ABM in the field of environment-migration relations with no convincing results published thus far. Although citing two potential issues with the method: limited availability of data on reactions of different groups to environmental stress and; the sudden and previously un-experienced nature of such stimuli, Piguet proposes that ABM retains clear potential within the field.

2.7 Summary

This chapter has outlined the key literature produced as a result of the academic evolution of interconnected disciplines that has led to this research. Starting with a description of the originally distinct fields of migration studies and climate change, the convergence of the two disciplines has been described and the nexus between changes in the environment resulting from climate change, and migration investigated. It is clear from analysis of the literature that has led to our current understanding of environmental migration that there are considerable degrees of complexity and uncertainty inherently involved in any attempt to predict the numbers of people likely to migrate in the future as a result of changes in climate. This complexity is seen to result from numerous components, not least of which is our current understanding of when relocation by an individual can be deemed to be environmentally induced, and whether or not such a move should be considered a proactive adaptation strategy or last resort.

Having highlighted the need for further research into the quantification of environmental migration the review turned to literature relating to climate change adaptation and migration in the case study location of Burkina Faso. With a historically mobile population that can be considered to be highly vulnerable to changes in rainfall, Burkina Faso is highlighted as a valuable opportunity for research into the influence of environmental change upon migration. This assessment is supported by the wealth of literature relating to both migration and climate change within the country, in particular a paper produced by Henry et al. (2004a) which provides clear evidence of a statistically derived link between rainfall and migration in Burkina Faso.

After defining the area of research targeted by this thesis and reviewing literature relating to the case study location this chapter then highlights the wealth of literature that has worked to conceptualise decision-making and, more specifically, migration decision-making from both theoretical and modelling perspectives. By drawing upon previous contributions to the field of migration decision-making, the incorporation of computational advances in social simulation is documented and the advantageous properties of agent-based models as tools for simulating complex systems portrayed. On the basis of the potential advances that may be garnered from the application of an agent-based approach to research in the social sciences, the agent-based modelling methodology adopted by this research is justified. The review then closes by outlining recent literature relating to the development of agent-based models within the fields of climate adaptation and migration.

By bringing together contributions from numerous disciplines this research therefore aims to develop an ABM that appropriately represents the complex and multifaceted process of migration decision-making in the context of Burkina Faso. As a result, a rigorous means of investigating the role of changes in rainfall variability upon migration flows is sought. By simulating both past and future migration flows resulting from different future rainfall scenarios the ability of the model to replicate and predict migration can be assessed and the future role of changes in rainfall variability upon migration within and from Burkina Faso quantified. The following chapter draws upon further existing literature to develop a conceptual model of migration adaptation to rainfall change in Burkina Faso.

Chapter 3

Conceptual Model Development

3.1 Introduction

As a cognitive modelling technique that, in this context, deals with the bounded rationality of individuals, the first stage in developing an agent based model (ABM) is the construction of a conceptual framework developed using relevant and measurable component parts. Such a framework sets out the basic structure of the individual cognition undertaken by agents and the manner in which external stimuli affect the decision-making process. This chapter presents the process and reasoning by which the conceptual basis for the Agent Migration Adaptation to Rainfall Change (AMARC) model has been developed. In constructing the conceptual model, existing models of both climate adaptation and migration were drawn upon that contributed to the final structure of the individual decision-making process used in the agent models.

3.2 Models of Migration and Climate Change

Migration has always been a fundamental component of human history. Migratory events may be classified under a number of broad descriptive typologies including international/internal, permanent/temporary, voluntary/forced and legal/undocumented. Generally used to define and measure migration, such typologies are important to consider but do not explain anything of the motives behind migration. People move for a wide variety of reasons and a large body of literature exists that attempts to conceptualise the migration decision. In his review of a volume dedicated to the topic of migration decision-making (De Jong and Gardner, 1981), Stark (1984) discusses the contribution of the work to identifying the role of institutions in affecting demographic phenomena for which individuals may be technically responsible but not, “decisionally accountable”. As well as addressing the role of institutions in the migration decision, articles within De Jong and Gardner’s volume deal with numerous additional influences and perspectives on the migration decision (DaVanzo, 1981, Gardner, 1981). The publication of De Jong and Gardner's work on migration decision-making provides a useful foundation upon which later developments in the field could be made. Judson's (1990) attempt to construct a direct link between the decision-making process and aggregate rates of migration supports the notional importance of considering migration flows in terms of individual actors around which this research is focussed.

There are at least two distinct approaches to the explanation of migration decisions in the existing literature. These are referred to as 'structural' and 'individual' approaches and help identify the conceptual standpoint from which any study of migratory motives is based. Structural/macro theories of migration place socio-economic structures at the centre of analysis and deduce generalised functions from the influence of overarching components such as wage differentials upon the opportunities available to individuals (Castles and Kosack, 1973, Nikolinakos, 1975, Sassen, 1988, 1991). The approach therefore considers individuals to have virtually no control over the structural components that impose limitations on their actions. In contrast to structural theories, the individual agency/micro approach to migration research focuses upon notions of creativity/humanism and relates to the capacity of individuals to act independently on the basis of their own freedom of choice (Ranis and Fei, 1961, Sjaastad, 1962, Todaro, 1969, Harris and Todaro, 1970). More recently, a possible third meso-level of analysis provided by institutional influences bridges the divide between structural and individual approaches to conceptualising migration by incorporating both. Central to this, the New Economics of Labour Migration (NELM) (Stark and Bloom, 1985) is reported (Hagen-Zanker, 2008, De Haas, 2010) to reconcile concepts of agency and structure by addressing both the excessive structural emphasis of a historical-structural perspective and the theoretical insufficiencies of the standard neoclassical individual framework.

In order to develop a conceptual framework of climate change migration it is useful to consider previous approaches used in research on the issue. Both climate and migration can be described as highly complex systems influenced by numerous feedbacks which require interdisciplinary understanding in order to fully comprehend them. Stehr (2001) suggests that most migration models can be thought of as focussing devices which reduce complexity by drawing attention towards certain aspects depending upon the theoretical approach employed by the model. By contrast, climate models (Burke et al., 2006) do not approach climate from a variety of competing theoretical viewpoints but are based on physical and chemical laws.

While climate models are generally mathematical, migration models, if mathematical at all, are described by Perch-Nielson (2004) as of an empirical nature and independent of time and space. Migration analyses therefore often take the form of conceptual models such as that described by Lee (1966) (Figure 3.1) of the simple concept of intervening obstacles that exist between a migrant's origin and destination. Lee's model accounts for the push and pull factors present in both origin and destination locations and identifies the presence of obstacles to undertaking migration. However, within its simplistic make-up, Lee's structural model does not consider either the specific perceptions of individuals or the institutional influences that may help them overcome the intervening obstacles.

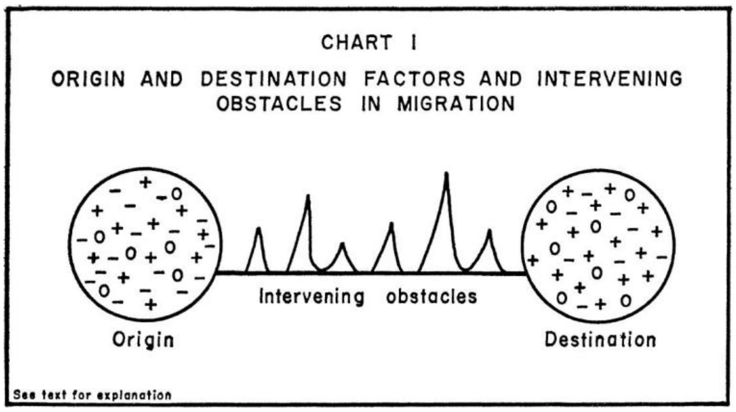

Figure 3.1: Simple Conceptual Model of Intervening Obstacles (Lee, 2006, p50)

McLeman and Smit (2006) present a more contemporary conceptual model (Figure 3.2) in their investigation of migration as a possible adaptive response to the risks associated with climate. The conceptual model attempts to bridge the divide between theoretical advances in migration and climate change scholarship by focussing on factors influencing vulnerability. Following the assumption that climate change stimulates some form of change in the environmental and/or socio-economic conditions of a community, McLeman and Smit's model first considers the ability of community institutions to make the necessary adjustments to protect the well-being of community members. If the community's institutions are unable to cope with the changed environment, the obligation falls to individual households to implement their own adaptive strategies. The options available to a household are seen to reflect their capital endowments in terms of whether migration presents a viable or unavoidable option. If household level adaptation results in migration, the size of the original community is modified and the loop of the model is completed.

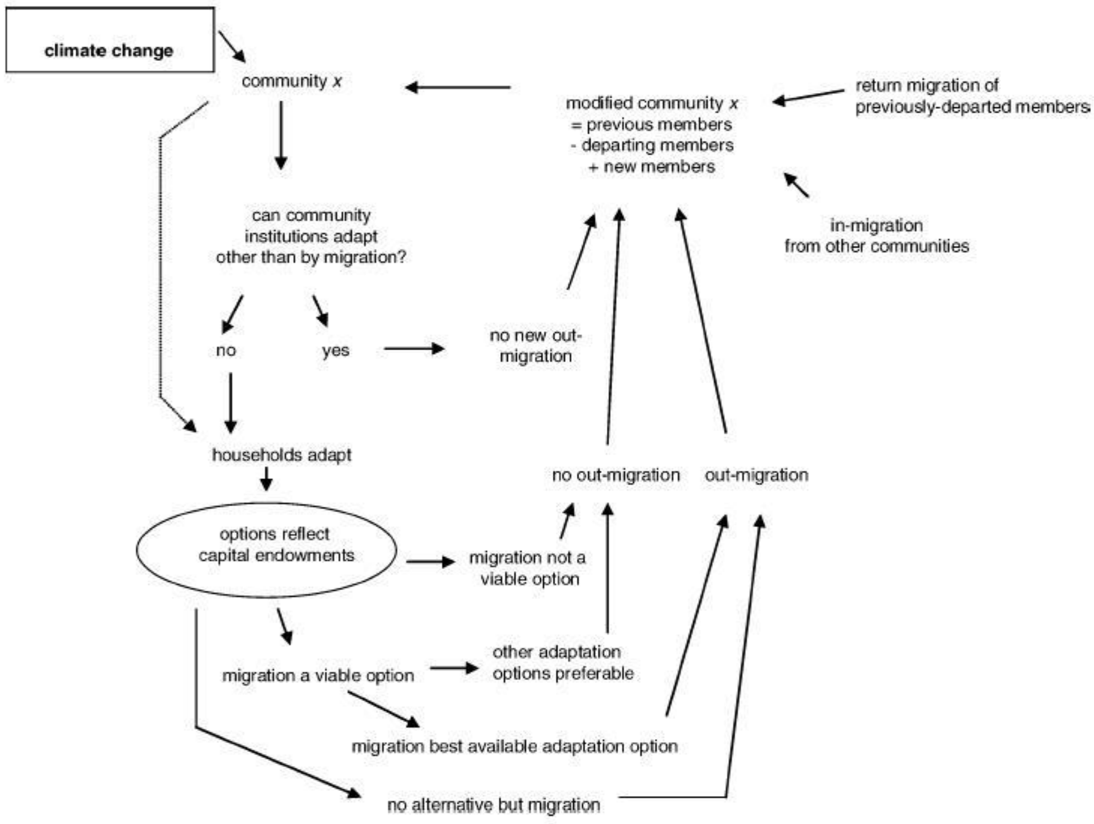

Figure 3.2: Model of migration in response to climate change (McLeman & Smit, 2006, p41)

As an investigative conceptual model McLeman and Smit's representation of the migration response to climate change presents a useful first step by developing the notions of vulnerability, risk and adaptive capacity in the context of migration. McLeman and Smit note that one of the inherent difficulties in constructing a conceptual model is the fact that the same climatic stimuli occurring in the same place but at a different point in time can lead to considerably different outcomes. As a result, they suggest that it is important to consider the adaptive capacity of the exposed populations in question and, with particular respect to the question of migration, consider the broader societal processes and contexts in which exposed populations are situated.

Within the household adaptation stage of McLeman and Smit's model the adaptation options available to households are reflected by their capital endowments. Although it is important that the model has identified such an issue, it goes no further in suggesting how the relationship between adaptive capacity and capital endowments affects the adaptation options available to individuals. In addition, although McLeman and Smit state that broader societal contexts will affect the adaptation options open to households, such factors are not explicitly incorporated into the model. Although increasing apparent complexity, incorporating societal and psychological components into a conceptual model of climate change migration will create a more accurate representation of the process being modelled.

McLeman and Smit suggest that their model is modified on the basis of migration theory to portray migration not as a simple binary phenomenon but as a process where multiple possible outcomes exist. This beneficial advance in conceptual model development is manifested through the influence of capital endowments in the model. However, with migration as the only adaptation option referred to and no inclusion of the psychological steps involved in taking action following exposure to risk, the value of the model for the purpose of developing an ABM is limited by its causal nature and lack of an individual decision-making component. Although not explicitly investigating the psychological steps behind migration, Black et al. (2011) present a model (Figure 3.3) that divides the factors that contribute to the decision to migrate in the face of environmental change into five drivers, the effects of which the authors describe as closely intertwined.

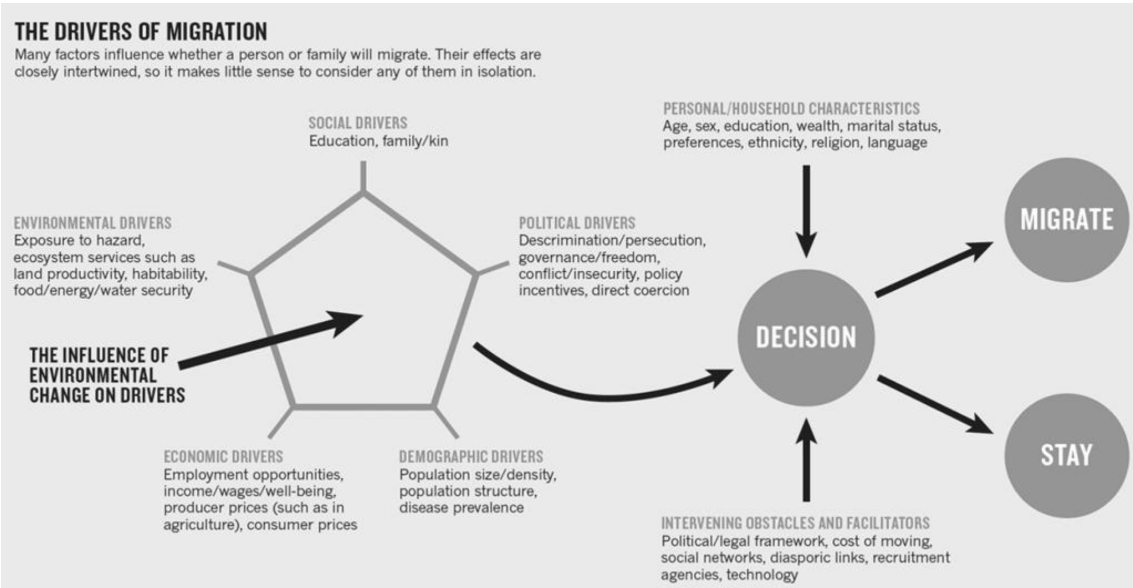

Figure 3.3: The Drivers of Migration (Black et al., 2011, p.448).

Black et al. (2011) divide the drivers of migration into: social; political; demographic; economic; and environmental. Environmental change is modelled as influencing all of these drivers in an interconnected manner through the pentagonal linked structure shown by the authors. These drivers, subject to the influence of environmental change, are then seen in the model to contribute to the decision to migrate which is itself affected by personal/household characteristics and intervening obstacles/facilitators. As a result, an individual or family decides to either migrate or stay. The primary value offered by Black et al.'s (2011) model is the representation of environmental change as affecting all five drivers of migration in an interconnected manner. As such, migration is presented as being potentially driven by environmental changes that can affect non-environmental drivers. Due to the multiple and potentially varied impacts of different forms of environmental change upon migration, the Drivers of Migration model is not able to explicitly identify the potential impact of changes in rainfall variability upon migration decision-making. Furthermore, by not resolving the contribution of each of the drivers into the actual process of decision-making, the model provides a useful representation of the potentially complex nature of the migration decision undertaken in the face of environmental change but is not suited to the development of an ABM. To incorporate the impact of decision-making into the conceptualisation of migration in the face of environmental change, the impact of cognitive influences must be considered.

3.3 Models of Climate Change Adaptation

In order to gain greater insight into individual decision-making in response to changes in climate, this research turns to wider contributions from the considerable literature on climate adaptation. The impacts of climate change upon human populations are often considered in terms of vulnerability. The vulnerability of a population to the impacts of climate change is reduced with increased adaptive capacity which is, in turn, affected by such factors as economic, human and social capital, institutional processes and access to information (Kniveton et al., 2008). Considering changes of climate from the perspective of adaptation and adaptive capacity permits the inclusion of migration as one potential adaptation strategy available to individuals and households. As such, climate change adaptation models provide a good starting point in the development of a conceptual model of the role of changes in rainfall variability in the migration decision-making process.

Adaptation strategies employed by individuals in response to climatic stimuli depend heavily upon variables such as the nature, duration and intensity of the stimulus, the present status of the individual, their previous experience and the networks to which they belong. In addition, the individual's perception of the event and their subsequent ability to manage, adapt to or escape from its impacts affects the adaptation strategy chosen. Perhaps as a result of the numerous contributing factors and their heterogeneous impact upon individuals, there is no explicit formula from which to accurately predict when migration is deemed to be the appropriate course of action. For an individual with the benefit of access to seasonal climate forecasts and information on predicted future climate change, the impact of such change will be assessed according to their perception of the risk posed to their livelihood. According to an individual's perception of that risk, and the potential for alleviating the risk by relocating to an alternative location, climate change may contribute to the decision of an individual to migrate. However, using an agent-based model, Ziervogel et al. (2005) show that the impact of using forecasts depends upon the level of trust an individual places in the information, a factor both difficult to assess and quantify.

Conceptualising climate change migration as occurring on the basis of prior information, such as seasonal rainfall forecasts, involves the decision-maker adopting a proactive/planned approach to adaptation. As a result, migration may be chosen as an active option that can alleviate the impact of an expected occurrence on the basis of anticipated outcomes. Moser and Ekstrom (2010) present a systematic framework to identify barriers that may impede the process of adaptation to climate change with a focus on the intentional, planned adaptation process. They suggest that an individual's choice of a particular scope and scale of adaptation has significant implications for the number and types of barriers activated and encountered. The barriers to which Moser and Ekstrom refer are simply impediments that can stop, delay, or divert the adaptation process. The authors present a graphical representation of the scope and scale of adaptation to climate change, based upon their extensive literature review (Figure 3.4). When defined according to the scope and scale of adaptation, migration would, in most cases, present something of a last resort adaptation strategy requiring a large investment in time and effort with potentially long term delays before goals are realised.

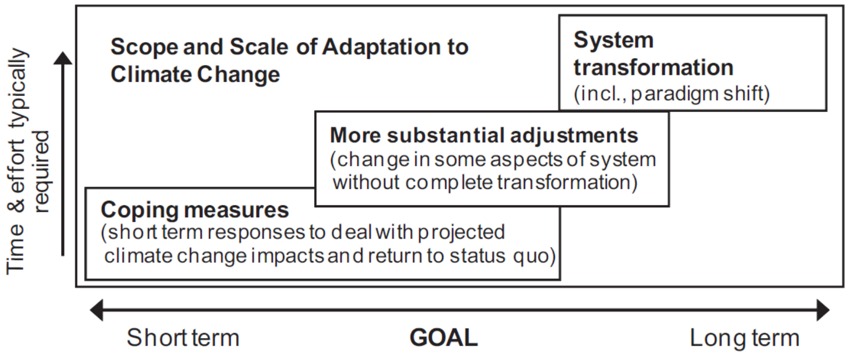

Figure 3.4: Moser and Ekstrom's (2010, p.22027) scope and scale of adaptation to climate change.

According to Moser and Ekstrom's representation of the scope and scale of adaptation, a high input, long term goal adaptation strategy approach such as migration would potentially result in what they term a system transformation. They suggest that such a system transformation will likely require more challenging barriers to be overcome than planning or implementing immediate measures to cope with a climate-driven disaster. In identifying and organising the barriers to such adaptation, Moser and Ekstrom consider the rational decision-making process of adaptation (Figure 3.5). Each of the nine stages in their adaptation decision-making model are systematically used by Moser and Ekstrom to identify potential barriers within the three core phases of *understanding*, *planning* and *managing* the adaptation process.

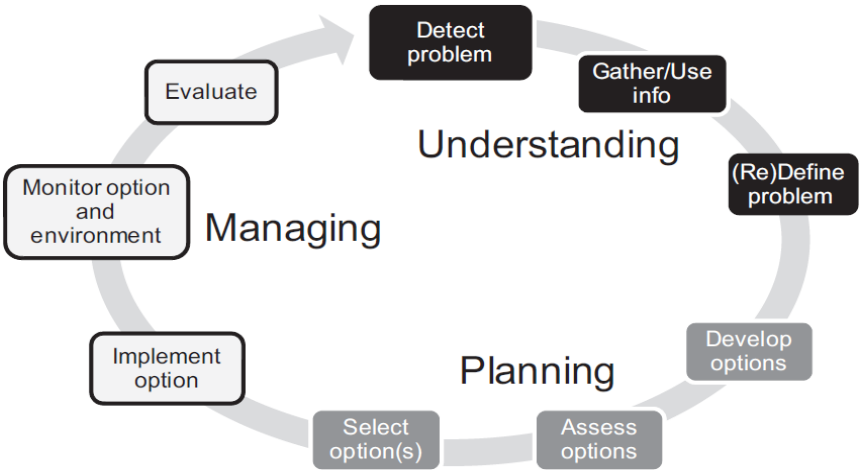

Figure 3.5: Moser and Ekstrom's (2010, p.22027) phases and sub-processes throughout the adaptation process.

Moser and Ekstrom's model presents the phases and sub-processes they deem to be involved in the rational decision-making of a planned adaptation to climate change and is useful as a first step in considering the migration decision. However, although the model breaks the decision down into three distinct sub processes within each of the three phases of the adaptation decision, the detail given for each of the sub processes provides an inadequately detailed basis from which to develop an ABM without considerable further data collection in the field.

Another endeavour to assess vulnerability and adaptive capacity among individual households is provided by Gilbert and McLeman (2010). Using the conceptual framework shown in Figure 3.6, Gilbert and McLeman examine how differential access to economic, social, and human capital influenced the capacity of households to adapt to severe drought conditions in 1930s rural Canada.

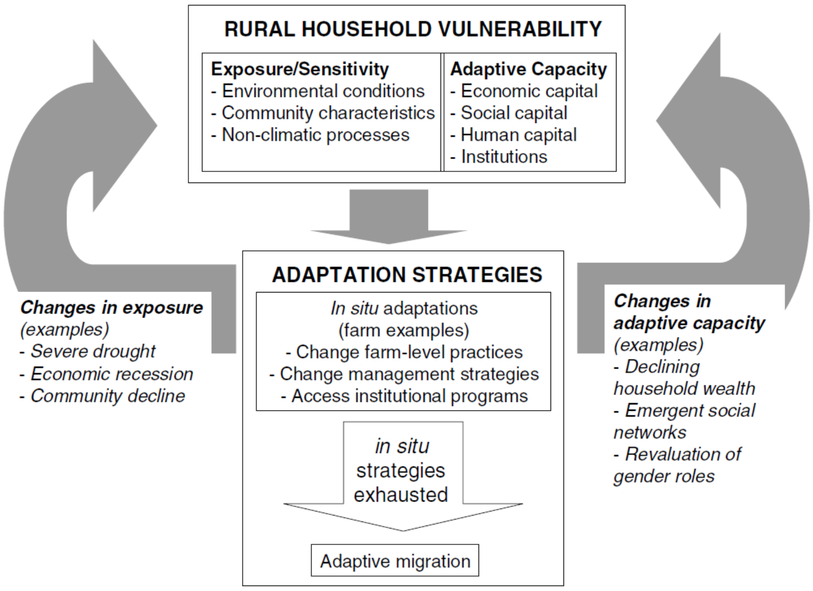

Figure 3.6: Gilbert and McLeman's (2010, p.11) conceptual diagram of rural household vulnerability.

Gilbert and McLeman's (2010) study finds that migration patterns witnessed during their study period can be seen as one option amongst the set of adaptations undertaken by the population in response to broader interactions of social, economic and environmental processes. These are described by the authors to result in different levels of vulnerability and adaptive capacity of individual households. Dividing vulnerability into discrete and dynamic *exposure/sensitivity* and *adaptive capacity* components and distinguishing between *in-situ* adaptations and migration are useful steps in developing the migration decision-making model required for this research. Although Gilbert and McLeman's conceptual model acknowledges the interacting roles of social, economic and environmental components in causing vulnerability and adaptive capacity, the model is not presented in a state whereby the decision-making process of an actively adapting agent can be established.

Investigating the same concept of vulnerability and adaptive capacity but from the converse perspective of susceptibility, Acosta-Michlik et al. (2008) use security diagrams to measure susceptibility from a socio-economic perspective. On the basis of their security diagrams approach, Acosta-Michlik et al. present a conceptual framework for determining susceptibility on the basis of socio-economic determinants provided by modernisation theory and trade dependency theory (Figure 3.7).

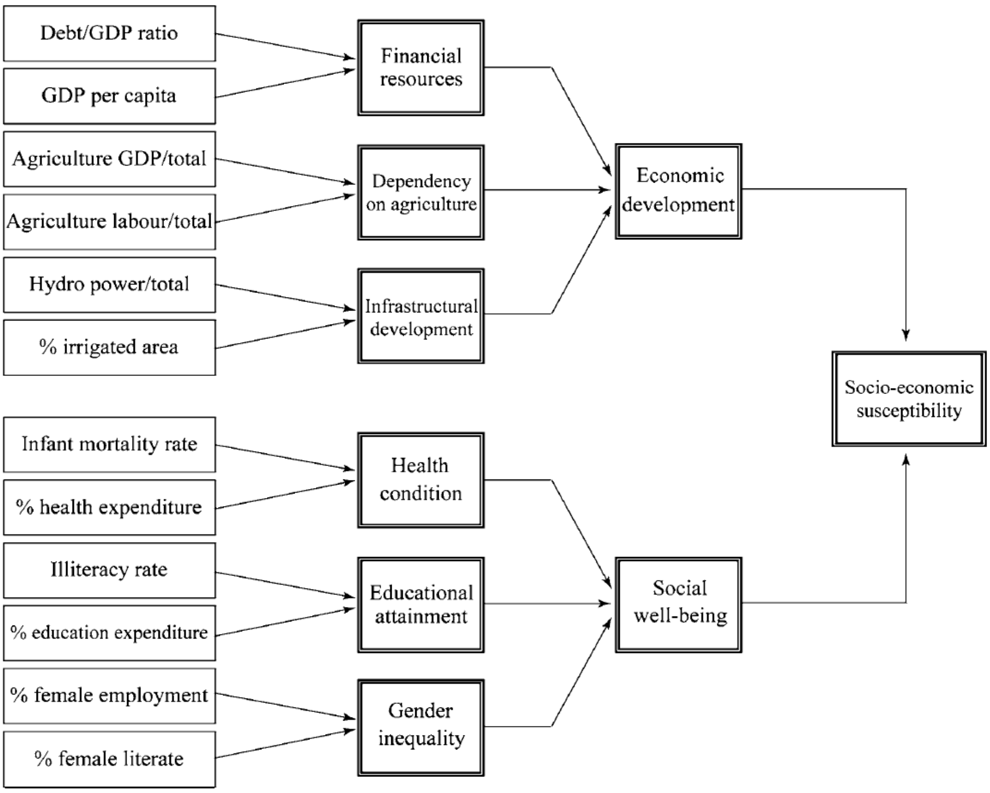

Figure 3.7: Acosta-Michlik et al.'s (2008, p.154) conceptual framework for socio-economic susceptibility.

Figure 3.7 shows Acosta-Michlik's interpretation of the economic development and social well-being components that contribute to socio-economic susceptibility to drought. The two components are both broken down into three contributory sub-components. As a result, economic development is seen to be a result of financial resources, dependency on agriculture, and infrastructural development while social well-being results from health condition, educational attainment, and gender inequality. The underlying concept that Acosta-Michlik et al.'s security diagrams and conceptual model emphasise is that the higher the levels of environmental stress and socio-economic susceptibility, the higher the probability that crisis will occur.

The conceptual framework presented by Acosta-Michlik et al. (2008) provides further insight into those components that contribute to an individual's adaptive capacity or susceptibility to changes in climate. Developed from a socio-economic perspective the conceptual framework includes important parameters for consideration in the development of a conceptual model of the migration decision but, as with the work of Moser and Ekstrom (2010), requires further contributions in order to both focus upon migration as the adaptation strategy of choice and provide a model basis tailored for translation into an ABM designed to simulate a human system where there is potential for emergent phenomena (Bonabeau, 2002).

3.4 Proactive Model Development

In a more detailed exploration of the human cognition behind adaptive capacity, Grothmann and Patt (2005) present a socio-cognitive model of private proactive adaptation to climate change (MPPACC) (Figure 3.8). Based on Protection Motivation Theory (PMT) which deals with the cognitive process mediating behavioural change (Sivakumar and Gnoumou, 1987), the model separates out the psychological steps to taking action in response to perceptions of climate.

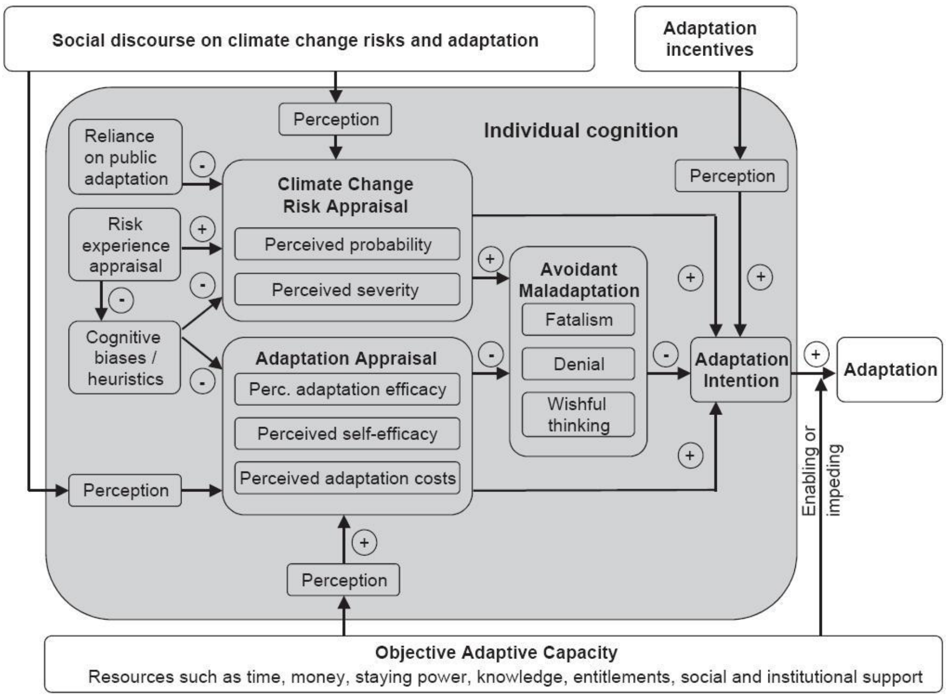

Figure 3.8: Process model of private proactive adaptation to climate change (MPPACC) (Grothmann and Patt, 2005, p.204).

By acknowledging the socio-physical context of the individual, the MPPACC attempts to explain why some people show adaptive behaviour while others do not. The model begins with a *climate change risk appraisal* within which there are two subcomponents; *perceived probability of exposure* and *perceived severity of harmful consequences*. The second major component, *adaptation appraisal*, comes after the risk perception process and only starts if a specific threshold of threat is exceeded. Within the adaptation appraisal, three subcomponents of *perceived adaptation efficacy*, *perceived self-efficacy* and *perceived adaptation costs* govern the response. Based on the outcomes of the risk and adaptation appraisal processes, an individual responds to the threat through either *adaptation* or '*maladaptation*' (which includes avoidant reactions and 'wrong' adaptations that inadvertently increase climate change damage). If an individual chooses to employ an adaptive response they first form a decision or intention to take these actions. Labelled as *adaptation intention*, this component of the model distinguishes between intention and actual behavioural adaptation. The MPPACC also incorporates an additional level of complexity by considering the *cognitive biases* that affect people's perceived adaptive capacity and their previous experience of risk affects subsequent appraisal.

Permitting deeper consideration of the cognitive process of individuals, the MPPACC also includes the socio-physical context of the individual by including *social discourse*. Based on Kasperson et al.'s (1988) framework of social amplification of risk, the inclusion of social discourse in the model permits the concept that people's perceptions of risk or adaptive capacity with regard to climate change may be amplified or attenuated by what they hear about the issue from the media, friends, colleagues, neighbours and public agencies. By highlighting the importance of people's perceptions of the stimuli affecting the appraisal processes, the MPPACC provides a good conceptual basis to consider the socio-cognitive process behind proactive adaptation to the risk posed by future climate change.

From the basic structure of risk and adaptation appraisals provided by the MPPACC, this thesis presents a conceptual agent-oriented model of the proactive adaptation to climate change (PACC) that, through a process of individual cognition, results in the selection of climate adaptation strategies, including migration (Figure 3.9). The model incorporates the two major appraisals of *climate change risk* and *adaptation* used in Grothmann and Patt's MPPACC, as well as the perceptions of *adaptation efficacy*, *self-efficacy* and *adaptation costs* contained within these appraisals. The main development presented by the conceptual agent-oriented model is the inclusion of a further level of detail within the adaptation appraisal and a subsequent comparison of adaptation options prior to the individual developing the actual intention to adapt.

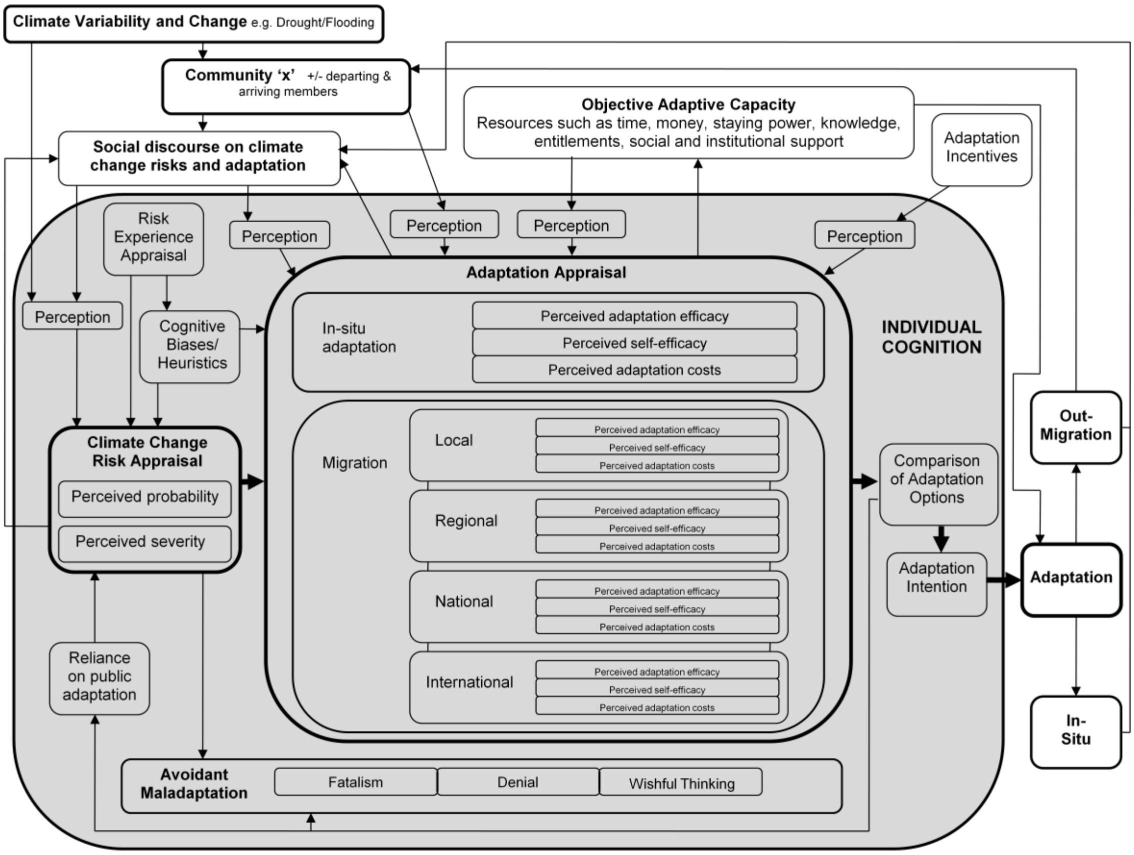

Figure 3.9: Conceptual model of Proactive Adaptation to Climate Change (PACC).

In the PACC model, both *climate variability and change* and the *social discourse on climate risks and adaptation* undertaken by *community 'x'* contribute to the first stage in the cognitive process; *climate change risk appraisal*. Also contributing to this evaluation of risk is an appraisal of the individual's previous experience of risk and their *cognitive biases/heuristics*. If the assessment of risk returns an outcome greater than a specific threshold, the individual moves on to perform an appraisal of the process of adaptation and the options available to them. Contributing to this are the individual's knowledge about the climate risk, their perceived *objective adaptive capacity* in the face of such risk, their perception of the departures and arrivals of other community members and any adaptation incentives such as financial assistance that may be available.

Within the *adaptation appraisal* individuals consider both *in-situ adaptation* and *migration*. If the adaptation appraisal returns a preference to adapt through migration, the individual weighs up the options for migration available to them (in terms of scale of movement) on the basis of the MPPACC's perceptions of *adaptation efficacy*, *self-efficacy* and *adaptation costs*. An individual's objective adaptive capacity is seen by this model to both affect the adaptation appraisal through a process of individual perception and be affected by that appraisal in a feedback mechanism where, for example, prior appraisals result in increased situational knowledge. *Adaptation incentives* also contribute to the adaptation appraisal from which the individual undertakes a comparison of their adaptation options and develops an intention to pursue in-situ or migratory adaptation strategies, rely on public adaptation, or pursue an avoidant maladaptation strategy. The chosen adaptation strategy then both impacts upon the social discourse on climate change risks and adaptation and affects the size of community 'x' which, in turn, further impacts upon the social discourse. With this feedback mechanism in place, the conceptual model is structured to represent the cognition of an individual agent whose actions then impact upon the modelled environment and affect the actions of other agents in the system.

Although the PACC model makes a valuable contribution to understanding the process of climate change migration decision-making it is limited in its capacity to suit development of an agent based model of climate migration in Burkina Faso as a result of two limitations. The first of these is the lack of explicit consideration of other agents by the PACC. In developing an adaptation intention the PACC only considers the input of other agents in terms of their contribution to the social discourse. However, one of the inherent advantages of an ABM is the influence of agents upon others in their network as a result of social interactions. Within a dynamic decision-making process Schwenk and Reimer (2008) conclude that the interaction of agent cognition is central to the course of social processes. They find that the relatively high status of influential others within a network can lead to the otherwise unlikely persistence of a minority faction. Without incorporating the influence of the views/experience of specific others in the agent's network, the PACC does not permit this level of influential interaction to occur and could therefore limit the emergent properties of the simulation.

The significant others affecting a migrant's decision may simply be interested others relating personal advice and preferences to an individual or family members with a vested interest in the successful outcome of the migration. A major contribution of Stark and Bloom's (1985) New Economics of Labour (NELM) approach is the observation that the migration decisions that lead to an individual relocating are not made by sole actors but are undertaken jointly by the migrant and a larger group of related people who act collectively to both maximise expected income and minimise potential risks (Massey et al., 1993). Influential others within an agent's network may therefore be family members that anticipate remittances from the migrant following their investment in the initial migration of a household member. The ability of a household to control risk by diversifying the allocation of the resources that contribute to its economic well-being makes labour migration of one member of the unit a useful strategy in countering the potential impact of deterioration in local economic conditions. The failure of PACC to explicitly consider the role of other agents, household members or otherwise, therefore limits its ability to incorporate the insight of Stark and Bloom's NELM.

The second limitation of the model is the proactive nature of the adaptive response being modelled. By including the climate change risk assessment component shown in the MPPACC, the PACC inherits the proactive nature of the model through the development of perceptions relating to the occurrence and severity of climate change. The structure of the model therefore follows proactive reasoning based on an individual's perception of the occurrence of climate change. In the behavioural response to structural components, Richmond (1993) argues for the existence of a continuum between the rational choice behaviour of proactive migrants and the reactive behaviour of those whose degrees of freedom are severely constrained. Richmond describes typical proactive migrants as professionals, entrepreneurs, retired people and temporary workers under contract. By contrast, he describes reactive migrants to include those who meet the UN Convention definition of refugees (people with a genuine fear of persecution and an inability or unwillingness to return) as well as others reacting to crisis situations caused by war, famine, economic collapse and other disasters. Although legally not meeting the UN Convention definition of a refugee (UNHCR, 2006), individuals reacting to degradation or crisis caused by environmental change would, on this continuum, fall towards the reactive end of the scale. Indeed, Richmond goes on to state that sudden changes in the economic, political or environmental situation may precipitate reactive migration. From a cognitive perspective, conceptualising the migration decision in question as more reactive also presents advantages in terms of the ability of people to make rational decisions on the basis of the information available to them.

3.5 Bounded Rationality

Humans are, to some extent, rational beings in the way that they attempt to understand things on the basis of logic and make sensible choices from this information. However, due to the size and complexity of our environment we do not have the capacity to understand everything. As a result of this, and the limits imposed by the mental structures we use to organise and simplify our knowledge of the world around us, our decisions cannot be described as completely rational.

Simon (1982) therefore suggests that there are two major causes of bounded rationality: the limitations of the human mind and the structure within which the mind operates. Kant and Thiriot (2006) suggest that more traditional agents developed from Classical Decision Theories or Game Theory undertake ‘too-rational behaviour’ that is not compatible with the limitations of human cognitive capabilities and so are not compatible with Simon’s concept of bounded rationality.

Further to the concept of bounded rationality, human actors are also considered to apply an optimisation process known as “*satisficing*” to decision-making processes. Simon (1957) proposes that the key to the simplification of choice processes lies in the replacement of an individual’s goal of *maximizing* to the optimal decision with the goal of *satisficing* to a near-optimal option. Built upon the notion that an individual does not possess an inexhaustible amount of time, effort or will to contribute to identifying the optimal solution to a problem, the concept of *satisficing* suggests that, in decision-making, an individual tends to select the first available option that meets the given need rather than invest greater amounts of time and cognitive resources to finding the “optimal” solution.

In order to incorporate the limitations of human capabilities, it is therefore important to start with a conceptual basis within which the bounded rationality and sub-optimal selection criteria of human decision-makers are considered. By failing to define what components make up the appraisal processes central to the PACC model it incorporates no limit on the rationality used by the modelled decision-maker and is thus overly complicated as a conceptual process. The reliance of a vast majority of the population of Burkina Faso on rain-fed subsistence agriculture and cattle-raising allows climate variability to have a dominant control over individual livelihoods. Although Roncoli et al. (2003) show that both local-cultural and regional-scientific forecasts of seasonal rainfall affect the cognitive frameworks of farmers, they find that such forecasts can be often contradictory and result in only a limited livelihood response by farmers. When modelling the information that is available to an agent in a situation such as this it is necessary to incorporate the concept of bounded rationality. Therefore, in the context of proactive model development, the information available to an agent and their network can be controlled to realistically limit their perception of, for example, a seasonal forecast. In order to both incorporate this notion of bounded rationality and move away from a proactive model of climate change we investigate theoretical developments that contribute to the development of a reactive model alternative. By developing a reactive model that includes consideration of bounded rationality the decision-making process can be modelled in a more realistic manner.

3.6 The Theory of Planned Behaviour

In order to overcome the issues identified with the PACC model it is necessary to construct a conceptual model based on a reactive decision-making process that incorporates the notion of bounded rationality by ensuring that the cognitive process remains relatively simple. Seeking a basis for such a model this thesis draws upon theoretical developments made in the field of social psychology. The Theory of Reasoned Action was developed by Fishbein and Ajzen (1975) as an expectancy-value model that recognises attitudes as just one determinant of behaviour within a network of predictor variables. The theory proposes that the proximal cause of behaviour is 'behavioural intention', a conscious decision to engage in certain behaviour. Making up this behavioural intention is the *attitude toward the behaviour* (defined as the sum of expectancy x value products) and the *subjective norm* (defined as the belief that a significant other thinks one should perform the behaviour and the motivation to please this person).

By extending the theory of reasoned action to incorporate the additional parameter of *perceived behavioural control*, Ajzen (1991) described the Theory of Planned Behaviour. Intended to aid prediction of behaviours over which a person does not have complete voluntary control, perceived behavioural control was conceptualised as the expected ease of actually performing the intended behaviour. This concept of perceived behavioural control serves a similar role to that played by the perceived self-efficacy component incorporated into the adaptation appraisal stage of the MPPACC. Including attitudes toward behaviour, a subjective norm and perceived behavioural control (as well as the beliefs that make up these components), the Theory of Planned Behaviour (Figure 3.10) can be used to effectively break down the cognitive process relating to the development of a behavioural intention.

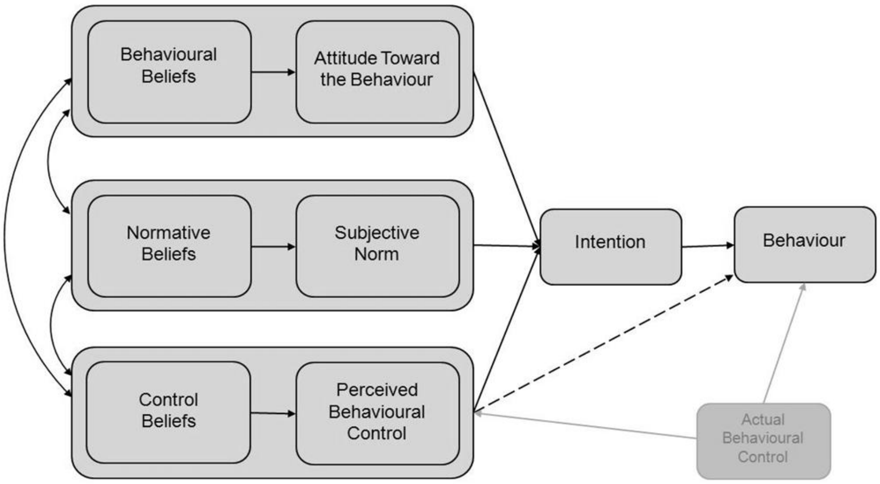

Figure 3.10: Theory of Planned Behaviour, adapted from Ajzen (2006).

Most previous applications of the theory of planned behaviour have investigated health-related behaviours such as exercise (Nguyen et al., 1997), diet (Conner et al., 2003) and condom use (Albarracín et al., 2001). However, the theory has also been applied to numerous fields outside health-related behaviour, including entrepreneurial intentions (Krueger and Carsrud, 1993), conservation technology adoption (Lynne et al., 1995) and wastepaper recycling (Cheung et al., 1999). In the field of migration research, Lu (1999) suggests that the theory of planned behaviour has been successfully used to investigate the reasons behind the inability of households to move when they express an intention to do so and the unexpected relocation of other households. De Jong (1999) backs this up by stating that the inclusion of expectations as a major component in the theory of planned behaviour is beneficial in capturing the dynamics of migration decision-making.

In adapting and applying the theory of planned behaviour to migration decision-making, De Jong (2000) suggests that intentions to move are the primary determinant of migration behaviour. Alongside this intention are the direct behavioural constraint and facilitator factors that make up the perceived behavioural control component of the model. The primary constraint/facilitator (contributing to the ability of the individual to undertake migration) is described by De Jong (2000) as prior migration behaviour in accordance with Ajzen’s (1988) assertion that prior behaviour is a major facilitator to any application with the theory.

By applying the theory of planned behaviour, De Jong (2000) suggests that expectations of achieving valued goals in a location other than the home community, along with perceived family norms about migration behaviours (the ‘behavioural beliefs’ and ‘normative beliefs’ from Figure 3.10) are the major determinants of migration decisions. Individual components such as age, education, marital status, dependants and income have long been cited in the literature as contributing to migration (Ravenstein, 1885, 1889). However, De Jong suggests that these components do not have a direct effect on migration behaviour due to their being mediated as constructs of other overarching factors. In adapting and applying the theory of planned behaviour to his general model of migration decision-making (Figure 3.11) therefore, De Jong does not explicitly mention these components but uses the overarching factors he considers to be the direct determinants of the migration decision.

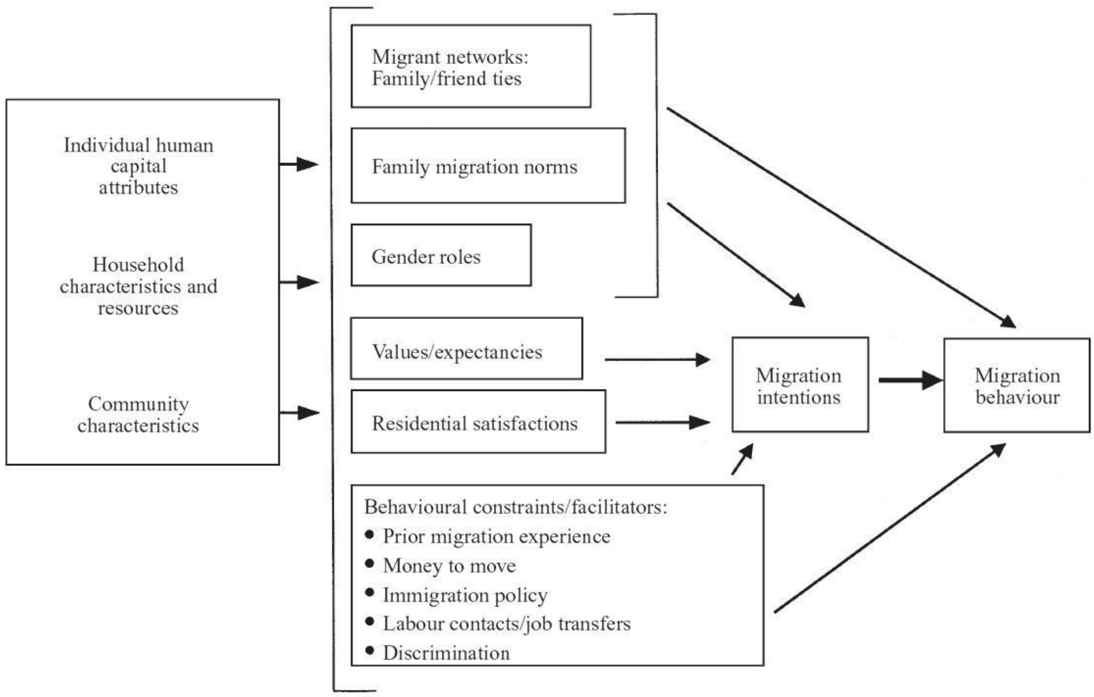

Figure 3.11: General model of migration decision-making (De Jong, 2000, p.310).

In De Jong’s model, individual, household and community characteristics contribute to six concepts that are identified as uniquely relevant to migration decision-making: migrant networks; family migration norms; gender roles; values/expectancies; residential satisfactions; and behavioural constraints/facilitators. These components combine to produce a behavioural intention and ultimately, migration behaviour. De Jong concludes that the migration proposition posed by the theory of planned behaviour that ‘intentions predict behaviour’, is a statistically significant explanation for more permanent, but not for temporary, migration behaviour in a Thai context.

As a theoretical basis from which to investigate the conceptual foundations of the reactive migratory behaviour of human agents in Burkina Faso, the theory of planned behaviour presents a model that is both theoretically and empirically founded. With previous applications to the field of migration decision-making (De Jong, 2000) and a more recent application to an ABM of the diffusion of organic farming practices (Kaufmann et al., 2009), the theory has some background in the topic. Although De Jong has adapted and applied the theory of planned behaviour to migration decision-making and incorporated components that form the attitude toward behaviour, subjective norm and perceived behavioural control, his general migration decision-making model is not suited to direct translation into an ABM due to the level of analysis used. While De Jong makes the valuable point that traditional explanatory components such as age, gender and marital status are likely mediated as constructs of other over-arching factors, the precise manner in which these individual/agent level attributes contribute to the overarching factors are required for an ABM. It is these individual-level characteristics and their translation into such overarching factors as norms and roles that are required within an ABM to produce emergent outcomes beyond those possible through traditional empirical approaches. Although theoretically very useful in conceptualising migration, the application of De Jong's model to the construction of an ABM is limited. By incorporating the value of Ajzen's (1991) theory of planned behaviour, and the conceptual advances by De Jong's (2000) model of migration decision-making, this research can work towards the development of a reactive model of climate change adaptation that is more suited to translation into an ABM.

3.7 Reactive Model Development

As suggested by Richmond (1993), sudden changes in the economic, political or environmental situation of individuals may cause them to undertake reactive migration. On this basis, the migration response of subsistence agriculturalists in Burkina Faso is considered to fall close to reactive on the continuum ranging from purely proactive to purely reactive migration. In developing a conceptual model of adaptation to climate change from which an ABM will be constructed, a more reactive approach to adaptation is therefore adopted by this thesis. The first proactive conceptual model presented here (the PACC) was constructed from the basis provided by Grothmann and Patt's (2005) MPPACC. With insight provided by the proactive conceptual model developed from the MPPACC and a theoretical basis offered by the theory of planned behaviour (Ajzen, 1991, De Jong, 2000), this thesis presents the conceptual agent-oriented model of reactive adaptation to climate change (RACC) (Figure 3.12).

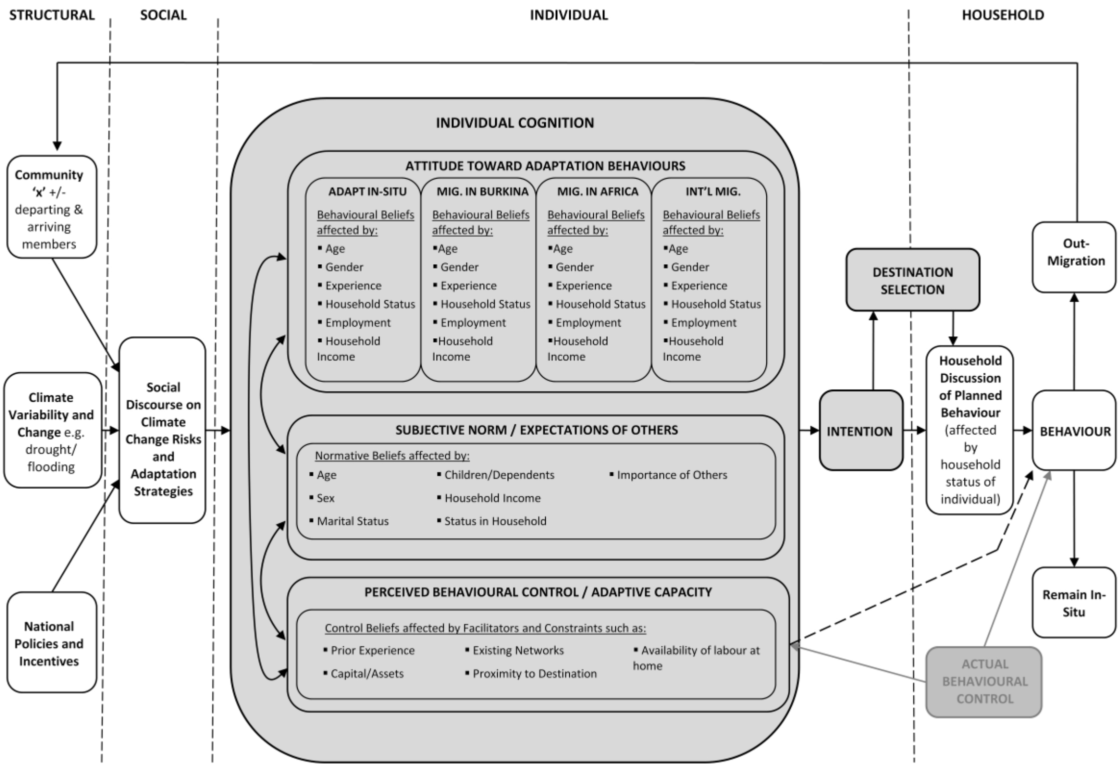

Figure 3.12: Conceptual model of Reactive Adaptation to Climate Change (RACC).

The RACC model incorporates much of the external structure used in the PACC model with the most significant changes made to the process of individual cognition. As a result of the reactive nature of the model, the individual climate change risk appraisal process of the PACC has also been removed with only a social discourse on events contributing to individual cognition. By basing the RACC model on the theory of planned behaviour the central appraisal components of the PACC are replaced with the core of the theory of planned behaviour: the *attitude toward adaptation behaviour*; the *subjective norm*; and the *perceived behavioural control*. The model is also divided into clear external, social and individual components, as well as an additional household level to aid the process of translation into an ABM. As a result the RACC is intended to identify the external factors that contribute to a social discourse, the impact of this discourse upon the individual cognition behind adaptation, how the intention developed by an individual plays a part in household discussions on adaptation and, ultimately, results in an adaptation strategy which feeds back to affect the original community. While the PACC model did not explicitly include a household level within its decision-making structure, the RACC incorporates such a level on the basis of the New Economics of Labour Migration (NELM) notion that migration be viewed as a family strategy aimed at both maximising expected earnings and reducing the risk of consumption failure by diversifying income sources across sectors or agro-zones (Lilleør & Van den Broeck, 2011). However, within the RACC, the primary level of decision-making power is left with the individual on the basis that the final decision to stay or go to a specific destination lies with the individual as opposed to the household.

The RACC model presents several advantages over both the PACC model and De Jong's (2000) general model of decision-making when applied to the context of constructing an ABM of climate change migration. Although both the RACC and De Jong's model are developed from the theory of planned behaviour, the RACC model presents a more explicit representation of the cognitive process undertaken by an agent. As a result, there is greater potential for translating the model into an ABM. Through consideration of the bounded rationality of humans, the RACC model develops the internal structure of individual cognition upon those aspects of an agent's environment that they are likely to be able to understand and use. By breaking down the components involved in the cognitive process, the RACC model serves to both more explicitly represent cognition and simplify the process into just three core components. As De Jong (2000) identifies, although not actual reasons in themselves that would drive migration, variables such as age and gender are however important components for consideration. On this basis, the RACC model manages to incorporate such factors into the context within which they influence migration decisions by placing them as underlying determinants within the three core components of the model.

Limiting the components involved in individual cognition within the RACC model both reduces the complexity of the cognitive process and removes the proactive component of the PACC model: the climate change risk appraisal. In this context, the rationality of the individual in perceiving climate change is bounded by the information available to them. Unless an individual is exceptionally well informed about the climate of their locality, it is unlikely that they would have the capacity to undertake an informed individual climate change risk assessment that could lead to proactive adaptation.

Roncoli et al. (2002) suggest that a certain amount of forecast knowledge is shared amongst farmers in Burkina Faso. This knowledge is comprised of indicators that are used throughout the year to predict the coming wet season and include: dry-season temperatures; flower and fruit production of local trees; the direction and intensity of winds; and the behaviour of birds and insects. In the RACC model this information would contribute to the social discourse on climate change risks and adaptation strategies. When undertaking reactive adaptive behaviour, it is proposed that an individual is likely to undertake a process of acceptance or denial of the social discourse on risks and adaptation that is available to them. As such, in the RACC model, the social discourse plays an explicit part in shaping the attitude of individuals toward adaptation behaviours, the expectations of others and their perceived behavioural control.

Incorporating an explicit input from the social discourse on climate change, the individual cognition occurring in the RACC model is broken down into three central and simultaneously occurring components: the formation of attitudes toward different adaptation behaviours; the consideration of the expectations of others; and the perceived behavioural control/capacity to undertake adaptation. The *attitude toward adaptation behaviours* is formed on the basis of a series of beliefs about those behaviours. In the RACC model these beliefs are characterised by an individual's previous experience of the behaviour (De Jong, 2000), their age, gender, ethnicity and status, and how these components are affected by the social discourse. The *subjective norm* component of the individual cognitive process represents the expectations of others and is developed from a series of normative beliefs. These beliefs are characterised by an individual's age, gender, marital status, and dependants, as well as their household income and status and the societal norms that exist for the community.

As well as involving an individual's perception about the expectations of others regarding a particular behaviour, the *subjective norm* component also incorporates the individual's willingness to please the relevant others (Ajzen, 1991) to which they are connected. The final component of *perceived behavioural control* relates to the adaptive capacity of the individual and is constructed on the basis of a series of control beliefs. These control beliefs are characterised by components such as an individual's assets, capital, social and institutional support, existing networks and access to resources. From these beliefs the individual constructs a perception of the ease/difficulty of performing a particular behaviour. As noted by Fishbein and Cappella (2006), perceived behavioural control is the same as Bandura's (1999) concept of self-efficacy which Grothmann and Patt use as one of the internal mechanisms of the adaptation appraisal component of the MPPACC.

3.8 Conceptual Model Development

The nature of the RACC model as incorporating both individual cognition and the external factors that contribute-to, and result-from, that cognition allows it to form the basic structure that each agent in an ABM can be hypothesised to follow. The RACC model has been developed as a conceptual basis from which the impact of changes in climate upon human migration can be investigated. While it is possible that climate may be an important factor in causing migration within and from Burkina Faso, it cannot by any means be considered to be the only factor contributing to migration in that region. As such, the conceptual model must be both expanded to acknowledge the input of other contributing factors such as employment opportunities and narrowed in scope to focus on just one of the many manifestations of a changing climate. From the RACC model this thesis therefore presents the final development of the conceptual basis from which the AMARC models are developed. The resulting model of Migration Adaptation to Rainfall Change (MARC) is presented as Figure 3.13.

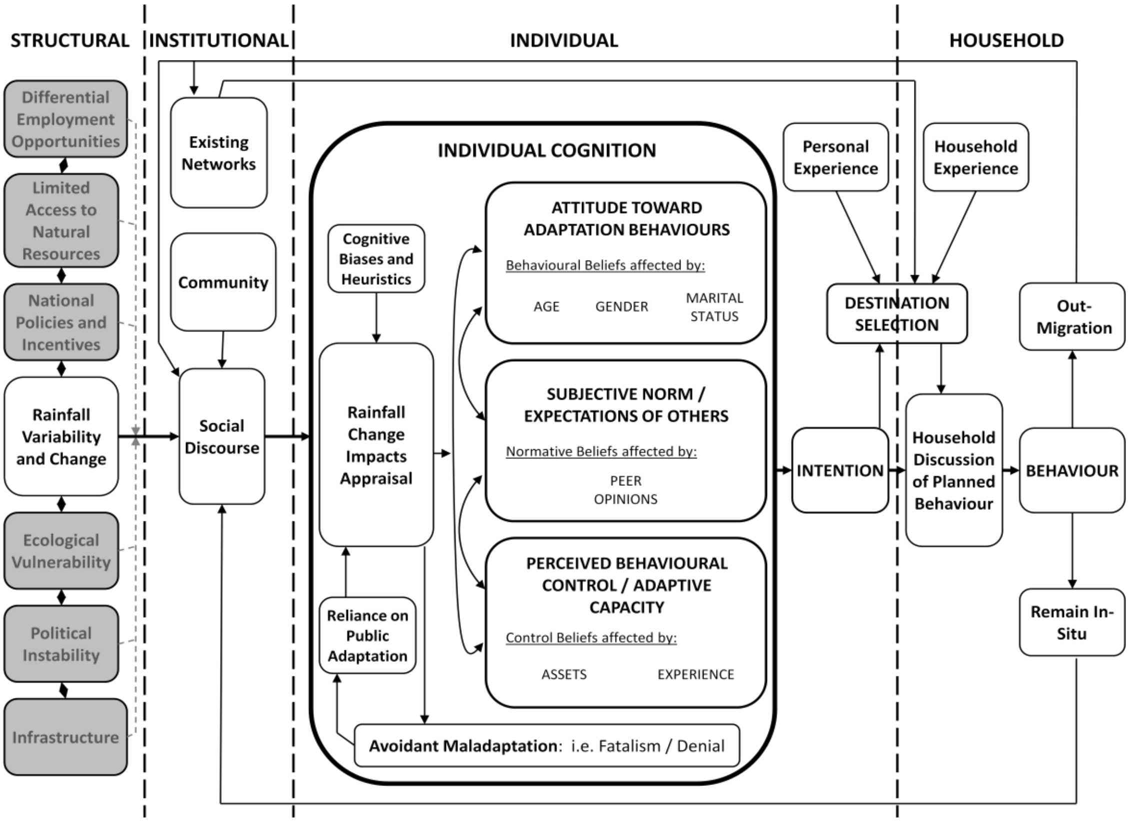

Figure 3.13: Conceptual model of Migration Adaptation to Rainfall Change (MARC).

The MARC model presents a number of developments over the RACC model. The most obvious of these are the narrowing of the climate component of the model to focus on rainfall variability and change and the addition of further structural components that can motivate migration both individually and in combination. Although the key structural component considered by the model is that of rainfall variability and change, the model presents those structural components (greyed) that may also cause migration but are outside the direct scope of this research. Within the individual cognition component of the MARC model a *rainfall change impacts appraisal* has been included that allows the individual to assess the impacts of the rainfall changes they are witnessing upon their livelihoods. In tandem with the cognitive biases and heuristics, avoidant maladaptation and reliance upon public adaptation components included in MARC, the rainfall change impacts appraisal is included in place of the *climate change risk appraisal* included in the PACC model seen as Figure 3.9. A further change seen in MARC is the reduction of the number of components included in each of the Theory of Planned Behaviour components included in the individual cognition component of the conceptual model.

An individual’s attitudes toward adaptation behaviours are, in the MARC model, restricted to being affected only by their age, gender and marital status. In the same way, their subjective norm is restricted to simply an assessment of the opinions of their peers, while perceived behavioural control is assessed on the basis of the individual’s assets and experience only. Although the RACC model included further components that are important considerations, the MARC model is intended for direct translation into the AMARC models. As such, in the same way that bounded rationality limits the information that a modelled individual can use in the analysis of their surroundings, the components that can be incorporated into an ABM are limited to those for which comprehensive data is available and the desired complexity of the model permits.

The final developmental change made for the MARC model when compared to the RACC model is the more transparent inclusion of a social network at both the institutional level in the form of peers and at the household level in the form of family members. Along with an agent’s own personal experience, the agents with whom they are networked contribute to the individual’s destination selection when considering migration as an adaptation strategy in the face of rainfall change. The final outcome of the MARC model is, like the RACC, the development of a behavioural intention towards adaptation options. As a result of household level interactions regarding the planned outcome, a final behavioural action is decided upon and undertaken. If the final action involves migration away from the origin location, information of this action then feeds back into the institutional level social discourse and plays a part in the later decisions of other agents.

3.9 Simplified Conceptual Model

For the purpose of producing an ABM of rainfall induced migration in Burkina Faso the MARC model provides a strong conceptual basis. In the actual translation of the conceptual MARC model into the agent based models of migration adaptation to rainfall change (AMARC) however, not all components are incorporated due to the need to retain an appropriate degree of model simplicity to aid effective analysis while including sufficient complexity to generate emergent phenomena. In order to construct an agent based model that generates results that can be traced back to their causal origins it is important to achieve a balance between realistically complex model elements and interactions and a simplistic enough model framework for effective analysis to be performed. As such, in translating the MARC model into the AMARC agent based models the simplified version displayed as Figure 3.14 is used.

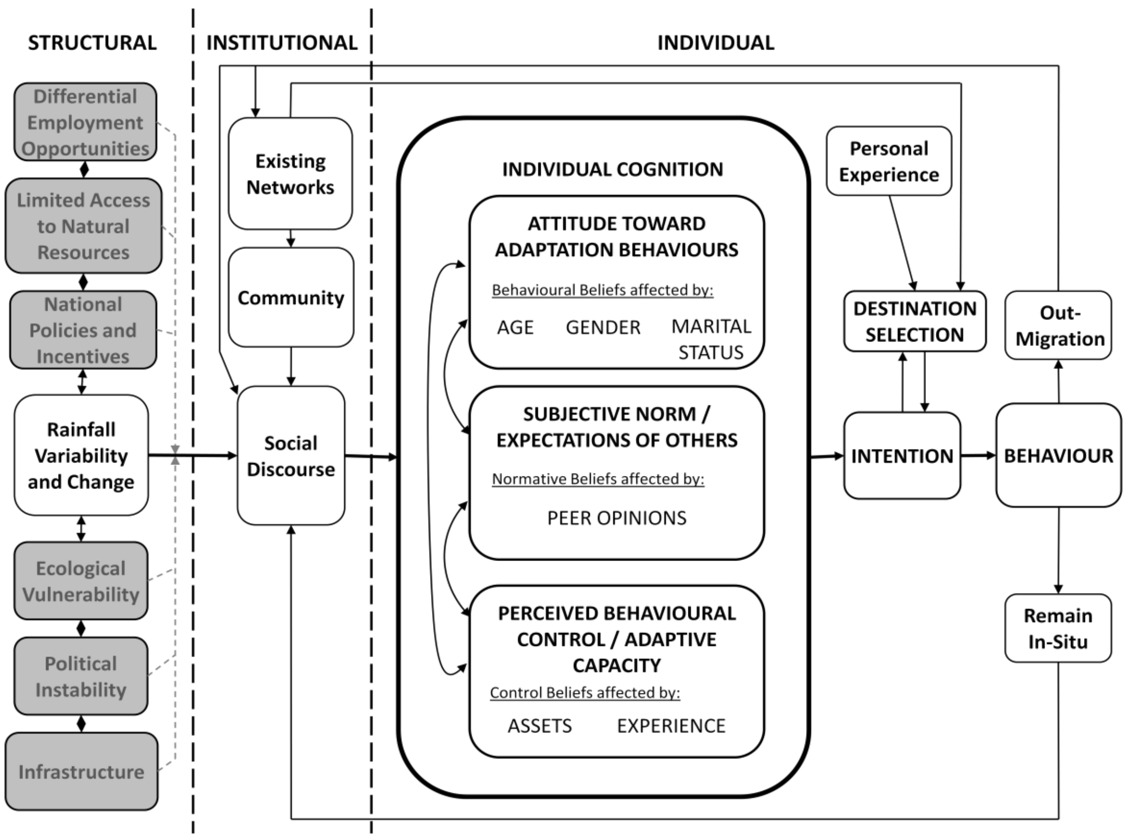

Figure 3.14: Simplified conceptual model of Migration Adaptation to Rainfall Change (SMARC).

The most significant difference between the MARC and SMARC conceptual models is the absence of the household level in SMARC. This results from both the desire to prevent over-complication of the model and the lack of evidence as to the nature of household level interactions over the migration decisions of individuals in Burkina Faso. The process of simplification has also led to the removal of the separate process of *rainfall change impacts appraisal* and its associated components from the individual cognition shown in MARC. The impact appraisal is not present in the simplified model due to the desire to avoid over-complicating the migration decision of agents within the final model. Although not explicitly stated in either the conceptual model or the final ABM, an impacts appraisal is implicitly incorporated into the 'attitude' component of an individual agent's cognition where behavioural beliefs towards each adaptation option include consideration of the rainfall change being experienced. Including a separate impacts appraisal in the ABM would construct a level of complexity beyond that useful to the successful development of behavioural intentions from the structural basis contributed by the theory of planned behaviour.

3.10 Summary

This chapter addresses the conceptual development necessary to construct an appropriate agent migration decision-making process within the final ABM. Drawing upon contributions from the fields of climate change migration, climate change adaptation, migration decision-making and social psychology both an idealised conceptual model and a simplified framework more suited to translation into an ABM are presented. Chapter 5 describes the process of translating the Simplified Model of Adaptation to Rainfall Change presented here into a working ABM. From the simplified migration adaptation to rainfall change (SMARC) conceptual model therefore, the ABM that forms the basis of this thesis can be developed. Chapter 4 describes the research methods and resources employed to develop the conceptual basis presented here into the AMARC agent model described in Chapter 5. Developing the ABM from this conceptual standpoint permits the model structure to have a theoretical basis developed from previous advances in the fields of migration and climate adaptation as well as contributions from social psychology through the inclusion of the theory of planned behaviour.

Chapter 4

Research Methods and Resources

4.1 Introduction

In order to fulfil the aims of this research, a combination of quantitative and qualitative approaches have been adopted to produce an agent based model (ABM) that can simulate the influence of changes in rainfall variability upon human migration in Burkina Faso. It is generally considered that the migration of people, be it in West Africa or elsewhere in the world, can be thought of as a highly complex and multi-causal phenomenon that is largely dependent upon the context, circumstances and motivations of the individuals making the decision. This research adopts a ‘hypothetico-deductive’ (Popper, 1972) approach whereby the final agent-based simulation is designed to show how an external change, such as rainfall, should in principle affect the multiple mechanisms affecting the migration decisions of groups of individuals. Such a model can then be tested against observed reality.

Although a number of definitions exist as to the precise nature of agent-based modelling and what sets it apart from other modelling techniques, from the viewpoint of practical applications, it can be defined as a decentralised, individual-centric (as opposed to system level) approach to model design. In modelling a complex process such as the choice made by a human decision-maker to migrate or stay under given conditions, the notion of individual agency is central to the simulation process in an ABM. As well as designating structural/system level components, when designing an ABM, the user must identify any active units of the model: agents, or software entities that are capable of action as a result of agency. These may be, for example, people, animals, organisms, companies, projects, assets, vehicles, products, etc. In the case of the ABM developed by this research there are five sets of active entities/agents, representing the populations of five model zones of Burkina Faso: Ouagadougou; Bobo Dioulasso; Sahel; Centre; and Southwest. After identifying the active entities of a model, the user can then define the behaviour of those entities using controls such as reactions, motivations and memory.

By placing the agents in a particular environment, in this case that of Burkina Faso, and establishing connections and processes of influence between both the agents themselves and the agents and their environment, the notion of an ABM is complete. Although far more complex to achieve in reality, once this stage is reached, running the resulting simulation may reveal unexpected global (system level) behaviour that emerges as a result of the interactions of many individual actors working to achieve their own goals. It is this emergent behaviour that is considered to be one of the key benefits of using agent-based modelling techniques.

Developing any computer simulation of a real-world phenomenon requires in-depth investigation of the event in order to create an appropriate portrayal of the underlying process. In order to gain the full picture where migration decision-making in Burkina Faso is concerned, two distinct avenues of investigation were pursued. The first of these was a quantitative exploration into the migratory habits of Burkinabé people through the analysis of data from the Enquête Migration, Insertion Urbaine et Environnement au Burkina Faso (EMIUB), a nationally representative survey carried out in Burkina Faso in the year 2000. The second involved a two month period of conducting focus group interviews with Burkinabé people living in different regions of Burkina Faso in early 2009. Although the primary aim of the fieldwork was to conduct the 30 focus group interviews, it also allowed extensive informal observation of daily life in Burkina Faso so that a comprehensive notion of the modelled environment and phenomenon could be gained. One of the key methodological advantages of using an agent-based modelling approach is the ability to include social interactions between agents and explore their impact upon an agent's world-view and personal motivations. As a result, another advantage of the time spent in Burkina Faso was the opportunity to observe interactions between individuals in the communities visited and question people on the impact of societal views and exchanges upon their own actions.

The conceptual Model of Adaptation to Rainfall Change (MARC) presented in Chapter 3 was constructed by developing previous migration and adaptation models, such as those presented by Grothmann and Patt (2005) and McLeman and Smit (2006), to incorporate the Theory of Planned Behaviour and other cognitive limitations such as bounded rationality. The process of breaking agent cognition down into discrete components for inclusion in the conceptual model enabled identification of what information regarding agent actions and interactions could be derived from the two primary information gathering approaches: analysis of the EMIUB data and focus group interviews in the field.

Following the process of conceptual model development outlined in the previous chapter, the core structure of the methodology followed by this research involved a number of steps. The first of these was the initial analysis of the EMIUB dataset made available to this research by the collecting institutions. The main aim of the analysis was to identify the scope of the dataset as a record of individual migration histories in Burkina Faso. By using existing theory to develop the cognitive structure of the model early on, the subsequent process of field interviews could be more easily structured to incorporate questions that could validate theoretical findings and fill any information gaps revealed through consideration of the cognitive basis and the information derived from EMIUB data analysis. The next step was therefore to conduct a series of 30 field interviews in Burkina Faso based on the information identified from the theoretical model development as required to construct the ABM.

Through the combined inputs of both the literature-based theoretical model development and the series of field interviews, rules of behaviour governing agent action could be assigned to different classes of agents in the model. This process of parameterising the rule base of the ABM was perhaps the most crucial aspect of the methodology. A model, by definition is an abstract representation of a process. As such, the value of any model is limited by the representativeness of the parameters used and the appropriateness of the ways in which they are deemed to interact. The availability of the vast, and rare, EMIUB data for Burkina Faso was instrumental in shaping the manner in which model design and parameterisation took place with agents being endowed with attributes that represented real world EMIUB interviewees. The EMIUB data was also used as a means of empirical parameterisation of the tendencies of different types of agents towards migration under different rainfall conditions. Due to the availability of the EMIUB data, the period of field interviews performed in Burkina Faso were used more as a ground-truthing exercise and permitted the collection of the kind of information that could have been used to develop what An (2012) described as experience- or preference-based rules if the need arose.

Another feature of the modelling process that was largely affected by the presence of the EMIUB data was the process of validation that could be performed in order to ascertain the ability of the model to explore the process of rainfall migration that was under scrutiny. The advantages and disadvantages of: a) using the entire EMIUB dataset to both parameterise and validate the model; or b) using a proportion of the dataset to parameterise and the remainder to validate was much discussed in the methodological development phase of this research. However, rather than follow the type of procedure that would be followed if the research were to follow a neural networks approach (option b), it was decided that it was advantageous to the output of the research and, in particular, its application as a predictive tool, to use the entire dataset for parameterisation. As such, an alternative means of interim validation was decided upon that, in addition to allowing a comparison of the model outputs with the observed data, would allow a proportion of the EMIUB data used in parameterisation to be 'thrown away' in order to test whether the model retained its validity. On this basis, the validation of the AMARC model was permitted from both a full-data (30 year migration history) and partial-data (10 year migration history) perspective and their different validation outputs compared. Although commonly used in the development of an ABM such as AMARC, parameter tuning (the adjustment of model parameters to attain a 'best fit' was not performed with any model parameter prior to validation.

Before the process of model development, parameterisation, verification and validation could be undertaken however, the most appropriate modelling software for the task had to be selected and a basic demographic model of Burkina Faso (with no migration decision-making component) developed. The demographic model of Burkina Faso was thus developed to replicate United Nations Population Division (UNPD, 2011) recorded demographic changes through appropriate agent birth and death rate functions. This demographic model was then used as the basis from which the agent model was developed through the inclusion of agent migration decision-making and appropriate agent-agent and agent-environment interactions. The following sections outline in more detail the processes followed at each step in the research methodology.

4.2 EMIUB – Initial Data Analysis

The data source used by this research is that collected by the Migration Dynamics, Urban Integration and Environment Survey of Burkina Faso (*Enquête Migration, Insertion Urbaine et Environnement au Burkina Faso"*) (Poirier et al., 2001). The survey, conducted in the year 2000 by the Demography Unit at the University of Ouagadougou (UERD), the Demography Department at the University of Montreal, and the Centre d'Etudes et de Recherche sur la Population pour le Développement (CERPOD), is nationally representative and comprises 4,258 households and 8,647 individuals aged between 15 and 64 at the time of the survey. Beauchemin and Schoumaker (2005) report that the questionnaire covered a number of topics, including migration, employment, marital and birth histories. In particular, the data includes a complete migration history from the age of 6 for each surveyed individual. These histories ranged from individuals who had never left their place of birth to a male from the southwest of the country who was aged 63 in the year 2000 and had relocated 21 times and changed jobs 11 times over the course of his migration history. With individualised migration trajectories spanning thirty or more years, the EMIUB data is almost unique for Africa and presents a valuable asset to this research.

The process of analysing the EMIUB data was necessary as the first step in both gaining familiarity with the migration histories of Burkinabé people and investigating the trends and themes evident in the data. One of the major tasks necessary in this process of analysis was the identification of what information was available from the dataset and what information would need to be gathered during the planned period of field interviews. The EMIUB data includes information on the geographical coordinates mentioned by respondents to the survey. As a representative national survey, these coordinates refer to locations across the whole of Burkina Faso. The geographical extent of the survey is displayed in Figure 4.1 where each unique location referred to by one or more respondent is identified by a marker and a reference number.

Figure 4.1: Screenshot from Google Earth showing the boundaries of Burkina Faso and neighbouring countries and each location referred to by a respondent to the EMIUB survey. Locations uploaded into Google Earth using a .kml file add-on.

One of the key pieces of information that it was hoped the EMIUB data might shed light upon for the purposes of this research were the motives for migration given by respondents. Research investigating the role of rainfall in the migration decision would greatly benefit from a detailed record of the motives given by individuals for their historical migrations. As such, any direct references to rainfall through mentions of phenomena such as drought or flood could be analysed along with indirect references such as records of bad harvest yields. Table 4.1 and Figure 4.2 display all data recorded by the EMIUB survey on motives given by respondents for relocations related to changes in both employment and residence. Over the full 47 years of retrospective migration history data available, this results in a total of 26,851 relocations for which motive information is available. Within these listed motives 179 different reasons for migration were recorded by the EMIUB survey. As a result, the motives presented in Table 4.1 and Figure 4.2 are grouped into 10 broader categories.

Motive:	Number:	Percentage of Total:
Family	11,278	42.0%
Work	3,980	14.8%
Money	2,989	11.1%
Housing	2,298	8.6%
Study	1,842	6.9%
Return	1,789	6.7%
Independence	1,152	4.3%
Agriculture	663	2.5%
Other	526	2.0%
Health	334	1.2%

Table 4.1: EMIUB data on the individual motives for migration cited by respondents.

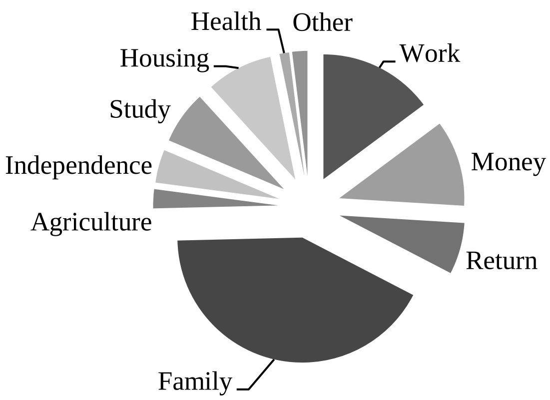

Figure 4.2: Proportional representation of the EMIUB data on the individual motives for migration cited by respondents.

It can be seen from the results displayed in Table 4.1 and Figure 4.2 that by far the most common category of motives for migration cited by respondents were related to Family (42% of total). Specific motives within the Family category include marriage, helping parents/inlaws, the death of a parent or child, and rejoining a spouse. Of these, the most common, and the main contributor to the status of Family reasons as the primary motive category, is marriage, cited 6,757 times. The second largest category of motives cited is Work, within which the majority of motives relate to new or changing contracts, passing exams and changing ownership/ management of companies. Unlike the motives listed that fall within the Family category, no one motive dominates. Instead numerous motives are mentioned a similar number of times, the marginally most common of which is job postings. The third most commonly cited motive category, Money, is dominated by references to both seeking money and seeking better welfare.

The motive category considered most likely to include any reference to rainfall is that of Agriculture within which only 2.5% (663) of recorded motives fell. The most commonly cited of these referred to the general wish to raise crops or cattle. However, one of the agriculture related motives for migration cited by respondents translates to "as the rains stopped, there isn't any more soil". However, this, the only direct reference to rainfall and its impact upon the ability of people to inhabit an area, was only cited by respondents as the motive for migration 5 times out of the 26,851 responses given. As well as this direct reference to rainfall there are three potential indirect references to rainfall conditions also made by respondents that fall into the Agriculture category. The most common of these translates as, "bad harvest/famine" and was mentioned 66 times by respondents. Another vague reference to rainfall, this time more to the structural conditions of the location than a climatic variation, is that motive which translates as, "because here you cannot cultivate well". This motive is referred to by respondents a total of 11 times throughout the EMIUB data. The final indirect reference to rainfall made in the Agricultural motives category translates as, "retreat of the gardening land" and is cited a total of 3 times.

Within the Agriculture category of motives cited by EMIUB respondents, a total of 85 of the total of 663 can be deemed to relate loosely to rainfall. Outside the Agriculture category, one other cited motive can also be considered to relate to rainfall. Categorised as falling within 'Other', this motive for migration translates to, "lack of water" and is cited by 15 migrants. Of the 26,851 motives cited for migrations recorded by the EMIUB survey, 100 (0.37%) therefore relate to rainfall. As discussed in Chapter 2, it is generally considered that people worldwide migrate for numerous, varied and interconnected reasons, and a single statement intended to capture one's motives for migration will rarely encompass the complexity of the factors pushing and pulling a person from one place to another. Despite the remarkably small number of references made to rainfall as the motive for migration in the EMIUB data, it can be assumed that rainfall is likely to have played a part in many more migration decisions than just the 100 recorded occurrences. For example, many of the references made to a change in employment status or seeking new employment may be partly due to changes in rainfall in one location but, in the eyes of the migrant, rainfall may not be the primary motive for migration. Instead, the economic circumstance an individual finds themselves in, perhaps as a result of rainfall conditions, may be considered the primary driving force behind the recorded relocation.

Due to the small number of references to rainfall as the motive for migration in the EMIUB data, and the difficulty of elucidating the role of changes in rainfall variability in causing other more often cited motives, there is little advantage to be gained through further analysis of the migration motive data obtained from the EMIUB survey. Although information on the migration motives of surveyed individuals is of limited use from the perspective of this research, the vast array of information contained within the EMIUB dataset is invaluable to the development of an ABM. The primary value of the data to this research is the information relating to the attributes of individuals seen to migrate at different points in time. In their analysis of the role of rainfall on the first out-migration in Burkina Faso, Henry et al. (2004a) used the EMIUB data to consider the factors affecting the first departure of an individual from their village. The authors found no evidence of an effect of rainfall conditions on the risk of first migration from rural areas when no distinction by destination or duration was made. They surmised that, overall migration behaviour in Burkina Faso was not very responsive to environmental factors as measured by rainfall variables but rather depended upon individual characteristics which, when taken into consideration, prove critical in measuring a relationship between rainfall conditions and the risk of leaving the village for the first time. The limited value of the migration motive information contained within the EMIUB dataset is reinforced by Henry et al.'s statement that the overall lack of a relationship between rainfall variability and migration agrees with results from the 1974-1975 National Migration Survey (Coulibaly and Vaugelade, 1981) where only 4% of respondents declared that they had migrated because of the severe drought occurring in the region at that time.

The retrospective nature of the EMIUB survey directly affects the temporal nature of the migration data it presents. Conducted in the year 2000, the survey covers only individuals that were alive and present in the survey locations at the time of interview. The age of respondents ranges from 15 to 64 years and is intended to record migration histories for each individual from the age of 6 years onwards. As such, the earliest possible record of migration in the EMIUB data should be 1942. However, as a result of the age profile of individuals, intended to be representative of the communities being surveyed, fewer records are available in the data for older agents. As such, the retrospective extent of the migration history recorded by the EMIUB data is restricted by the age profile of the respondents. Figure 4.3 displays the age profile of the 8,647 respondents to the EMIUB survey.

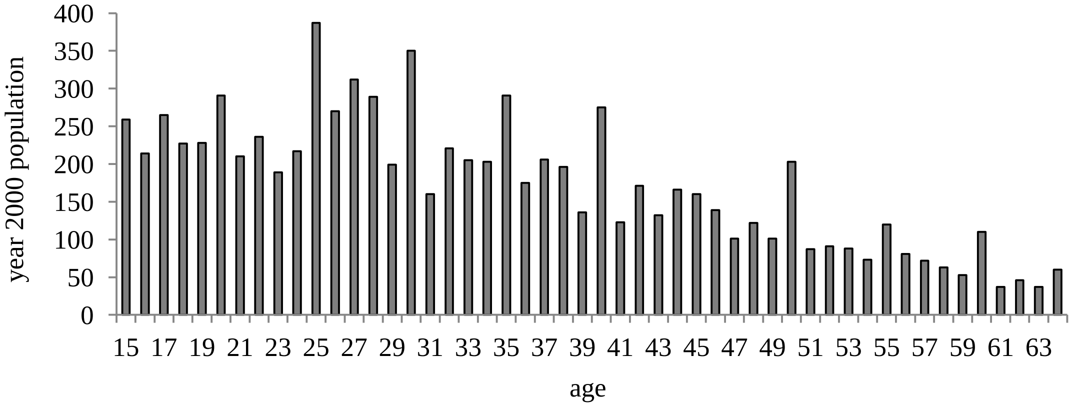

Figure 4.3: Age profile of individuals surveyed by the EMIUB.

It can be seen from Figure 4.3 that there is a general trend of decreasing numbers of individuals recorded by the EMIUB survey with increased age. This is due to the retrospective and representative nature of the data and the relatively short life expectancy of Burkinabé people (currently reported by the UNPD (2011) as 57 years for women and 55 years for men). As such, the migration histories recorded by the survey will, as a function of the population interviewed, include a migration multiplier effect through time. The more individuals who are old enough to have been of an adequate age to migrate at any point in time, the more migration events will be recorded in the data. Figure 4.4 displays the number of migrations mentioned by all respondents to the EMIUB survey over the appropriate retrospective period.

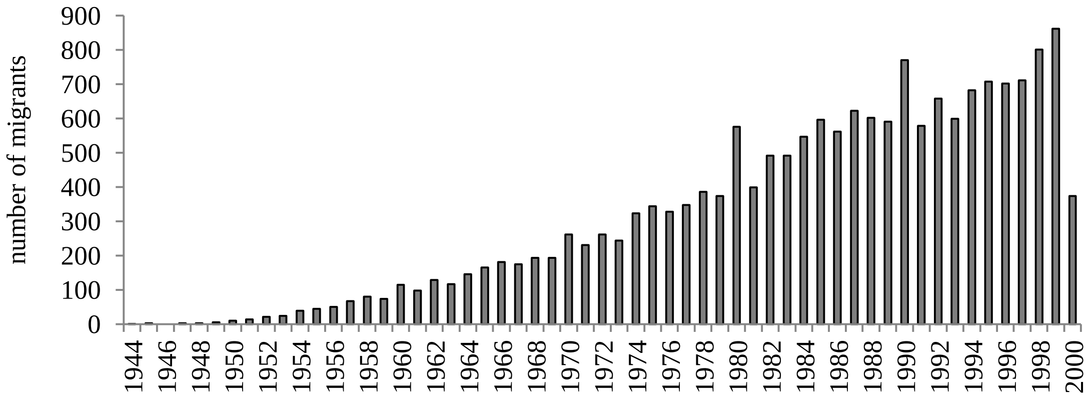

Figure 4.4: Migration profile recorded by the EMIUB survey between 1944 and 2000.

As anticipated, Figure 4.4 displays a general pattern of the number of recorded migrations increasing over time towards the date of the survey in 2000. The number of migrations recorded ranges from 1 in 1944 to 862 in 1999. A significant drop in the number of migrations can be seen in the year 2000 due to that being the survey year and therefore incomplete. The nature of the migration data as increasing over time presents a challenge for this research in terms of the process of data analysis required to inform ABM construction. Rather than an observed record of actual migration in Burkina Faso in each year, the EMIUB data is instead a retrospective history recounted only by those still alive and present at the time of the survey. Any individuals who were deceased or had migrated at the time of the survey are thus not included in the data. As such, in performing data analysis it is important to remember that the migration data available should not be considered in real terms but as a proportion of the population upon whom data is available at the time in question.

Despite missing data on individuals who had migrated at the time of the survey, the retrospective nature of the EMIUB data should enable a relatively complete historical record by including individuals who were active migrants in previous years. Even if the then most active migrants within the population were absent from the record, the migration tendencies of such individuals should still be reflected in the historical record. By looking at the age structure of the surveyed individuals presented in Figure 4.3 it is proposed that the real impact of the potentially reduced record of year 2000 active and absent migrants is minimal. Many of the individuals surveyed in 2000 fall into the approximate age category within which migration is generally perceived to be most likely. However, in order to gain further insight into the existence of such a phenomenon, analysis of the gender distribution of survey respondents can be undertaken. A total of 53% (4,571) of all individuals surveyed by the EMIUB were females with 47% (4,076) males. The official UNPD (2011) year 2000 Estimate Variant sex ratio is 97.9 males per 100 females. This should result in a population that is 50.5% females. The marginally higher percentage of females surveyed by the EMIUB may therefore suggest the existence of both the demographic phenomena identified by the United Nations and the aforementioned absence of some male migrants at the time of the survey. Along with age and gender information, the final primary demographic component clearly evident in the EMIUB data is the marital status of the surveyed individuals. Figure 4.5 displays the data relating to the marital status of respondents in the year 2000.

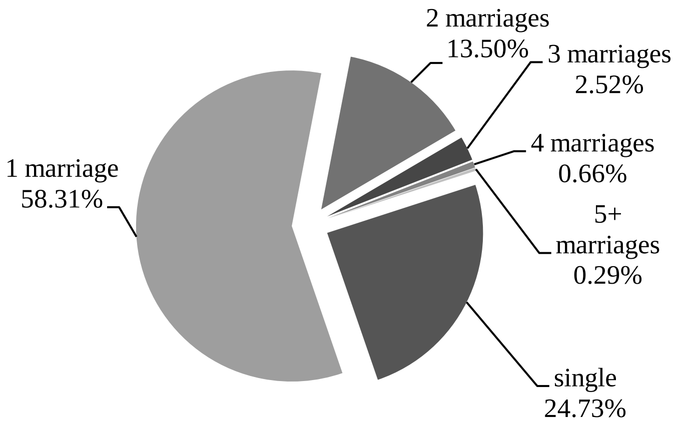

Figure 4.5: Percentage marital status of individuals surveyed by the EMIUB in 2000.

It is evident from Figure 4.5 that the most common marital status of surveyed individuals in Burkina Faso in 2000 was married (with one spouse). Meanwhile, 25% of individuals were single at the time of the survey. A total of 13% of individuals had married twice while only 4% had married more than twice. Due to the limited information provided by the EMIUB data on rainfall-related motives for past migrations, the key benefit that can be drawn from the dataset is the annual migration record and temporal migrant attribute information it provides.

4.3 Field Interviews

It is useful to approach fieldwork intended for ABM data collection with an idea of the conceptual basis of what is being investigated. From such a vantage point data collection undertaken in the field can be guided by the principles presented through prior theoretical advances. However, although this basis can be used to inform the interview process, to ensure constructive and accurate model development, it is important not to approach field interviews with a preconceived bias as to the expected findings. When conducting interviews intended to inform the development of an ABM it is therefore possible to guide interviewees towards the issues being investigated (which may be informed by theoretical developments such as MARC) but important to refrain from leading their responses. In order to avoid purely top-down development of a model, it is necessary to conceal from respondents the outcomes that you anticipate from the interview component of the research.

The process of conducting a series of focus group field interviews across Burkina Faso required considerable logistical planning. In order to identify which locations in Burkina Faso would be visited and focus group interviews carried out, further analysis of the EMIUB data was performed. By looking at each of the locations listed in the migration histories of the 8,647 respondents of the EMIUB survey it was possible to identify the twenty most commonly cited locations. These were then used as a guide in selection of the most appropriate regions to visit. A large proportion of the top twenty most commonly cited locations in the EMIUB data were situated in the centre of Burkina Faso, in the close vicinity of the capital, Ouagadougou. Another cluster were located in the Southwest in and around the second largest city, Bobo Dioulasso. A third and considerably smaller cluster was located in the far southwest near the town of Banfora. The remaining locations were found distributed both in the northern Sahel region and to the north east and north west of Ouagadougou in the central plateau area. According to the distribution of commonly cited locations across Burkina Faso, it was therefore evident that, in order to fulfil the aims of the fieldwork component of this research, numerous regions across Burkina Faso must be visited.

A second factor considered in the process of selecting appropriate locations for focus group interviews was the rainfall gradient referred to by Henry et al. (Henry et al., 2004a) (Figure 4.6). This gradient divides the country into four zones lying approximately north to south with the lowest annual rainfall in the northern departments and the highest rainfall in the south-western tip. It was therefore decided that the locations visited during the fieldwork component of this research should both correlate well with those identified as common to migrants surveyed in the EMIUB and fall within all four of the distinct rainfall zones identified by Henry et al. By visiting each of the four rainfall zones in Burkina Faso both interviews and informal observations could be conducted in locations that experience each distinct level of reported rainfall.

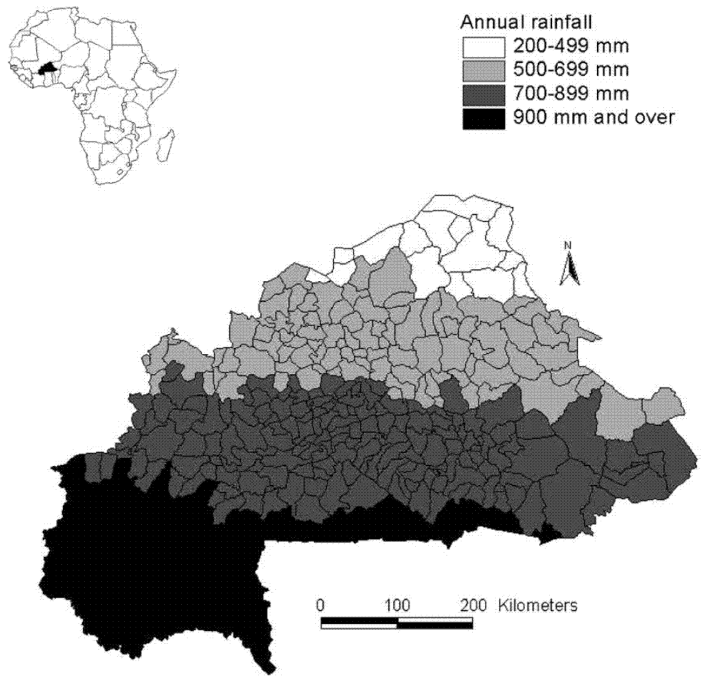

Figure 4.6: Rainfall gradient in Burkina Faso. Taken from Henry et al. (2004a, p.246).

As a result of both the location preferences identified from the EMIUB data and the rainfall gradient evident in Burkina Faso, thirty focus group interviews were planned in seven departments across the country. These departments coordinated approximately with the popular destinations of EMIUB data migrants and at least one of these departments was located in each of the four rainfall zones. The departments visited were Dori in rainfall zone 1 (200-499 mm annual rainfall), Djibo in rainfall zone 2 (500-699 mm), Fada N'Gourma, Kadiogo and Ouarkoye in rainfall zone 3 (700-899 mm) as well as Bobo-Dioulasso and Banfora in rainfall zone 4 (> 900 mm). Figure 4.7 displays the location of the departments visited in relation to the rainfall zones illustrated in Figure 4.6. The fieldwork component of this research therefore consisted of thirty focus group interviews conducted in urban and rural locations across Burkina Faso throughout January and February 2009.

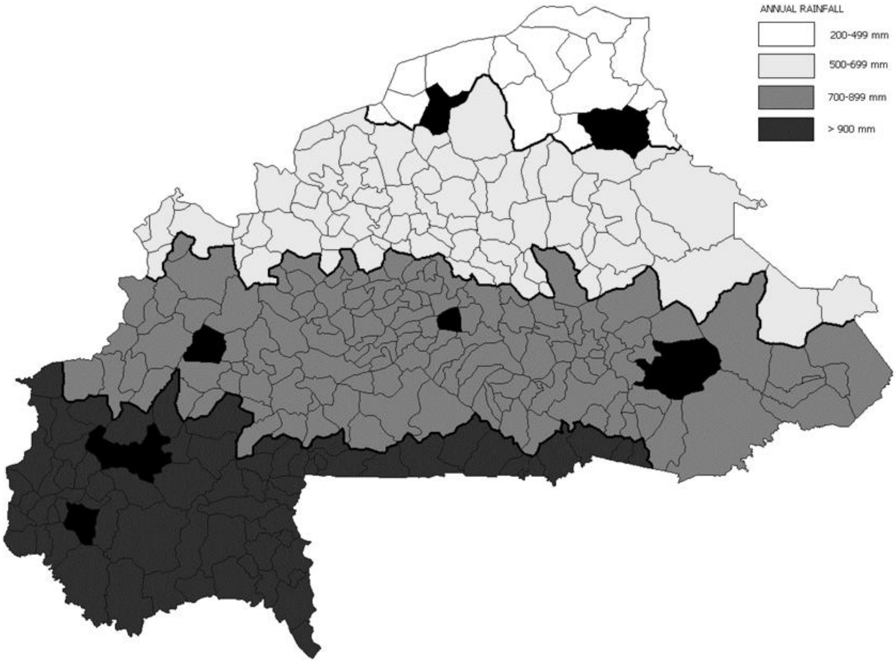

Figure 4.7: Departments of Burkina Faso visited between January and March 2009 (shown in black) in relation to the rainfall gradient identified in Figure 4.6.

As a result of limitations imposed by time and ease of travel within Burkina Faso, coverage of the two northernmost rainfall zones was not as great as anticipated. Access into the Sahelian departments north of Dori was difficult without a means of private transport, limiting the distance into the northern regions that interviews could be conducted. Although some interviews were conducted within Ouagadougou (the centrally-located capital city located in Kadiogo department) and Bobo Dioulasso (the second largest urban area and itself a department), the main focus of the field interview process was more rural locations. Interviews in urban locations were however interesting, particularly in terms of identifying which regions of the country people living in these cities in 2009 had originated from, and their reasons for moving there. As the two large urban centres of Burkina Faso, focus group interviews conducted in Ouagadougou and Bobo Dioulasso were likely affected by the general tendency of people to migrate from rural to urban areas. Although the main focus of this research are therefore those individuals that live in largely rural areas and subsist through small-scale farming, and are therefore most likely to be vulnerable to the impacts of environmental change, interviews were also sought within urban populations.

While the official government language is French, Burkina Faso is reported to have 68 living languages (Lewis, 2009). As a result, conducting focus group interviews in different rural locations around the country posed a significant linguistic challenge. A local translator was hired for the two month period of fieldwork. As well as being fluent in French, the translator was also a native speaker of Mòoré, the most widely spoken of the local languages. In many instances, focus group interviews could be conducted in Mòoré or French with occasional translations of finer points into another language for the benefit of an individual in the group. Responses given to the translator in Mòoré would then be repeated in English. In some instances however, particularly in the more rural locations, only one of the focus group participants was able to speak either French or Mòoré. In these situations the translator would pose questions to the individual with whom he could communicate, who would in turn pose the questions to others in one or more local languages. Answers to these questions would then be returned along the same linguistic train to the researcher and research assistant in English. All focus group interviews were digitally recorded and notes taken by both the researcher and research assistant.

In contrast to a questionnaire that is generally posed to an individual on a one-on-one basis and can be anticipated to generate responses within the confines of the specific topic of reference, the purpose of the focus group interviews was to generate discussions that provided subject information while also enabling the observation of interactions between individuals. By observing such interactions it was hoped that some idea could be gained as to the role of social interaction in defining the role of networked others in the migration decisions of an individual. As a result of the focus group setting of the interviews, the issue posed by the language barrier between researcher and interviewees, and the means of translation used, was likely greater than might have existed using a formal questionnaire technique. However, due to the enormous value of the EMIUB data in providing quantitative information on individuals and their migration histories in Burkina Faso, the purpose of the fieldwork component of this research was not to produce hard data for the purposes of quantification but for the researcher to gain qualitative information on the role of peers in the migration decision and the perceptions of respondents on factors that may facilitate or impede the migration process.

A total of ten initial questions were posed to focus groups. The interviews started by collecting the basic demographic information of each interview participant and then led to questions designed to elucidate information relating to migration when considered on the basis of the Theory of Planned Behaviour. The three core components of the theory are described in Chapter 3 as *behavioural attitude*, *subjective norm*, and *perceived behavioural control*. In the context of migration these components can be considered to be an individual’s attitude towards migration, how they think others consider the migration, and their perception of how easily they can undertake the migration respectively. Questions focussing on social networks were aimed at both understanding the impact of networked peers upon an individual's subjective norm (ease of migration) and the actual use of such migration networks by interviewees.

Appendix 1 displays the briefing sheet and list of questions in both English and French that was used by the translator during interviews. In order to reduce the possibility that interviewees might misinterpret the role of this research as being related to official government or NGO activities, the manner in which each interview was approached was carefully considered. The process leading up to an interview involved visiting the government allocated head of the relevant department to request permission to conduct interviews within the region. This process was aided by an official letter of recommendation from the Director of the Institut Supérieur des Sciences de la Population (ISSP) in Ouagadougou. Once a letter of consent had been obtained from the head of the department, appropriate contacts in surrounding villages were sought. Although not always used, seeking these contacts provided information on reliable sources of interviews in rare instances where people in some villages were unwilling to engage with the interview process. On arrival in villages where no suitable contact was known, the village elder/head would be sought and his permission requested to undertake a group interview.

Requesting permission from the head of a village generally resulted in his involvement in the focus group and his selection of similar acquaintances (male elders often in positions of relative authority within the village) as the other participants. This was not ideal but the involvement of the village head was a necessary step in securing permission for the interviews. To counter the resulting bias, it was requested that each focus group be made up of a cross section of the community, although such a request was rarely heeded, with groups often made up exclusively of older men. Another strategy was to specifically request groups of women for focus groups, although as the researcher, research assistant and translator were all males, these groups could only be requested when a female colleague (researcher from ISSP or local Peace Corps volunteer) was found to accompany the research team.

The means of transport used to access villages was also carefully considered. As most government or NGO activities in Burkina Faso are seen to take place in a village following the arrival of a white four wheel drive vehicle, considerable effort was made to avoid such an arrival. As such, public buses were used to access each of the departments visited in Burkina Faso. Bicycles purchased in Ouagadougou were carried on the roof of each bus and then used to access villages that could not be reached by bus. Arrival of the three person research team on bicycles was met with considerable surprise in many instances but was often a useful ice breaker as water would generally be offered by villagers. Whether or not this manner of approaching villages was successful in avoiding preconceived ideas by interviewees as to the responses they perhaps 'should' give a government agency or NGO who may be assessing the value of providing some form of aid to the community is unclear. However, it was important that interviewees spoke freely of their perceptions on migration without being impeded by possible preconceptions of what the research team might want to hear. For the same reason, rainfall and climate were expressly not mentioned by the researchers unless first mentioned by an interviewee.

Key themes generated from the thirty focus group interviews conducted across the four rainfall zones of Burkina Faso were analysed in terms of their contributions to the consideration of migration from the perspective of the Theory of Planned Behaviour. The full breakdown of these findings into the rainfall zones from which they were generated is displayed in Appendix 2. However, the key findings from each zone are summarised below. At no point were focus group interview participants told that the primary focus of the research was on rainfall and its impact upon migration.

4.4 Themes from Zone 1 "The Sahel"

In the northern zone with the lowest annual rainfall (200-499 mm) focus group interviewees identified age, gender, marital status, employment, previous migration success, level of poverty and reports on migration by others as being the primary components that would affect their attitude towards migration. It was suggested that life in the north of Burkina Faso is hard with more available labour than jobs. Although migration is very common, particularly during dry years, people will remain at home if they possibly can. Migration was therefore reported to be lower during wet years. However, most focus groups reported that it was generally not possible to grow enough food during the wet season to last an entire year. Migration and migrant remittances were therefore described as central to life in the Sahel region.

Focus group participants in Sahel suggested that poor 18-35 year old males were the most likely migrants, particularly if newly married. Men aged 36 to 45 may also migrate under extreme circumstances although this is rare. Beyond that age, men were reported to almost never migrate as they usually have sons who can migrate in their place. Most groups reported that migration within Burkina Faso was the most common and relatively accessible to all due to the low investment in travel required by the migrant. Whether or not the migration proves to be successful is seen as largely down to luck. Migration out of Burkina Faso into neighbouring African countries is considered to be a secondary option that often requires initial internal migration to save enough money to afford the travel and border costs. Such migration is viewed by many in this region to be a bad thing for the local culture as it draws young men away from their homes. International migration is seen as a potentially successful but rare venture.

With respect to the subjective norm component of migration in the Sahel zone, most interview participants claimed that the decision to migrate lies with the migrants themselves with very little input from parents or peers. While this may be true in the case of an individual's actual development of an overall attitude towards a migration option, it is less likely to be so in terms of the more subtle interactions that will affect an individual's awareness of potential migration options and the slight positive or negative feelings towards them that may be associated with such criteria as the person who imparted the information and the manner in which it was communicated. The individual nature of the migration decision described by respondents was also generally referred to in the context of parents trying to persuade their children to stay rather than go. It appears that, in many cases, the hard nature of migration makes parents unwilling to send their children away except under extreme circumstances when there is no alternative. A number of participants did however refer to some circumstances where the male head of the household is the primary decision maker for the family and suggests certain family members migrate. In such circumstances a common approach appears to be to send, for example, three sons away during the dry season with two returning to help with the harvest at home during the wet season. In accordance with the New Economics of Labour Migration (NELM) described by Stark and Bloom (1985) and Taylor (1999), the son that remains away from home contributes to the household income through remittances which provide a positive and stabilising contribution to household income.

With respect to the perceptions of individuals on their own ability to undertake migration, the common theme mentioned during interviews in the Sahel was that, although migration can be expensive, almost anyone can undertake an internal move if they need to. Some mentioned that it was even the poorest people who are most likely to migrate as they have the greatest need. However, longer distance migrations to destinations outside Burkina Faso were described as often harder to achieve and as generally requiring savings or loans to complete. From the five focus group interviews conducted in the Sahel region, the general theme appeared to be that migration was a necessary part of life in the dry area but was not something that was enjoyed or desired by occupants, most of whom referred to a strong tie to their home. Such reference to a strong tie to home may however result from a bias induced by generally interviewing people in their home location. By conducting focus groups with the residents of a migration source area, those present for interview would likely be those who had chosen not to migrate, or had attempted to migrate and failed. As such, the strong ties to home mentioned by interview participants may not reflect the feelings of all people from that location.

4.5 Themes from Zone 2, "Northern Centre"

In the northern part of the central zone a total of four focus group interviews were performed in and around the town of Djibo. Being close to the border of the 200-499 mm annual rainfall zone, responses given during interviews in the 500-699 mm annual rainfall zone were unsurprisingly not greatly dissimilar to those heard in the Sahel zone. The general tendency toward migration referred to by most interviewees appeared to be driven by the need for families to supplement their harvests and incomes through migration due to the inability of people to grow enough food during the wet season to last an entire year. Seasonal internal migration is referred to as a good option for people living in this region while migration to other African countries such as Côte d'Ivoire is considered to be a more dangerous option but one with potentially greater financial return. People who migrate out of Burkina Faso are described as being less likely to return for the wet season. International migration outside Africa is described as being potentially fruitful but a miserable experience that requires existing networks in destination countries to be successful.

The key characteristics of migrants referred to by interviewees in the northern central zone as affecting migration tendencies were age, gender and marital status. Young men aged between 17 and 20 years of age were described as being the most likely to migrate first with men aged between 18 and 35 years making up the majority of migrants from the area. Males beyond the age of 35 years were described as being unlikely to migrate unless they are very poor or have no sons to send in their place. While young married men are likely to migrate, their wives were described as usually remaining at home. Older men meanwhile were said to only migrate during very bad seasons, while men over 60 years of age and married women were described as never moving.

With regard to the influence of others on the migration decision of an individual in the northern central region, a more powerful role of parents was suggested than was heard during interviews in the Sahel. Although parents were reported not to want their children to migrate, it was generally considered an unavoidable necessity and the migration of children was described as an agreement between father and child that could be prevented by the parent if necessary. The influence of friends in selecting a migration destination was also mentioned along with the powerful influence of tales of the successful migration of others.

Interview participants in the northern centre suggested that poorer people are the first to migrate and do so the most, but that their migration is restricted to Africa. By contrast, richer people were described as not necessarily having to migrate but doing so as a means to get richer. Such migration may involve relocating to destinations outside Africa. For poorer people, travel costs were described as being the greatest challenge when migrating. However, it was reported that people will sell what they have in order to pay travel costs. Those who have enough money in this region are described as migrating straight to plantation jobs in Côte d'Ivoire while those who cannot afford direct travel may migrate in steps, earning money along the way to pay for the next leg of their journey. Interview participants in this region suggested that years of low rainfall result in greater numbers of migrants. In extreme circumstances, entire families may relocate if they suffer multiple bad harvest years.

4.6 Themes from Zone 3, "The Centre"

A total of eight focus group interviews were conducted in the 700-899 mm annual rainfall zone, Centre. Most of the locations visited within this region were clearly very different to those seen in the northern reaches of Burkina Faso. The higher level of rainfall was evident in January 2009 from far greener surroundings and more trees than were seen further north. As well as common references to migration in dry years, flooding was also stated as a cause of short term migration within this region.

The general trend towards migration reported in the zone shows similar patterns to those heard elsewhere. Most migration involves individuals leaving their place of residence for seasonal employment elsewhere. However, in the Centre region there is no mention of the urgent need to migrate almost every year as a result of the inability of the people to grow enough food to last the duration of the year. Rather than not being able to grow enough food due to low annual rainfall, reference was made to a need to migrate due to a shortage of land available for farming. It appears that competition for land in this more fertile region is more of a problem than the actual process of growing the crops themselves. Perhaps as a result of this feature of the region, much of the internal migration reported by interviewees was rural-urban migration to Ouagadougou. Migration to other African countries was described by one group of interviewees as the only worthwhile form of migration from their location due to the notion that, if one cannot make a living in their location, the only source of better options is abroad.

The most likely migrants were described by interviewees in this zone as being young men aged between 20 and 35 years, particularly those failing to find employment at home. Young women were also described as commonly migrating for marriage. Older people are described as never really migrating from the zone, even in the worst (lowest rainfall/drought) years when they might be expected to follow younger people and migrate. The poorest people in this zone were generally referred to as the first to migrate, particularly over short distances.

The decision to migrate was described by interviewees in the Centre zone as being related to the migrant's culture. While asking others for their opinions in Bwaba culture was described as being rare, such consideration of the opinions of others is was described as more common in Mossi culture. As such, the migration decision was described by some as being that of the individual alone with profit as the only consideration. By contrast others described it as a family decision, often overseen by the head of the household. In such family-oriented instances, migration of family members was described as being carefully managed to prevent the household being left shorthanded.

References to the cost of migration from the Centre, and the ability of people to afford it, appears to mirror those statements made by interviewees in other zones. It was reported that an individual migrating alone can do so for virtually no cost, particularly over a short distance. Those with the means to do so can travel by bus, although the individuals who need to migrate the most were described as being unlikely to be able to afford the fare and travel by foot, bicycle or other cheap means. Moving an entire family is described as being a very expensive undertaking. One interviewee referred to 2004 when the harvest was very bad. Many families wanted to migrate but were unable to do so as they could barely afford to eat, let alone travel. A step by step form of migration where an individual works their way towards a destination in small, relatively cheap moves while earning on the way was described as a common means of affording longer distance migration. However, most interview participants agreed that, when there was plentiful rain in the Centre zone, there was little need to move.

4.7 Themes from Zone 4, "The Southwest"

The change in vegetation visible between the north and central regions of Burkina Faso was again visible when arriving in the southwest. This region, with annual rainfall of greater than 900 mm, provides opportunities for migrants from other zones in the form of plantation-based employment and borders Côte d'Ivoire, a nation whose economy is largely based upon large scale plantations. A total of five focus group interviews were conducted in the Southwest region where the major causes of migration were described to be poverty and lack of jobs.

Interviewees suggested that one could remain in the Southwest all year as a result of the relative abundance of food, even during years with comparatively low rainfall. Some respondents mentioned the value of dams in both providing year-round employment in market gardens and securing a supply of food during the dry season. Due to the relative abundance of food reported in the Southwest it was suggested that there is usually no need to migrate as a result of low rainfall. However, specific reference was made to the occurrence of floods and their causing entire households to relocate temporarily, and sometimes permanently, to higher ground.

The general trend mentioned by respondents in the Southwest therefore related to migration in search of increased income. Furthermore, most migrants were described as leaving the Southwest in favour of relocating abroad, most commonly to neighbouring Côte d'Ivoire. Use of the Southwest region as a staging post for migrants from other regions on their journey to Côte d'Ivoire was also mentioned. Although migration to destinations outside Africa was mentioned as a very successful means of increasing income, focus group participants described it as a difficult prospect, particularly when relatively good money can be made on the plantations in neighbouring countries. Those considered most likely to migrate from Southwest were described to be young men, particularly those who are unmarried.

The decision to migrate was described by respondents in the Southwest as mainly a personal decision with little or no input from parents and friends. While family and friends were described as not being able to ask another individual to migrate, references were also made to the inability of a parent to prevent the migration of a child. While an individual may be persuaded to stay if there is work available, if not then there are no grounds for one to persuade another to remain. Migration, mostly by young single males, to the most common destination, Côte d'Ivoire was described as very expensive compared to internal migration due to the necessity to pay bribes and transport costs. While such migration is still deemed to be within the reach of an average member of the community, most would consider migration outside Africa to be beyond their means. The general notion mentioned by respondents was that, the further one travels, the more costly the migration. It was agreed between participants in one focus group that it would take an average worker approximately two years to save enough to migrate abroad. Respondents in another group mentioned that one's ability to move depends upon job and income. While a gardener in the region may be able to sell all their stock and migrate immediately, an employee of the gardener may have to save for a considerable time to afford to move.

4.8 Translation of Information and Data

It is evident from the brief outline of the focus group interviews conducted in different regions of Burkina Faso that the lifestyles and migration tendencies of the inhabitants vary considerably. While inhabitants of the dry northern region, Sahel, reported that it was generally not possible to grow enough food during the wet season to last an entire year, those in the wetter Southwest stated that no such necessity to migrate exists due to the relative abundance of food there. While individuals from a region such as Sahel therefore report the need to migrate for survival, those in the Southwest report a similar level of migration but largely for the purpose of increasing household income. Furthermore, while individuals from Sahel may commonly migrate to other destinations within Burkina Faso, most migration is reported by people in the Southwest as being aimed at travel to neighbouring Côte d'Ivoire.

The construction of a standard framework from which the different qualitative migration patterns/tendencies evident across Burkina Faso could be translated into a manner that can be quantitatively assessed was an important step in enabling field interview data to be incorporated into this research. Focus group comments from all rainfall regions that related to external influences of migration and the three theory of planned behaviour components were investigated. The criteria identified for each of these levels of analysis are displayed as Figure 4.8.

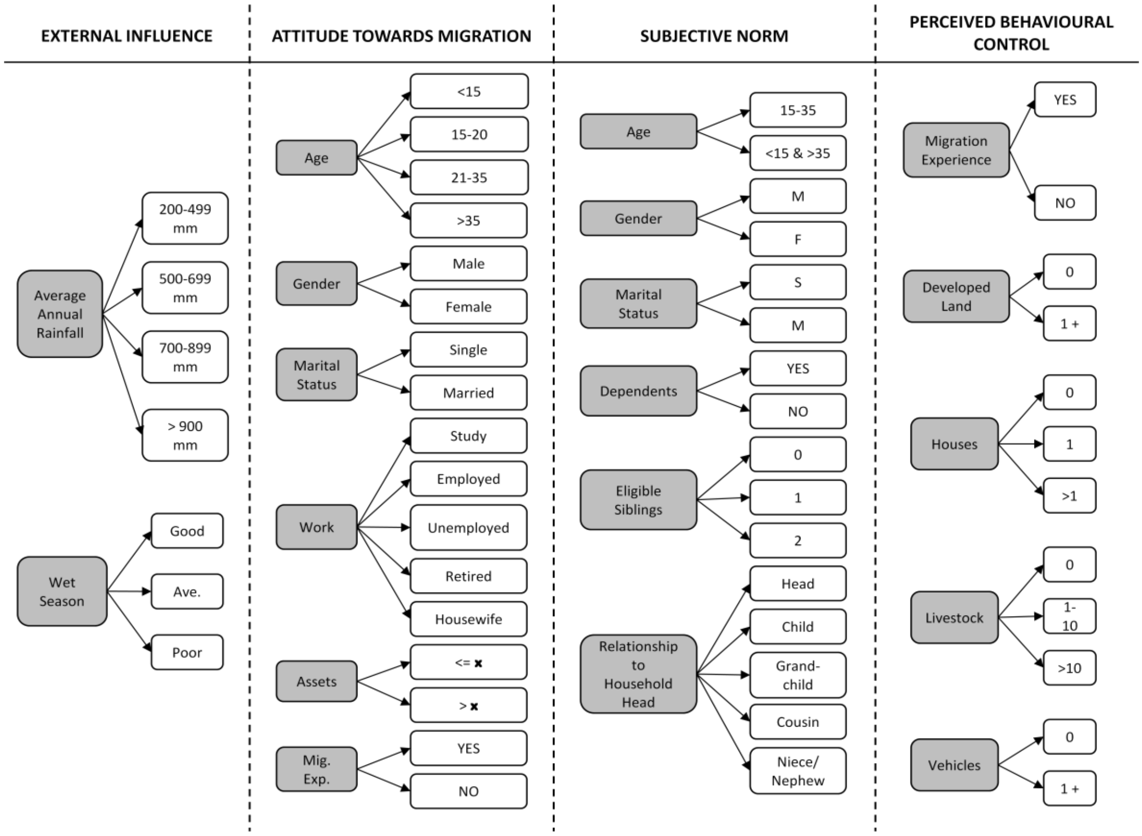

Figure 4.8: Components identified by focus group interview respondents as affecting an individual's migration decision-making.

Figure 4.8 identifies the components referred to by focus group participants from across Burkina Faso as commonly affecting migration. The components are broken down into external influences, factors affecting an individual's attitude towards migration, the factors affecting an individual's subjective norm and the factors relating to their perception of the cost of migration and their ability to invest in a move. In terms of external influences, focus group participants in the northern zones of Burkina Faso mentioned the importance of the harvest yield following a wet season as an important component affecting migration. Furthermore, it is evident from the range of responses gained from each zone that the average rainfall conditions that influence each zone of Burkina Faso play an important part in governing the migration decisions of individuals.

With reference to the attitude of individuals towards migration, focus group participants cited age, gender, marital status, work activity, assets and migration experience as significant determinants. In age terms, participants referred to 15 years being the threshold at which an individual starts to make their own migration decisions. After the age of 15, migrants were described as having differing tendencies towards migration depending upon the age range within which they fall. Crucial differences were described as existing between the age ranges 15-20 years, 21-35 years and 35+ years giving rise to the age categories identified in Figure 4.8. In gender terms, males and females were identified by participants as having different attitudes towards migration. So too were individuals, both male and female, that were single or married. Although different forms of employment were mentioned by participants to be directly linked to the level of income that an individual receives, simple distinctions were made by participants in terms of whether an individual is likely to migrate when employed, unemployed, retired or a housewife. Participants also cited that assets beyond a specific (but varying from location to location) threshold generally enabled migration while previous experience of migration also increased an individual’s propensity to do so again.

The subjective norm, or influence of others upon migration decisions, was referred to by focus group participants as depending largely upon attributes relating to the individual decision-maker. The impact of others upon an individual were described as being dependent upon the potential migrant’s age, gender, marital status, dependents, eligible siblings and relation to the household head. Focus group participants largely agreed that individuals aged between 15 and 35 years were affected by the influence of others in a different way to those aged under 15 or over 35 years. Furthermore, while males and females are subject to different influences, so too are people who are single or married. Different influences were also cited as existing for individuals with other siblings eligible to migrate in their place or with differing relationships to the head of their household.

Finally, Figure 4.8 displays the factors described by focus group participants as affecting their perceptions of the cost of migration or perceived behavioural control. As well as numerous asset components, also cited as affecting such perceived costs was previous experience of migration. Increased experience of migration was reported by respondents to increase the ability of a potential migrant to accurately perceive the cost of planned migration. The asset factors proposed by focus group participants across Burkina Faso as affecting an individual’s ability to invest in migration included owning parcels of developed land, houses, livestock and vehicles.

As a result of the significant contributory factors identified from the focus group interviews conducted across Burkina Faso, the core components contributing to the Burkinabé decision to migrate could be considered. Using the components identified under the structure of the theory of planned behaviour, further analysis of the EMIUB dataset could be undertaken to provide a quantitative basis from which the ABM was developed. The attitude of an individual towards a type of migration was therefore approached from a statistical perspective by considering the relevant components identified in Figure 4.8.

4.9 EMIUB-Derived Attitudes towards Migration

An (2011) reviews numerous agent-based modelling approaches that have been used in simulating human decisions in coupled human and natural systems (CHANS). The author describes nine types of decision models used in the reviewed articles: microeconomic; space theory based; psychological and cognitive; institution-based; experience- or preference-based; participatory; empirical or heuristic rule; evolutionary programming and; assumption and/or calibration-based rule models. An concludes that the models range from highly empirically based to more mechanistic or process-based with both extremes of this gradient having both strengths and weaknesses. While broadly falling within the category of psychological and cognitive modelling as a result of the use of a conceptual model of agent cognition, the model developed by this thesis also adopts an empirical rule-based approach. As a result of the availability of the EMIUB data, an empirical approach is chosen as the preferable course of model development. As such, rather than using theories of behaviour gained from either published academic literature or field research, the rules of behaviour that contribute to the cognitive MARC model presented in Chapter 3 are developed from empirical evidence gained from the EMIUB data. While theories presented in the literature relating to tendencies towards migration decisions in the face of environmental change are seen to contrast with variations in location, constructing rules of behaviour on the basis of empirical data collected in the case-study location avoids such potential misrepresentation. Furthermore, the challenge of addressing the impact of different individual attributes such as age, gender, marital status and origin location on tendencies towards migration can be easily represented in a stochastic manner.

Although field interviews conducted across Burkina Faso were undertaken in a manner that permitted focus groups to be conducted in each of the rainfall zones identified by Henry et al. (2004a) in Figure 4.6, the EMIUB data divides Burkina Faso according to an alternative zonal breakdown. Figure 4.9 displays the zones into which Burkina Faso is divided according to the EMIUB data. While the Sahel and Southwest zones represent those of the 200-499 mm and 900+ mm Henry et al. rainfall zones respectively, the two central zones (500-699 mm and 700-899 mm) are merged into one Centre zone within the EMIUB breakdown. Two further zones are identified within the EMIUB data, the capital city Ouagadougou and the second largest city, Bobo Dioulasso. For the purposes of this research, migration is defined as the movement of an agent from their model zone of origin to any other model zone within Burkina Faso, or out of the country. This contrasts with the definition used by Henry et al. (2004a) where migration is defined as, "a change of residence involving a departure from the village for a duration of at least three months" but enables clearer zonal separation of agent movements as migration. The spatial resolution used in the definition of migration used by this research is chosen in order to focus further upon the role of changes in rainfall variability in each model zone and reduce the complexity of modelled agents by locating them simply in a geographical zone rather than attributing specific coordinates to their respective origins and destinations.

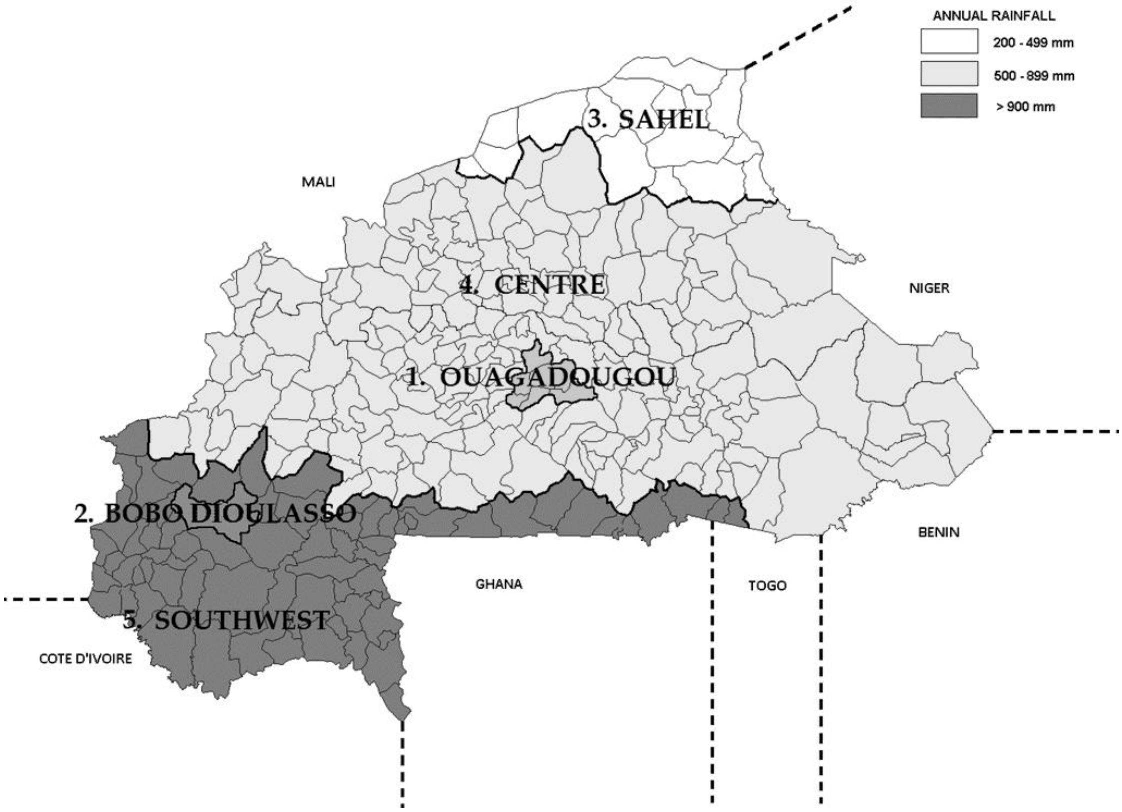

Figure 4.9: Division of Burkina Faso into five zones according to the EMIUB data breakdown.

With Burkina Faso therefore divided into five separate zones, the probability of an individual within each of those zones migrating to one of the alternatives or out of the country could be calculated. The process of translating field interview outputs into a usable framework (Figure 4.8) identified age, gender, marital status, work, assets and migration experience as the key attributes contributing to an individual's attitude towards migration behaviour. While all of these apart from assets are temporally referenced by the EMIUB data only age, gender and marital status were used to calculate behavioural attitude values. By including three different age categories, two gender categories and two marital status categories, a total of twelve combinations of attributes exist for which attitudes towards migration were required. Furthermore, with five potential destination options available to individuals residing in one of five origin locations, a total of twenty five potential origin-destination combinations exist. As a result, by limiting the individual characteristics identified by the field research to just age, gender and marital status, a total of three hundred individual attitudes towards migration options must already be calculated from the EMIUB data. Including two categories for migration experience and four for work would increase the number of attitude values required to two thousand four hundred.

In order to test the value of agent attributes age, gender and marital status as independent variables to be used in the calculation of migration probabilities, a series of binary logistic regressions were initially undertaken to test the statistical relationship between each variable and an individual deciding to migrate or stay. The results of these independent binary logit models are displayed in Table 4.2. When considered as independent variables, from the data record of 171,209 individual records, components of age, age^2 (in order to test the non-linearity of the relationship between age and migration), gender and marital status all showed strong statistical significance in determining migration ($p < 0.01$). Furthermore, the additional variable of origin location, inherently included in migration probability calculations from each of the five model zones, was shown to be independently statistically significant. Using Ouagadougou as the reference category for the logistic regression, the origin zones of Bobo Dioulasso, Sahel and Centre were shown to result in significantly different migration ($p < 0.01$), while Southwest was less significant ($p > 0.10$). Finally, using dry conditions as the reference category, rainfall was shown to be independently not significant in determining migration ($p = 0.565$ and $p = 0.977$ for average and wet conditions respectively). The full outputs of each binary logit model are displayed as Appendix 3A.

Independent Variable	Odds Ratio	P <	95% Confidence Interval	
age	1.208	0.000**	1.193	1.223
age2	0.996	0.000**	0.996	0.996
gender_2	0.773	0.000**	0.745	0.802
marital	0.807	0.000**	0.776	0.840
origin_2	1.123	0.000**	1.052	1.198
origin_3	1.147	0.000**	1.078	1.221
origin_4	1.104	0.002**	1.038	1.175
origin_5	1.063	0.098*	0.989	1.144
rainfall_2	0.988	0.565	0.947	1.030
rainfall_3	0.999	0.977	0.954	1.046

Table 4.2: Individual variable binary logit model results from an EMIUB record of 171,209 migrating and non-migrating individuals between 1970 and 1999. ** p = < 0.01. * p = < 0.05.

When used in a multivariate binary logit model however, the significance of some migration determinants changed as a result of the implicit impact of some variables changing the standalone relevance of others. The results of the multivariate binary logit models are displayed in Table 4.3. Individual variables of age and age^2 remained highly significant ($p < 0.01$) with the relevant odds ratios showing a U-shaped relationship between age and migration so that migration increases with age but only to a certain point. Using males as the reference category, gender was also seen to retain strong significance ($p < 0.01$) so that the likelihood of a female migrating was significantly lower than that of a male when considered alongside all other variables. However, when considered in this manner, marital status lost some of its significance ($p < 0.05$), likely due to the difference in migration behaviour of single and married individuals being significantly affected by gender. Furthermore, the significance of origin locations as a determinant of migration increased with the least significant difference seen from one origin being Southwest ($p < 0.05$). Finally, the impact of rainfall as a determinant of migration was seen to increase appreciably when considered as part of a multivariate binary logit model ($p = 0.268$ and $p = 0.371$ for average and wet conditions respectively) but did not reach overall significance. On this basis, individual variables of age, gender, marital status and origin location were seen to be appropriate determinants of migration for use in the calculation of behavioural attitude probability values. Furthermore, the fact that the significance of rainfall as a determinant was seen to increase when considered alongside these variables suggested that they were appropriate proxies through which the role of changes in rainfall variability in migration decision-making could be considered. The full outputs of each multivariate binary logit model are displayed as Appendix 3B.

Independent Variable	Odds Ratio	P <	95% Confidence Interval	
age	1.202	0.000**	1.193	1.223
age2	0.996	0.000**	0.996	0.996
gender_2	0.735	0.000**	0.745	0.802
marital	1.068	0.039*	0.776	0.840
origin_2	1.142	0.000**	1.052	1.198
origin_3	1.125	0.000**	1.078	1.221
origin_4	1.133	0.000**	1.038	1.175
origin_5	1.087	0.015*	0.989	1.144
rainfall_2	0.976	0.268	0.947	1.030
rainfall_3	1.021	0.371	0.954	1.046

Table 4.3: Multivariate binary logit model results from an EMIUB record of 171,209 migrating and non-migrating individuals between 1970 and 1999. ** p = < 0.01. * p = < 0.05.

The three hundred attitude values calculated therefore represent the probability of an individual recorded by the EMIUB data with specific age, gender, marital status and origin location attributes relocating to another zone. In order to inform the ABM with agent behavioural attitude values that reflect these probabilities during dry, average or wet rainfall years, the number of attitude values that must be calculated increases to nine hundred using age, gender and marital status attributes alone over the 30 year test period from 1970-1999. Due to the necessity of calculating nine hundred behavioural attitude values from the EMIUB data it is not possible to display all the results here. While Chapter 5 displays a small proportion of those values calculated, Appendix 4 displays the full tables of probability values in a series of weight matrices.

4.10 Modelling Software Selection

The process by which the conceptual model developed in Chapter 3 is translated into the migration decision undertaken by agents in the ABM is described in Chapter 5. Before such advances can be documented however, the basic model structure within which agents perform their migration decision was made. Numerous programs are available for creating agent-based models, each of which varies in simplicity, accessibility and programming language. AnyLogic is a software tool developed by XJ Technologies to support common simulation methodologies such as agent-based, system dynamics, discrete-event, continuous and dynamic system modelling. Although AnyLogic's internal language is Java and a model developed using AnyLogic is fully mapped into Java code, the backbone java class structure is automatically generated by AnyLogic permitting the user to employ a combination of Java code and graphical utilities. The software allows either discrete or continuous space to be used in a model. This permits layout-based detailed models where agents can inhabit any location within the defined environment. Such a function is in contrast to more traditional software packages such as NetLogo in which agents are confined to a grid. Finally, while time in other modelling packages is discrete, with agent actions only permitted to occur on synchronous time steps, agents in AnyLogic are able to schedule events themselves at any moment of time in an asynchronous manner. As a result of these advantages AnyLogic presents a platform from which significant and complex model developments can be achieved with only limited experience of Java programming.

4.11 Simple Agent-Based Model Design and Development

Before an ABM of climate-induced migration in Burkina Faso could be constructed and the important interactions between agents defined, a basic, representative demographic model of the Burkinabé population was developed. This model included processes of birth, marriage and death in order to capture underlying demographic structures before the introduction of agent-agent interaction, agent-environment interaction and migration decision-making. The model developed by this thesis starts in the year 1970 and is populated with agents that are initialised from individual entries in the EMIUB dataset. As a result, each model agent initialised into the model in 1970 has attributes that reflect those of an EMIUB survey respondent who was alive that year. Rather than use the precise coordinates of each agent's location at any point in time (a computationally demanding endeavour requiring a large database containing latitude and longitude reference data) the locations of all agents were defined simply on the basis of the EMIUB zone within which they were born. As a result, all agents representing EMIUB surveyed individuals born in the Sahel zone will initialise into the model in a random location within that zone.

Using the five zones into which the EMIUB data divides Burkina Faso permitted agents to be easily located into the correct zone using the same data source used to inform other attributes such as age, gender and marital status. In addition, using a zone level of agent distribution reduced model complexity and allowed clear identification of a threshold beyond which an agent's movement would be classed as 'migration'. Rather than defining a distance greater than which an agent's relocation might be classed as migration when they select one of numerous destination options, the division of Burkina Faso into distinct zones allows a simple definition of migration that is easily observed and quantified within the confines of the output of the model.

The first step in constructing an ABM using AnyLogic was to create and define the active object classes, or agents, of the model. In order to align with the geographical structure of the EMIUB data, defined by five distinct zones within three of the four rainfall zones identified by Henry et al. (2004a), five active object classes were created. These five agent classes represent the population of EMIUB surveyed individuals alive in 1970 and born in each respective zone. The virtual environment constructed within the model contained the five sets of agents and was visually defined using an image of Burkina Faso that displays the five model zones (Figure 4.9). By placing the agents within a virtual environment it is possible to control such important components as the size of the environment, the type of space that environment comprises (discrete or continuous), the layout of the agents on model start-up and the type of network to which agents can belong.

The model environment selected for the ABM constructed by this thesis was a 2D continuous environment. Use of such an environment permits the current location of an agent to be both set and retrieved, allows agents to be moved with specified speed from one location to another, and allows connections to be established between agents. As well as defining agents and their environment within the model, an important stage in the development of an ABM in AnyLogic is the definition of time. The model time units used by the model were defined as 'days' through the use of a calendar to run the model from and to defined start and end points. In early versions of the model it was run for the thirty year period from the 1st January 1970 to the 31st December 1999.

On model startup agents retrieve age, gender, marital status, migration experience and employment attributes stored within connected Excel spreadsheets and populate their respective zones. Each of the attributes retrieved by an agent from the Excel spreadsheets represent real individuals recorded by the EMIUB as alive in 1970. Although the study was conducted in 2000, the retrospective nature of the survey provides temporal data on the surveyed individuals. For example, a 47 year old married individual interviewed in 2000 may provide attributes for an unmarried modelled agent with a 1970 age of 17. The main motive for modelling agents from a past state is the greater ease of model validation that can be undertaken by direct comparison of observed and modelled migrants. Starting from an initial agent state defined at 1970, it is possible to more accurately recreate past flows using past circumstances.

When the EMIUB survey was conducted in the year 2000 only people over the age of 15 were interviewed. As a result, using a population demographic that used year 2000 data would result in no agents aged 14 and under being present at model startup. This would lead to either a 15 year gap between the youngest initial agents and those ‘born’ into the model, or the need to make up the attributes of a younger generation to fill the void. By using 1970 attributes of surveyed agents, although reducing the number of agents for whom data is available (due to the retrospective nature of the survey), the accuracy with which the agent population is represented is increased. This does however then present the problem that older people are not included in the 1970 population. In order for someone of 60 years of age in 1970 to have been surveyed in 2000 they would have had to be 90 years old. However, the lack of older modelled agents will have been remedied by the time a model run has reached 1999 as a result of the ageing model population. As such the demographic structure of the model population will not affect migrant numbers modelled post-2000 in later model applications.

Following the method of agent initialisation described above, the number of agents initially inhabiting each of the five model zones is limited to the number of people surveyed in 2000 but recorded as living in each zone in 1970. As a result, 661 agents were initialised into Ouagadougou, 893 into Bobo Dioulasso, 898 into Sahel, 1,363 into Centre and 634 into Southwest. Intended as a representative survey, the EMIUB data individuals initialised into the model zones as agents should broadly represent the real demographic structure of those zones. The EMIUB attributes assigned to individuals update as the model progresses forwards from 1970 in the manner displayed in Figure 4.10. On a predefined increment of time agent variables such as age and marital status, as well as zone level variables such as population, are updated to reflect the change in characteristics that have occurred between time ‘t’ and time ‘t + 1’.

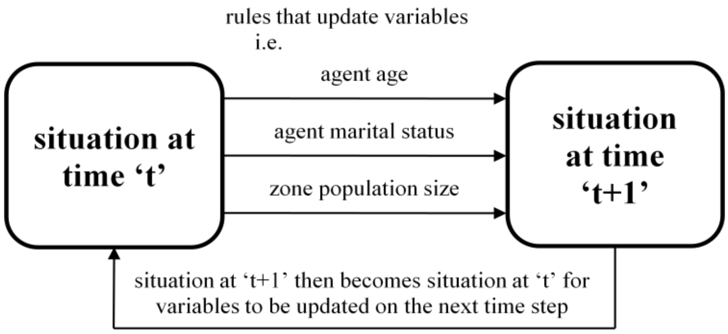

Figure 4.10: Diagrammatic representation of the means by which agent attributes are updated as model time progresses.

4.12 Agent Birth, Ageing, Marriage and Death

In order for the ABM to function in a continual manner that can represent real demographic change over time in Burkina Faso, functions of agent birth, ageing, marriage and death are important. At the start of every calendar month simulated the age of all modelled agents increases by 0.083 (1/12th year). Also triggered at the start of every calendar month are functions that control agent birth, marriage and death. Both birth and death functions use UNPD (2011) defined rates for Burkina Faso which, between 1970 and 1999, are broken down into medium variant rates for each 5 year period (1970-1975, 1975-1980 etc.). These figures, provided by the United Nations as crude rates per 1,000 population are used in the ABM as a probability of occurrence. For example, a crude birth rate of 48.1 per 1,000 population translates into a statistical modelled likelihood of a new agent being born to an existing agent of 0.0481. When a new agent is born into the model their age is set at zero, marital status at zero and gender applied at a 1:1 ratio (50% chance of being male or female). The additional agent attribute of assets, are assigned to newborn agents randomly at the rate they are calculated as being distributed across the initial population.

While the UNPD birth rates can be directly applied to the model population, death rates cannot be so simply employed. In order to prevent some agents living indefinitely through model runs (particularly when the model is applied to future simulations towards 2050), a threshold must be constructed beyond which agents must die. In the ABM constructed by this thesis, this threshold is defined as 70 years, 6 years older than the oldest individual surveyed by the EMIUB in 2000 and 13 years older than the average male life-expectancy. As a result of the application of this threshold, the UNPD defined crude death rate must be modified. Sensitivity testing of the death rate function revealed that crude medium variant figures gained from the UNPD data were required to be reduced by 40% (multiplied by 0.6) in order to be statistically effective.

Changes in the marital status of agents is controlled through a function that, on the basis of agent attributes, applies marriage to individual agents according to a predefined rate. As agents within the model are not arranged into households, agents are not required to find an eligible partner in order to marry. Marriage functions for males and females are therefore separate. In the case of male agents, individuals aged 21 and over who are unmarried are considered eligible to marry and, at a rate of 25% of eligible individuals, do so. In the case of female agents, those who are unmarried and aged 18 or over are considered eligible and, at a rate of 50% of eligible individuals, marry. The different propensities of males and females towards marriage and the different ages at which they become eligible were developed from information revealed during the focus group interviews conducted in Burkina Faso. Despite males in Burkina Faso often being polygamous, model agents are only permitted to marry once. Allowing female agents to marry from a younger age and carry a greater propensity towards marriage will result in a larger number of married females than males in the model. This is deemed not to be a problem as the marriage functions for both males and females have been developed to reflect their real-world marriage tendencies in Burkina Faso. Furthermore, the fact that agents within the ABM are not organised into discrete households makes this form of marriage representation appropriate.

4.13 Modelling and Validating Migration Decision-Making

As previously mentioned, the EMIUB data analysis described above is used within the migration decisions of agents as a probability function that contributes to the behavioural attitude component of a migration decision that is structured around the theory of planned behaviour. The probability values calculated from the EMIUB data are used to represent a form of agent knowledge in terms of their ability to address a given problem (the need to migrate) using partial information. Figure 4.11 displays how such agent knowledge is represented in the form of probability values representing the likely value of a potential solution (migration or other adaptation option) to rectifying the problem state.

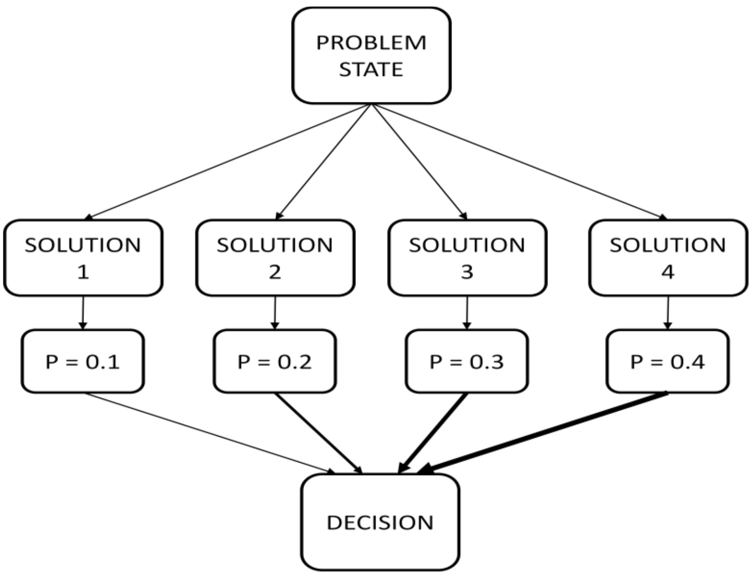

Figure 4.11: Diagrammatic representation of an agent's use of probability values to represent the potential value of solutions to a problem given partial information in the formation of a decision.

Through the use of the probability values and random number generators, agents can effectively select behavioural strategies in accordance with the notions of satisficing and sub-optimal selection described in Chapter 3. If a random number is generated by the agent that falls below the highest probability value retrieved, that option is selected as the behaviour of choice. However, if the random number is above the highest probability value the agent moves on to the second highest scoring probability. As with the first, the “dice” is rolled again and the agent determines whether or not the option that the second highest probability represents will be selected. In this manner the probability values retrieved by an agent that related towards their behavioural intention may be assessed and prioritised.

Following the construction of an ABM a process of model validation can be undertaken to establish how adequately the model implements and reflects those aspects of the real world that it is designed to model. As a result, the representative value of the model can be ascertained. Carley (1996) suggests that general discussions of validity for computational models point to one or more of six types of validation: conceptual (adequacy of underlying concept in characterising the real world); internal (correct computer code); external (linkage between the simulated and the real); cross-model (degree to which two models match); data (accuracy of real and generated data); and security (safeguards to ensure model changes do not alter other parameters). However, Carley suggests that the most pertinent of these to the outcome of a social simulation is the external validity or the comparability between the simulated world of the model and the real world.

In a decision-making context such as rainfall change migration in Burkina Faso it is possible to assess model validity by comparing the quantitative migration output to migration data for the region. On this basis, if the model data relates well with the observed data, it is generally assumed that the model fits the human data well and that the model is externally valid. A number of statistical approaches can be used to establish such a ‘goodness of fit’. The most common of these are the calculation of correlation coefficients to capture relative trend magnitude and root mean square deviations (RMSD) to show divergence in the data. Roberts and Pashler (2000) comment that many modelled theories are supported mainly by demonstrations that they can ‘fit’ data. This fit illustrates that the parameters can be adjusted so that the output of the theory resembles actual results. Although this fit is intended to show that the modelled theory is conceptually sound, Roberts and Pashler propose a number of serious problems with this validation argument. The most pertinent of these is the concept that, with a sufficient number of parameters, any model may fit any data almost perfectly. By tweaking modelled parameters to produce the desired output the evidence-base from which the model was developed is lost and the value of representing an observed process lost. If, for example, data analysis or fieldwork reveals that married men do not often undertake migration in Burkina Faso but, in tweaking the model to 'fit' reality, the number of married men in the community must be decreased far below the observed figure, the value of the model is lost, even if it can be termed a good fit.

In constructing an ABM it is therefore useful to place some limit on the number of parameters used (maintaining model simplicity) and avoid tweaking those parameters to produce the desired outcome. Although it is beneficial to conduct sensitivity analyses - where each parameter is varied over its entire range to test its impact upon the model - using this to over-fit the model should be avoided. As a result of the emergent nature of the outcomes of agent-based models, a number of model runs should be performed to test the variation in outcomes generated, allow a degree of randomness to be introduced to the simulation and be characterised. Doing this reveals how the context and circumstances of agents has a considerable impact upon their behaviour according to the rules specified. As a model runs through its time-steps, the context and circumstances of agents changes as a result of their own behavioural activity and their impact upon their social and physical environment. As a result, when externally validating a model, these multiple simulation runs should be considered along with their deviation away from each other and the real world. The model validation process used by this research involved comparing modelled outputs with the migration trends observed in the EMIUB data and is described in detail in Chapter 6.

4.14 Rainfall Data

Intended to elucidate the role of changes in rainfall variability upon the migration decision, a central component of the ABM developed by this thesis is the rainfall that affects each model zone. The historical data used as a record of rainfall in each of the model zones of Burkina Faso between 1970 and 1999 comes from the University of Delaware Air Temperature and Precipitation record* which provides monthly global gridded high resolution (0.5 degree latitude x 0.5 degree longitude global grid) data from 1950-1999. Figures 4.12 to 4.14 display the annual rainfall retrieved for each of the five zones in Burkina Faso from 1970-1999.

** UDel_AirT_Precip data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/*

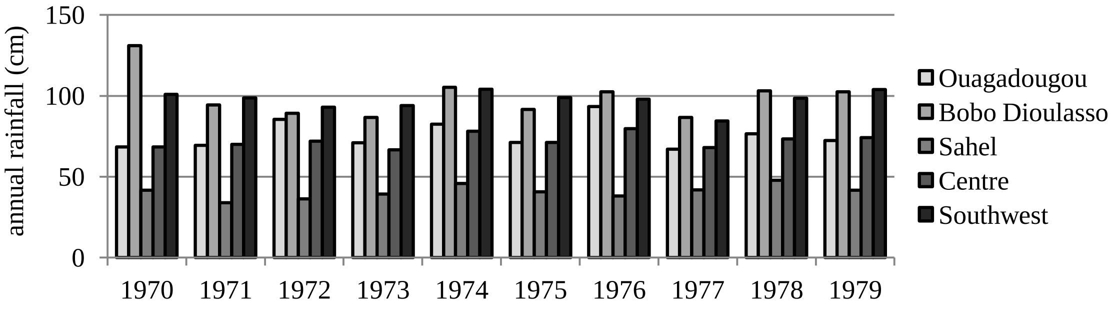

Figure 4.12: Delaware annual rainfall data recorded for the five model zones between 1970 and 1979.

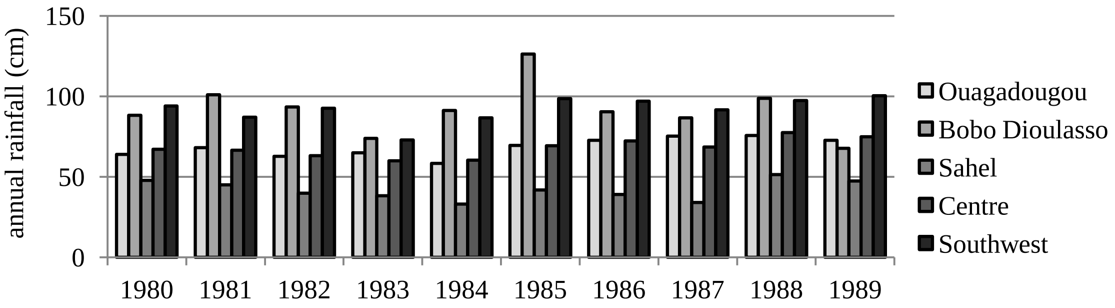

Figure 4.13: Delaware annual rainfall data recorded for the five model zones between 1980 and 1989.

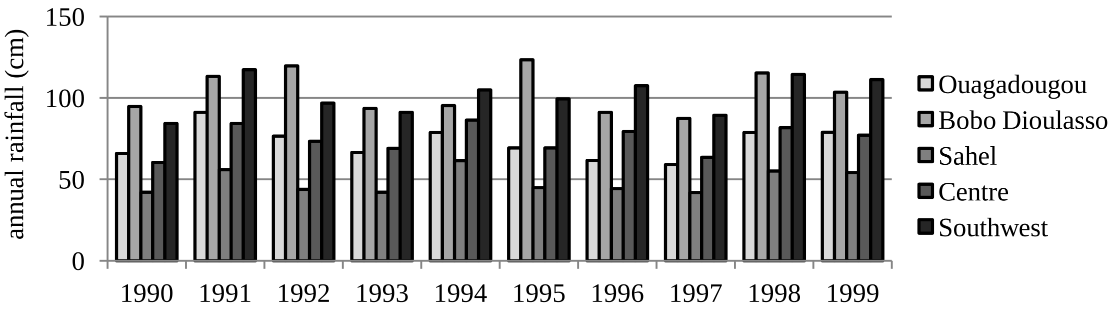

Figure 4.14: Delaware annual rainfall data recorded for the five model zones between 1990 and 1999.

It can be seen from the Delaware rainfall data displayed in Figures 4.12 to 4.14 that two model zones, Bobo Dioulasso and Southwest, experienced consistently higher annual rainfall than the other zones. The zone with the lowest level of rainfall was, in each of the thirty years between 1970 and 1999, Sahel. Ouagadougou and Centre zones are both recorded by the Delaware data as having a median level of rainfall, consistently higher than that recorded for Sahel but, in all years bar 1989, lower than that recorded for Bobo Dioulasso and Southwest. The rainfall data gained from the Delaware dataset illustrates the rainfall gradient evident across Burkina Faso. Figure 4.15 displays the rainfall gradient shown by the Delaware data as existing across West Africa over the data period 1970-1999. The white box on Figure 4.15 indicates the approximate location of Burkina Faso and shows the strength of the rainfall gradient recorded in the context of West Africa.

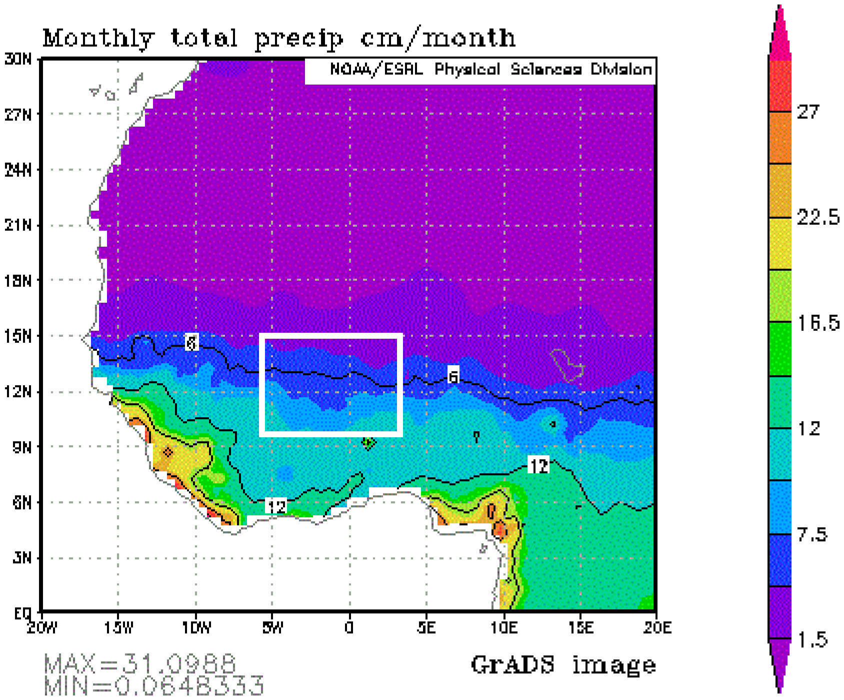

Figure 4.15: Rainfall gradient recorded by the University of Delaware Precipitation data across West Africa between 1970 and 1999. White square indicates the approximate location of Burkina Faso.

The historic rainfall data retrieved from the University of Delaware resource is used as the basis from which the impact of rainfall upon the migration decision of Burkinabé people is assessed by this research. Used to inform the EMIUB data analysis required in order to calculate behavioural attitude values used in the modelled decision to migrate in Chapter 5, the data is also input into each ABM model run so that the migration decisions of agents can be undertaken on the basis of the rainfall conditions experienced in each zone between 1970 and 1999. In later versions of the ABM that investigate future migration trends the modelled impact of rainfall upon migration uses a number of different rainfall scenarios described in Chapter 8 that provide stochastic rainfall data for each zone to 2050.

Crucial to the use of both the University of Delaware rainfall record and the different rainfall scenarios that provide rainfall estimates for each zone to 2050 is the classification of each year as having average, below average (dry) or above average (wet) rainfall. Classifying each year as average, dry or wet provides a vital framework by which the influence of rainfall upon migration can be simply assessed. In terms of the calculation of behavioural attitude probability values for example, the difference between the likelihood of a particular class of agents migrating from one location to another in average, dry and wet rainfall conditions provides the core statistical insight required for model development. Rather than classify each year on the basis of annual rainfall however, the rainfall record is interpreted in order to identify rainfall during the three month period during the crucial crop growing period, July-August-September (JAS) when rainfall in all zones is greatest. Figure 4.16 displays the 1970-1999 monthly average rainfall recorded by the University of Delaware Precipitation data between 1970 and 1999.

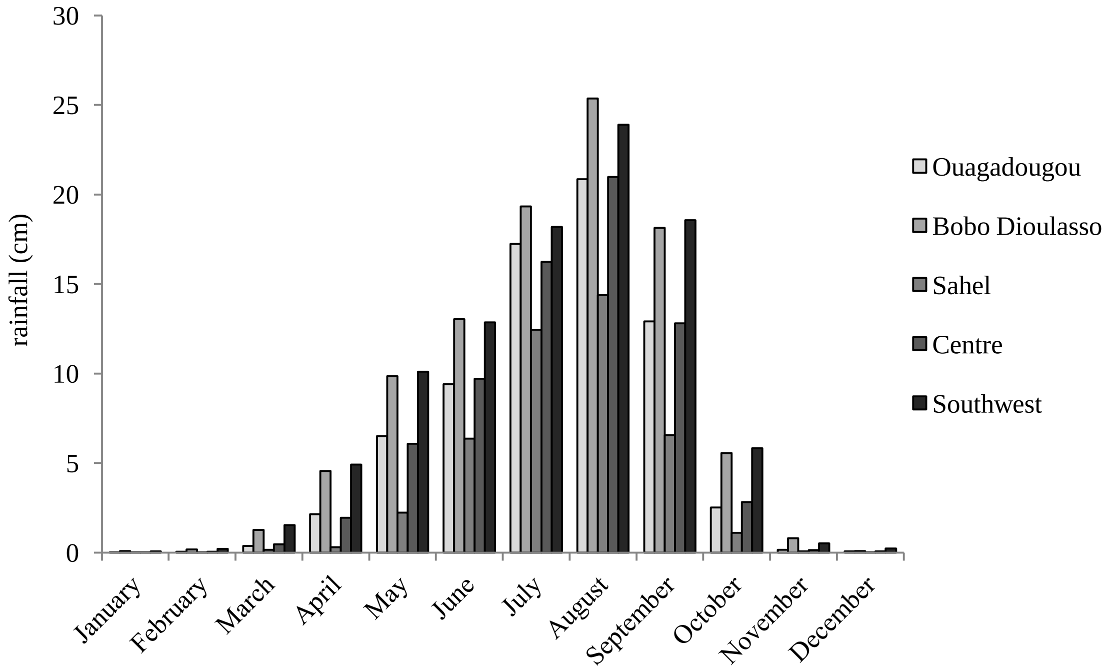

Figure 4.16: 1970-1999 monthly average rainfall recorded by University of Delaware Precipitation data for the five model zones.

As can be seen from Figure 4.16, the month with, on average, the greatest rainfall across all the model zones of Burkina Faso is August. The months with, on average, second and third highest levels of recorded rainfall are July and September respectively. These patterns of average rainfall support the decision to use JAS rainfall values in order to assess the rainfall classification of each model year. High rainfall within a zone during this JAS period should ensure a relatively successful harvest yield thereby directly affecting the ability of households within that zone to support themselves that year. The thresholds that define each model year as dry, average or wet were calculated using quartile values derived from the 1970-1999 JAS rainfall record of each zone. Each model year was therefore defined as dry, average or wet on the basis of whether the JAS rainfall falls above or below the 1970-1999 quartile thresholds displayed in Table 4.4.

Zone:	1st Quartile – Dry/Below Average Rainfall Threshold:	3rd Quartile – Wet/Above Average Rainfall Threshold:
Ouagadougou	47.31 cm/3months	55.20 cm/3months
Bobo Dioulasso	56.61 cm/3months	67.14 cm/3months
Sahel	29.85 cm/3months	37.50 cm/3months
Centre	46.92 cm/3months	53.67 cm/3months
Southwest	57.90 cm/3months	64.80 cm/3months

Table 4.4: 1970-1999 rainfall thresholds used to determine dry, average and wet model years in each of the five zones.

Throughout model runs, the JAS rainfall for each zone in each simulation year is read from an excel spreadsheet linked to AnyLogic. Using the thresholds identified in Table 4.4 the rainfall in each zone is classed as dry, average or wet. These classifications then affect the migration decision-making processes of agents by controlling the behavioural attitude values they retrieve and permitting changes in their rainfall-based assets. The impact of changes in rainfall, and therefore rainfall classification, upon individual agents then cascade through the modelled system affecting an individual's migration history and affecting the communications made through agent-agent interactions.

4.15 Summary

This chapter has identified the methodological approach adopted by this research and the numerous resources used. The main source of secondary data used by this thesis came from the EMIUB survey described at the start of this chapter. The survey results were used to inform both the conceptual development of the modelled migration decision and the focus group interview process performed as primary data collection in Burkina Faso. Following a description of the themes identified by the focus group interviews, the means by which this information was translated into a format that could be used in the construction of the ABM was described. Once the nature of the proposed model had thus been defined the selection of an ABM software package and process of constructing and testing the required model functionality were outlined. The closing section of the chapter deals with the collection and interpretation of rainfall data, the final component required in the construction of the ABM. Chapter 5 describes the process of implementing the migration decision-making structure into the ABM and the role of changes in rainfall variability in that decision.

Chapter 5

Agent Model Development

5.1 Introduction

The Agent Model of Adaptation to Rainfall Change (AMARC) presented by this thesis is implemented in AnyLogic 6 University Edition, version 6.5.1. Constructed using five sets of agents defined according to their birthplace or “origin zone”, the model environment is that of Burkina Faso with migration being defined as the relocation by an agent from their zone of origin to any one of the other four origin zones or out of the country. As shown in Figure 4.9, the model environment of Burkina Faso is divided into five zones (1. Ouagadougou; 2. Bobo Dioulasso; 3. Sahel; 4. Centre; and 5. Southwest) that provide an approximate division of the country according to the north-south rainfall gradient seen in Burkina Faso.

Although the potential exists to schedule model occurrences in an asynchronous manner within AnyLogic, the control of time steps in agent-based models produced using the software is often defined using an “event”. Using a synchronous recurrence time of 1 day, the event component of the model controls agent birth, ageing, marriage and death on a monthly basis. As a result, each month, agents can be born into all five origin zones of the model at a rate defined by a birth rate function at model startup. Those agents already initialised into the model will age by 0.083 (1/12th) of a year each month and agents with appropriate existing age and marital status attributes will marry and die according to marriage rate and death rate functions also established at startup. As a result of the birth, ageing and death functions that occur throughout a model run, the number of agents inhabiting the modelled environment of Burkina Faso is intended to change in accordance with the median variant national population growth rate reported by the UNPD.

In order to test the ability of the basic model to replicate the UNPD observed and forecast rates of demographic change to 2050 Figure 5.1 displays the change in crude birth and death rates (per 1,000 population) and the resulting population change rate provided by the UN for Burkina Faso between 1970 and 2050 and used in the ABM. Values for birth and death rates between 1970 and 2010 are “Estimate Variants”. Values for the period 2011 to 2050 are “Constant-fertility scenario”.

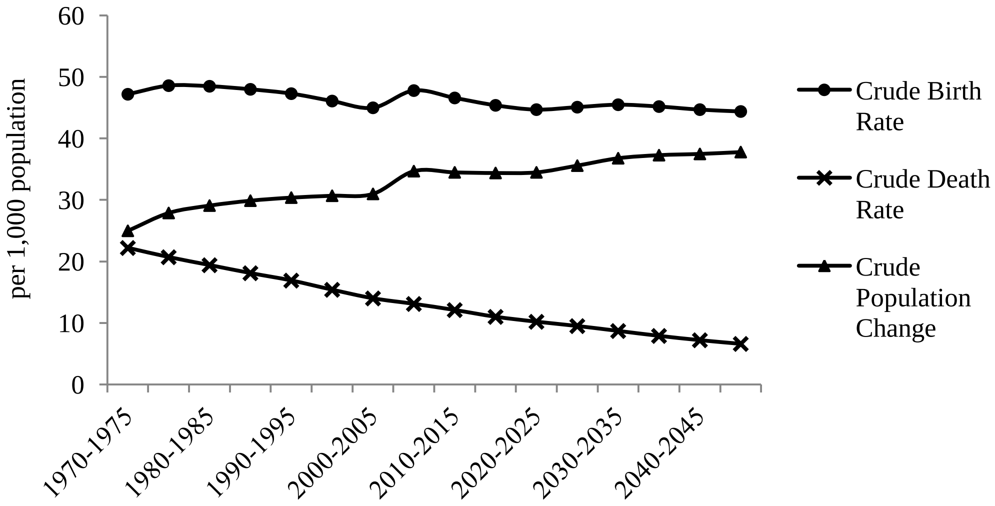

Figure 5.1: Burkina Faso crude birth, death and population change rates per 1,000 population between 1970 and 2050.

The initial population of each of the five zones at model startup is defined by the number of individuals for whom 1970 data was available in the EMIUB dataset. The data, collected in the year 2000 as a retrospective survey, provides information on more than 8,000 individuals in Burkina Faso. However, due to the retrospective nature of the survey, less than the total number of surveyed individuals were alive in 1970 and therefore eligible to be used in the model at startup. As a result the model starts with a total of 4,449 agents: 661 in Ouagadougou, 893 in Bobo Dioulasso, 898 in Sahel, 1,363 in Centre, and 634 in Southwest. As the model progresses, these population statistics change due to birth and death functions programmed into the model to replicate demographic change.

By applying the UNPD crude birth and death rates to the 1970 model population of Burkina Faso (over the 90 year period from 1970 to 2050) the target demographic change the ABM should replicate can be calculated. The first step in developing the model is therefore to construct a demographic basis that reconstructs the population changes forecast by the UN for Burkina Faso from 1970 to 2050. The AMARC_Population model was used as the base version from which demographic change can be verified as accurate and upon which the ABM can be developed. It was important that the base model accurately portrayed the demographic change forecast to occur in Burkina Faso. This is due to the fact that investigation of the causes of the migration seen in later versions of the model must consider the impact of demographic change on migrant flows in order to elucidate the role of changes in rainfall variability in the migration decisions of Burkinabé people.

The model population calculated using the UNPD statistics and modelled using the same data showing a correlation value of 0.999 suggesting the strong ability of the model to appropriately replicate demographic change. The marginal difference between a statistical application of the UNPD rate of demographic change and the manner in which this rate of change manifests itself in the ABM results from the death rate function used in the model. Rather than permitting the same UN death rate to apply to all agents where any individual would have an equal likelihood of death, the rate of agent mortality must be applied in a manner that also places some limitation upon the maximum lifespan achievable. Using a single death rate function, an agent could potentially survive well beyond the age a human can be expected to live. As such, an artificial limit of 70 years (6 years older than the oldest individual interviewed by the EMIUB in 2000) is placed upon the potential lifespan of all agents. If agents in the model die automatically at 70 years of age rather than at the hands of the UN defined death rate function, the UN rate must be adjusted to retain the appropriate level of mortality of those individuals under 70 years old. As a result, the correlation seen between calculated and modelled populations between 1970 and 2050 stands at the highly significant 0.999 as opposed to 1.

The original demographic model and subsequent agent models all run using daily timesteps on a calendar system. The central model component controlling the occurrence of different model functions at different timesteps is the “event”. At the start of every calendar month, the ageing function is called from event, causing all agents to age by one month. Also called on a monthly basis is the marriage function which permits eligible agents within the model to marry. Because the UNPD provide crude birth and death rate data as annual figures, birth and death functions within the model are called by “event” at the start of each year. The combination of these model components creates the basis of the AMARC_Population model used to verify demographic change above.

5.2 The Migration Decision

Also controlled through the event component but only modelled as occurring once a year at the end of the wet season is the migration decision undertaken by agents. The migration decision is represented in the AMARC models as occurring only once a year in order to permit greater ease of analysis of the preliminary results gained by this research. Furthermore, the migration decision is modelled to take place at the end of the wet season as a result of the numerous references to migration decisions being undertaken post-harvest by focus group participants across Burkina Faso. Migrants are then modelled to return by the end of the subsequent dry season, resulting in migration modelled by the ABM appearing seasonal. Although appearing seasonal, the migration probabilities used within the model represent the likelihood of an individual migrating away from their home location for any period classed by EMIUB respondents as migration. As such, the model does not attempt to distinguish between seasonal, short- or long-term migration but simulates all departing agents as returning the following calendar year.

The modelled migration decision is broken down into three components: the sharing of migration information by each agent with their peers; the assessment of the migration options available to each agent and; the development of a final intention to migrate or stay. The migration decision is performed following the wet season and culminates in the development of a behavioural intention towards each migration option in September of each year. Although not entirely representative of the real-world migration decision of an individual who would likely consider their options year-round, structuring the migration decision in this manner enables clear model implementation and analysis.

Taken on the basis of an agent’s combination of personal characteristics and their circumstances in terms of the rainfall conditions affecting their location, the core migration decision component undertaken in September of each year by all eligible agents follows the decision-making structure presented by SMARC in Chapter 3. The migration decision of agents aged 15 years and over within any origin zone of the model is therefore comprised of three core components: behavioural attitude; subjective norm and; perceived behavioural control. In order to develop a preferred course of action in response to the rainfall conditions affecting an individual, each agent will score the five active options available to them (migrate to one of the four other zones, or migrate internationally) on the basis of these core components.

The behavioural attitude (BA), subjective norm (SN), and perceived behavioural control (PBC) values calculated by agents contribute to their behavioural intention (I) towards the migration option being considered. As shown in Equation 1, an individual agent's behavioural attitude is adjusted according to the combined impact of their networked peers (subjective norm) and their perception of whether or not they have the assets/experience necessary to undertake the migration (perceived behavioural control). Agents perform the intention calculation for each of the migration adaptation options available to them.

$$I = (BA \times SN) \times \; PBC$$

(Equation 1)

In their development of a final intention towards their favoured course of action, an agent scores each of the options available to them. As such, each option is considered in parallel with the others through the process of intention formation. Although Equation 1 appropriately represents the intention formation undertaken by an individual agent, when the process of developing behavioural intentions is undertaken in the model by a large cohort of agents, the equation used to determine intention values must be altered. In order for behavioural attitude values to represent the correct probability of migration to the desired zone, BA values are adjusted to represent the likelihood of an individual within the reduced cohort of agents who decide they can afford to invest in migration, migrating. As a result, an additional component is incorporated into the decision to migrate that permits modification of BA values used in the model. Named perceived behavioural control population ($PBC.pop$), this component is incorporated into the model as per the conditional term used in Equation 2, below.

$$\boldsymbol{FOR\ ALL}\ I, PBC\ \boldsymbol{IN}\ Agent$$
$$((BA \times PBC.pop) \times SN == \boldsymbol{IF}\ PBC \mathrel{/=}\ 0\ \boldsymbol{THEN}\ I\ \boldsymbol{ELSE}\ == 0);$$

(Equation 2)

The conditional term above therefore states that if PBC is not equal to zero, then I is equal to multiplication of BA, $PBC.pop$ and SN. However, on the condition that PBC is equal to zero, the multiplication process is void and the I value returned by the agent for that option is zero. In order for the behavioural attitude component of the modelled migration decision to be appropriately scaled, the first step in the migration decision of an agent and their cohort is therefore the development of PBC values towards each available migration option.

5.3 Perceived Behavioural Control

With reference to the notion of perceived behavioural control (PBC), focus group participants in Burkina Faso tended to agree that, although it is easier to meet the cost of migration through savings or the sale of assets, even those who do not have such capacity may still migrate. Participants referred to the fact that it is often those with the least to invest in migration that are in most need of the additional income that may be gained through migrating. As a result, numerous respondents referred to the potential of borrowing money from friends, family or local lenders in order to invest in migration. Failing that, the possibility of migrating in small steps was mentioned with migrants moving relatively short distances with very little investment necessary before working and saving money in order to migrate further. As a result, from a conceptual standpoint, the 'control' being placed upon an agent through this component of the modelled migration decision does not necessarily mean that an individual with no assets cannot migrate. However, the chances of their being able to do so are reduced. The perceived behavioural control of an agent, or their perception of whether or not they have the assets/capability to undertake a migration adaptation option, is therefore made up of two components. The first of these involves an assessment of whether or not the agent has the assets necessary to undertake the migration option. The second considers whether or not an agent has previous experience of migration. The final outcome of the PBC calculation is a binary result that denotes whether or not the agent believes they have the means/experience necessary to undertake the migration option being considered. In this version of the model, no distinction is made between the means required to migrate to each of the different destinations. As the likely increased cost and reduced probability of any individual migrating to a distant location is implicitly incorporated into the behavioural attitude probability values, the PBC component of the decision to migrate is retained as a simple yes/no determination of perceived capacity to migrate.

In their investigation into the relationship between migration and rural income diversification in Burkina Faso, Wouterse and Taylor (2008) suggest that, in the context of West Africa, a large proportion of household income is derived from cash crops and the diversification of income into livestock. While they describe cash crops as being both labour intensive and risky, Wouterse and Taylor suggest that, although entailing risk and initial capital outlay, livestock production tends to be contrastingly labour-extensive with high output per worker day. The authors go on to describe the value of livestock to households in Burkina Faso due to their recurrent production of goods such as milk, wool and manure, their functions such as transport and traction and their important representation of a capital asset that may enable a household to meet unexpected expenditures (Udo and Cornelissen, 1998). Although wealth in Burkina Faso may be measured using numerous other metrics such as land or property ownership and monetary savings, the availability of data on livestock assets and the relevance of these to rural livelihoods makes them the focus of the asset basis for this research. Unlike financial holdings, property ownership and possession of consumer goods, livestock assets are well covered in the EMIUB dataset.

For the purposes of the AMARC model, different types of livestock are assigned different but relative value approximations in order for a standard calculation of livestock assets to be achieved. These relative values have been assigned as a result of consideration of the potential value of an animal to a household in Burkina Faso following 2 months of fieldwork in the country interviewing people in rural and urban locations. Of the livestock types recorded by the EMIUB data, cattle are proposed to be of the greatest livestock value to Burkinabé people. Wouterse and Taylor (2008) note that cattle represent a considerable capital asset as they provide continual supplies of milk and manure while also offering the potential to be used for transportation and traction. As such, in the relative asset value approximation used by this research, one head of cattle is scored as having an asset value of 0.2. In decreasing relative value, a donkey is scored as 0.1, a goat or sheep as 0.05 and a chicken as 0.02. As a result, one head of cattle is considered to be the approximate equivalent of 2 donkeys, 4 sheep or goats, or 20 chickens. Calculated therefore on the basis of a household's stock of poultry, sheep, goats, donkeys and cattle, livestock assets (la) in the EMIUB dataset range from 0.02 (1 chicken) to 45.6 (a herd of 228 head of cattle).

Although the EMIUB does not provide time dependent data on the assets of individual migrants, the survey includes information on the year 2000 livestock assets of respondents. As a result, data on the ratio of livestock distribution in each of the model zones in 2000 is available. This rate of distribution is used to assign livestock assets to the individual agents of each zone of the ABM. Figure 5.3 displays the proportional distribution of livestock assets across the entirety of each of the five model zones.

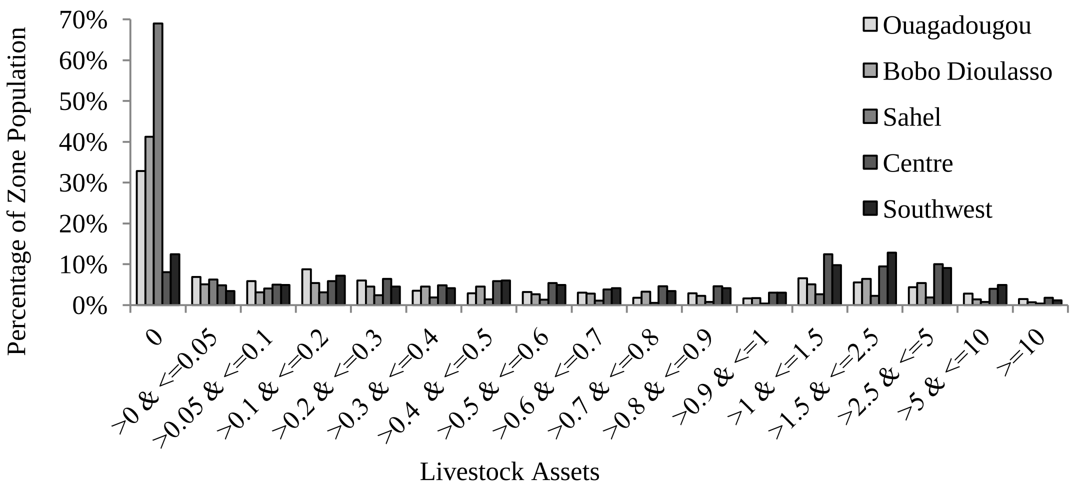

Figure 5.2: Proportional distribution of livestock assets across each of the five model zones of the model environment of Burkina Faso.

It is evident from Figure 5.3 that the model zone within which the most year 2000 EMIUB surveyed individuals had zero livestock assets is Sahel. In this zone almost 70% of respondents had zero livestock assets. By contrast, less than 10% of the surveyed inhabitants of Centre had zero livestock assets. Perhaps due to the necessity of this study to use livestock as the sole asset indicator or perhaps due to high levels of poverty in urban areas the two urban zones, Ouagadougou and Bobo Dioulasso are also shown to have a relatively high proportion (33% and 41% respectively) of individuals with zero assets. As well as having low proportional populations with zero assets, the two apparently ‘wealthiest’ zones in livestock terms, Centre and Southwest, also have clearly larger proportional populations of individuals with higher livestock assets. From the EMIUB dataset the year 2000 rate of distribution of livestock assets in each of the five model zones is known. Livestock assets are therefore assigned to agents in the model according to this rate.

In addition to livestock assets the final asset rate that contributes to the PBC component of the modelled decision to migrate is also affected by a rainfall asset (ra) function. In many communities across Burkina Faso, the relative wealth of a household may be highly dependent upon the success of the harvest making seasonal rainfall directly influence household assets and affect an individual’s perception of whether or not they can afford to invest in migration. Rainfall assets (ra) are calculated on the basis of the current year’s ($r1$) and two previous years’ ($r2, r3$) regional rainfall classified according to whether they were dry (below average), average, or wet (above average) and scoring 0.01, 0.05 and 0.1 respectively. Rainfall assets are calculated by each agent using Equation 3.

$$ra = (r1 + r2 + r3)$$

(Equation 3)

On the basis of Equation 3, three dry rainfall years will return a rainfall asset value of 0.03, therefore having only a marginal impact upon an agent's asset rate. If any of the three rainfall years considered in Equation 3 are classed as either average or wet however, a greater positive rainfall asset score will be returned. The asset rate (ar) that an agent uses in the calculation of their PBC value thus incorporates both livestock assets (la) and rainfall assets (ra) and is calculated using (Equation 4).

$$ar = la + ra$$

(Equation 4)

In developing an agent's intention towards migration, some equations used in the model use random number generators to randomly assign whether or not a desired threshold is crossed. Such random numbers range from 0 to 1. For example, if a probability of 0.5 is used in the modelled decision, ~50% of random numbers generated will fall below this probability threshold and ~50% above. As a result, the outputs of most instances where Equation 4 is used are required to fall between 0 and 1 in order for the asset rate to be effectively incorporated into the model. However, in the few cases where agents have livestock assets of greater than 1, Equation 4 permits automatic perception by that agent that they are able to invest in migration. By contrast, those agents with livestock assets of less than 1 are, depending on how far below 1 their assets fall, increasingly more likely to perceive themselves as unable to invest in migration. Only ~2% of random numbers generated between 0 and 1 would fall below 0.02 meaning that an agent with livestock assets of 0.02 (1 chicken) has only a 2% chance of perceiving themselves capable of migration.

Considered to be an additional component that has the potential, during periods of bountiful rainfall, to increase the perceived behavioural control of an individual with low livestock assets, rainfall assets are classified within the model as having a relatively marginal impact upon PBC. As a result, rainfall asset values calculated by agents range from 0.03 (three consecutive dry years) to 0.3 (3 consecutive wet years). While the addition of 0.3 to a livestock asset score of 45.6 would have no impact upon determining whether an individual perceives themselves to be capable of migrating, adding 0.3 to livestock assets of 0.02 would have a considerable proportional impact. However, as a result of the rainfall asset component, those agents with zero livestock assets are still able to return a binary PBC score of 1 and undertake migration. However, the chances of them doing so are reduced compared to an agent in the same zone that is 'asset rich' and therefore considered more able to easily invest in migration.

The second component of the PBC calculation permits an agent to return a higher value towards a migration option if they have previous experience of migration, either to the destination in question or another. Calculation of the experience rate (er), defined on the basis of an agent's experience of migration to the destination in question (de) and their experience of migration in general (ge), is performed on the basis of Equation 5. In the formation of an experience rate that contributes to the PBC value, each prior experience of migration to the destination in question is results in a de value of 0.1. If, for example, an agent has migrated to the destination in question on four previous occasions they will return a de value of 0.4. Intended to have a more marginal impact upon the experience rate, an agent will score 0.05 towards their ge for every experience they have of migration to destinations other than that being considered. An agent that has migrated to other destinations a total of six times will therefore return a ge value of 0.3. The combination of de and ge values represent the total number of times an agent has migrated within their lifetime. Throughout the duration of model execution, or an agent's lifetime, er may ordinarily range from 0 to a maximum of approximately 1 (scored for example as five migrations to the selected destination and 10 to others).

$$er = de + ge$$

(Equation 5)

A calculation of behavioural control (BC) is performed using an agent's asset rate (ar) and experience rate (er) in the manner displayed in Equation 6 and is undertaken as a step in the final formation of the PBC value required by agents.

$$BC = ar + er$$

(Equation 6)

Following an agent's calculation of a BC value towards the migration option being considered, the agent's final PBC score can be calculated using the conditional term shown in Equation 7.

$$\textbf{\textit{FOR ALL}}\ rn, BC, PBC\ \textbf{\textit{IN}}\ Agent$$
$$(1 == \textbf{\textit{IF}}\ rn <= \ BC\ \textbf{\textit{THEN}}\ PBC\ \textbf{\textit{ELSE}}\ == 0);$$

(Equation 7)

If a random number (rn) between zero and one generated by the model is less than the resulting BC value, a score of 1 is therefore allocated to PBC, migration is perceived by the agent to be within their means, and through Equation 1, an individual agent would develop an intention value towards that option. Otherwise a value of 0 is assigned to PBC and, through the use of Equation 1, an individual agent's intention to migrate to that destination will be zero. The higher an agent's asset rate (ar), experience rate (er) scores, the higher the BC value calculated and the greater the likelihood that an agent will return a PBC value of 1. The agents' perceptions of their behavioural control return a binary outcome in order to aid clarification of the migration decision. Rather than an agent thinking they 'might' have the capacity to migrate, their consideration of an option is defined as a yes/no decision formed on the basis of assets and experience. This enables clearer definition of an agent's options and a greater ability of the model to quantify the 'able' population.

As illustrated by Equation 2, the model code necessary to fully implement the impact of PBC upon behavioural intention requires the use of an additional parameter: $PBC.pop$. Each agent that scores a PBC value of 1 for a migration option is placed in a virtual cohort with all other agents from their origin zone that have a PBC score of 1 for the relevant option. The size of this cohort is then the $PBC.pop$ value used in Equation 2 that is used to adjust BA values to reflect the likelihood of an individual within this new cohort migrating. As probability values have been calculated without any notion of perceived behavioural control, failing to incorporate this $PBC.pop$ adjustment would mean that the original BA values would be applied to an artificially small population of agents resulting in inappropriately small modelled migration flows.

5.4 Behavioural Attitude

The behavioural attitude (BA) component of the decision to migrate is, for each agent, selected from a matrix of values stored within the model and represents the probability of an agent from origin location (l), with rainfall conditions (rc) that year and with current age (a) gender (g) and marital status (s) attributes, migrating to the destination option (o) being considered. The origin location ranges from 1 (Ouagadougou) to 5 (Southwest) in the model while rainfall conditions range from 1 (dry) to 3 (wet) through 2 (average). Although a more continuous set of rainfall values could have been developed through the calculation of statistically-derived functions between rainfall and the other model inputs, the tertiary (dry, average, wet) approach adopted by this research was selected in order to facilitate clearer analysis of model outputs. Inevitably, the use of a tertiary classification will have introduced some margin of error due to the creation of discrete classifications defined by specific thresholds. However, the potential advantages of fuzzier thresholds that would have resulted from the use of a function was deemed inadequate to justify the lack of clarity in model output analysis that would result.

The probability value (PV) of an agent migrating to destination option (o) is therefore calculated from the number of individuals within the EMIUB data with defined attributes a, g, and s who are migrants (m) from location l, under the prevalent rainfall conditions rc in the period 1970-1999, divided by the population (p) of that location with the same defined attributes at that point in time (Equation 8). The 1970-1999 probability values stored within the matrix are derived from analysis of the EMIUB dataset and represent the likelihood of an agent with the same characteristics undertaking migration as an adaptation strategy in the face of the existing conditions.

$$PVo(a,g,s,l,rc) = \frac{m(a,g,s,l,rc)}{p(a,g,s,l)}$$

(Equation 8)

The probability values retrieved by an agent, as well as being defined on the basis of variables a, g, s, l and rc, are further controlled according to the section of the EMIUB data from which they were calculated. The model can therefore be run using probability values derived from a total of four separate weight matrices calculated from combinations of two rainfall precursors and two data time periods. In rainfall terms probability values can represent the likelihood of an individual migrating in a year defined as dry, average or wet according to the July to September (JAS) rainfall conditions of that year (ppt) or the current year and two preceding years ($ppt3$). The purpose of the second rainfall weight matrix component ($ppt3$) is to accommodate the possibility that the migration response to a factor such as rainfall may be more of a slow onset decision to longer term trends than a rapid response to a short term change.

In time period terms, the two approaches used to calculate probability values are distinct as a result of the section of the EMIUB data analysed to produce the values stored in the relevant weight matrices. The EMIUB data provides reliable retrospective migration data from Burkina Faso for the thirty year period 1970-1999. By using the migration record for the period 1990-1999 ($mp10$) to calculate PV for use in the AMARC model, the migration record from 1970-1989 can be used in a format where one third of the available data is used for model parameterisation and the remainder for cross-validation. Such an approach is often used in the field of artificial intelligence when training a neural network that is intended to abstract the high level of complexity inherent to most biological systems and focus on the core information processing structures. However, in accordance with the notion of data fitting (Schittkowski, 2003) and in order to calculate more accurate migration probability values from a longer time period, the entire EMIUB migration data period of thirty years (1970-1999) has also been used to calculate alternative probability values for the AMARC model ($mp30$). On the basis of Roberts and Pashler's (2000) and Fum et al.'s (2007) comments on parameter fitting, the AMARC model can be strengthened by using the $mp30$ weight matrices that fit model parameters to the overall variability found in the full range of data, thereby avoiding 'overfitting' and permitting more representative future simulations in post-validation model applications. The four PV weight matrices available in the AMARC model are therefore $ppt.mp10$ (1 year rainfall and 10 year migration data analysis), $ppt3.mp10$ (3 year rainfall and 10 year migration data analysis), $ppt.mp30$ (1 year rainfall and 30 year migration data analysis), and $ppt3.mp30$ (3 year rainfall and 30 year migration data analysis).

Whichever combination of ppt or $ppt3$, $mp10$ or $mp30$ the AMARC model probability values are derived from, those retrieved by each agent reflect the likelihood of an individual with age, gender and marital status characteristics a, g and s migrating. However, as only those agents who perceive that they are able to complete the migration in question will actually do so, the values are adjusted to represent the increased likelihood of an agent within this reduced 'able' population migrating. Such agents are those that return a PBC value of 1 towards the option in question and so consider themselves capable of migrating as a result of the behavioural control (BC) value calculated in Equation 6. The adjusted probability value represents the behavioural attitude (BA) of the agent and is calculated on the basis of Equation 9 using the probability value for the relevant population of the agent's origin location (PV) and the population of agents that have scored 1 for their PBC value towards that option ($PBC.pop$) in the current model cycle.

$$BA = \frac{PV(a, g, s, l, rc)}{PBC.pop}$$

(Equation 9)

The probability values assigned to each option considered by each agent thus reflect the likelihood of an agent with the given characteristics migrating under the relevant circumstances. Because the different combinations of characteristics used to govern the migration decisions of agents in the model result in twelve unique descriptions of agents that inhabit five different origin locations and respond to three different levels of rainfall, the matrix containing the probability values retrieved by agents is very large. In order to present an idea of the overall migration tendencies of agents in each of the five zones across all rainfall levels, Figure 5.3 displays the sum total of the probabilities of agents with characteristics a, g and s migrating to any available destination under all rainfall conditions. Although sum probabilities do not provide the full detail used by the ABM, the data displayed in Figure 5.4 provides an indication of the overall tendencies of agents with certain characteristics towards migration.

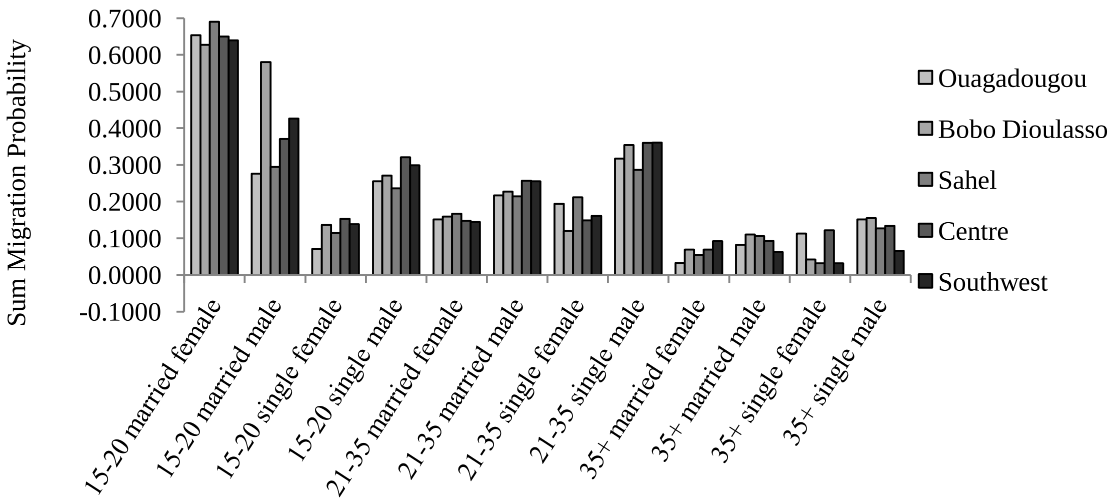

Figure 5.3: <u>Sum</u> probabilities of agents with given characteristics migrating from one of the five zones of origin to any other destination.

The sum probability of any class of agent migrating from one origin location to any other destination ranges from 0.0313 for 35+ single females originating in Southwest to 0.6901 for 15-20 married females originating in Sahel. As a result of the nature of the probability values used (the number of individuals with defined characteristics migrating from one origin location to an alternative destination in a particular year, divided by the number of individuals with those characteristics present in that origin location that year), they are dependent upon both the number of migrants with the defined characteristics and the size of the population with those same characteristics. As identified in Chapter 4, those individual migrations recorded as being undertaken for the purposes of marriage and postings were removed from the analysis.

Migration probability values may therefore result from two features of the data. The first of these is the number of individuals with the given characteristics who migrated under the appropriate circumstances in the EMIUB data each year during the relevant EMIUB data analysis period. The second component is the population of individuals with the given characteristics that were present in the EMIUB data each year. A high migration probability value therefore indicates that a high proportion of the total population of agents with defined characteristics migrated but gives us no information on the actual size of that population. Equally, a low probability value suggests only that a small number of the population of unknown size were seen to migrate in the data. As a result, it is important in the development of the model to ensure that the population of modelled agents display a similar demographic structure to those in the dataset from which the specific probability values were derived.

In addition to demographic change in the form of birth, ageing and death, due to the definition of classes of agents according to age, gender and marital status, functions controlling the rate of marriage within the model must accurately portray the rate of marriage witnessed in the data. This is important because of the cultural norm referred to during focus group interviews in Burkina Faso that leads women to marry at a relatively young age and men to marry slightly later in life. As a result, a woman in her mid-thirties is more likely to be married than a man of the same age. The likelihood of there being an unmarried female of over 35 years of age in the EMIUB data is therefore low. If one were to be present in the data, should they migrate during the analysis period of 1970-1999, the probability of such an agent migrating in the model would increase significantly. To permit the probability values retrieved by agents in the model to have the appropriate impact upon migration, the population structure of the modelled agents must therefore reflect that of the real world population surveyed by the EMIUB in 2000. Figure 5.4 displays the 1970 population structure of individuals surveyed by the EMIUB in 2000.

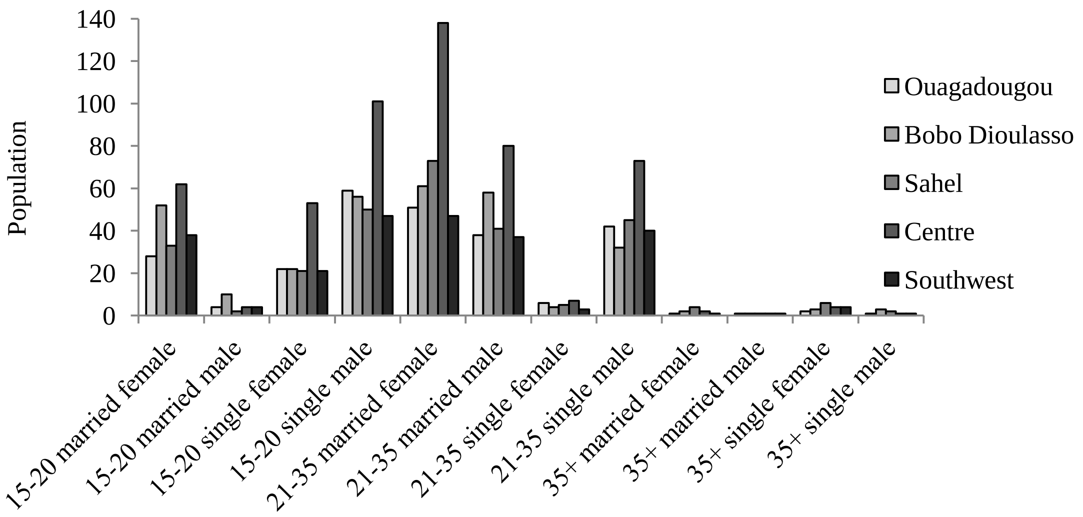

Figure 5.4: 1970 EMIUB population of individuals in each zone that fall within each category of agent characteristics.

It is evident from Figure 5.4 that there are relatively few over 35 year old agents in the model at startup in 1970. This results from the retrospective nature of the EMIUB dataset (survey conducted in 2000, therefore restricting the number of individuals with records reaching 1970 to those aged 30 and over in 2000) and, in post validation runs of the AMARC model, is rectified by modelled demographic change creating a more representative population structure. In early versions of the model, required for as stringent validation as possible, the 1970 population of agents are followed to the year 1999 and their model migrations compared with those recorded in the EMIUB data. Using EMIUB data from the entire period 1970-1999 allows the full spectrum of agent probability values to be captured. If only 1970-1979 data were used, probability values relating to older agents may be developed from a relatively small sample. Similarly, if the 1990-1999 data alone were used the same result would be felt on younger agents.

Of those agents aged between 15 and 20 years, very few are seen in Figure 5.4 to be married males. Similarly, if we were to extend the analysis to consider a date closer to 2000, very few of the agents aged 35 years and over, either male or female, would be single. This results from the cultural norm relating to marriage in Burkina Faso. The EMIUB data suggests that most individuals, male or female, are married by the age of 35. The greatest population classification represented in Figure 5.5 is that of married females between the ages of 21 and 35 years. This may again result from the cultural norm surrounding marriage in Burkina Faso. While there are a comparatively large number of married females aged between 21 and 35 years, there are a correspondingly small number of single females within the same age bracket. As a result, the total number of males and females within the age groups is comparable, with differing gender norms relating to marriage generating different population distributions within the agent classifications used in the model.

The EMIUB data provides the ABM developed by this thesis with the behavioural attitude values used in the migration decision-making process of each agent. Although these attitude values are affected by population dynamics such as those described above, the impact of these upon the actual running of the model is minimised by using the EMIUB data as a basis from which the agent population is constructed and changes over time. Demographic functions that affect behavioural attitude values retrieved by each classification of agent should therefore be reflected in the agent population as the model runs. Rules controlling marriage within the model are different for males and females in order to reflect the different ages at which males and females tend to marry in Burkina Faso.

The combination of agent characteristics apparently most likely to migrate according to the data presented in Figure 5.3 are married females aged between 15 and 20 years. As mentioned in Chapter 4, individuals surveyed by the EMIUB were asked to provide information on their motives for migration. Unfortunately, data on the motives of migrants was not comprehensive. Nonetheless, in performing data analysis to derive migration probability values, those individuals who stated that their motive for migration was marriage (coded as 435 in the EMIUB) were removed, as were those who listed their motive as a work-related involuntary posting (coded as 105 in the EMIUB). Migration listed as being motivated by either marriage or a posting were removed from the data analysis as they are both considered to be largely independent of rainfall. Although the timing of the relocation of a female individual to a new location for the purpose of marriage may be affected by rainfall in terms of, for example, the ability of the household to invest in a dowry, it was considered by this research that the destination of the migrant is unlikely to be influenced by rainfall. Similarly, a work-related posting such as, for example, to fill a government position in a different department, is considered external to the influence of rainfall. Although the value of this decision may be debated it is important to note that the exclusion of individuals migrating for marriage and postings is consistently and transparently retained throughout this research.

Despite this measure to remove the influence of marriage migration from the EMIUB data record, the apparent high proportion of married females aged between 15 and 20 years can likely be attributed, in part, to marriage migration as a result of the incomplete record of migrant motives. Field interviews performed in Burkina Faso in early 2009 provided verbal evidence that young married females are in fact very unlikely to migrate and would largely do so only when the family's harvest yield was so low that family members could not be supported at home. Young females are however very likely to migrate for the purpose of marriage between the ages of 15 and 20 years. Despite removing those individuals that cited marriage as their motive for moving from the data analysis, the limited information on motives for migration results in numerous marriage migrants remaining in the data. Despite the fact that a large proportion of migrants in the EMIUB are young females probably migrating for marriage, they cannot be removed from the data on this assumption alone. The fact that the probability of migrating is considerably higher for married females aged 21-35 years than single females of the same age is however evidence of this phenomenon. As the EMIUB data analysis identified the number of migrants with given characteristics each year, those young females who migrated for marriage would have become married that year and therefore been represented in the data as married women. This phenomenon can be assumed as a result of the structure of the EMIUB data and resulting analysis. However, no action has been taken to rectify the anomaly due to the lack of concrete evidence and an unwillingness to 'fix' the data to better suit the world view as seen by the author. Given infinite time and resources, it would be possible to undertake such a fix and test its influence upon model outcomes. However, within the constraints of this research, such a step was deemed unnecessary.

Other than the potentially anomalous results for married females aged between 15 and 20 years, the migration probability values calculated for agents originating in each of the five zones show a good level of similarity in terms of the general migration trends for each classification of agent characteristic. The agent classes with generally the most consistently high trends towards migration are seen to be single males aged between 15 and 35 years. This aligns well with information on the migration of Burkinabé people collected during the field study period of this research. Focus group interviews conducted across Burkina Faso support the notion that the first and most willing to migrate are young males, particularly those who are unmarried. Overall, apart from the potentially anomalous probability results for married females aged between 15 and 20 years, female agents are, as a result of the behavioural attitude score they retrieve in the formation of their intention towards migration, less likely to migrate. This fits well with evidence collected during focus group interviews conducted in Burkina Faso where the general consensus appeared to be that women and old men only migrate away from their home village in years with a very bad harvest.

The behavioural attitude values retrieved by agents in the ABM reflect the agent's age, gender, marital status, origin location, and the rainfall conditions affecting them in the year in question. The five standard weight matrices used by the five sets of agents in the ABM (ppt.mp30) each have 36 behavioural attitude probability values that may be retrieved by an agent on the basis of their individual characteristics. With a total of 180 behavioural attitude values thus available to each of the five sets of agents included in each model run (giving a total of 900 probabilities), the sum probability of all agent classes migrating are presented here. The full range of weight matrices used in each model run are included as Appendix 4. Figure 5.5 displays the sum probability of all agent classes from Ouagadougou migrating to any destination under dry, average and wet rainfall conditions according to the current year's rainfall and migration data from 1970-1999 ($ppt.mp30$). The sum of all agent classes from a particular origin zone represents a crude and simplistic means of calculating the likelihood of migration on the basis of the sum of the parts. Such information can be used in later analysis in order to identify the similarities and contrasts between a simplistic statistical approach and the ABM method described by this thesis.

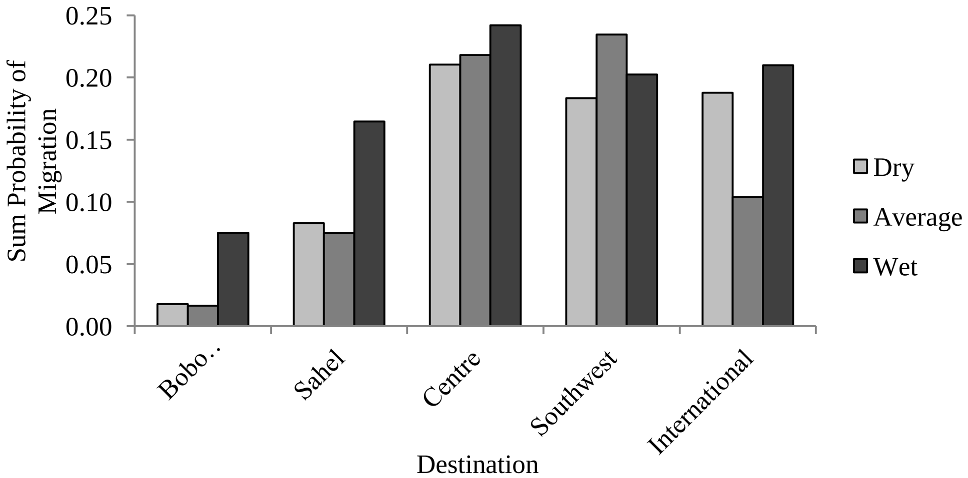

Figure 5.5: Sum probability of all individuals originating in Ouagadougou migrating to alternative destinations in dry, average and wet rainfall years using $ppt.mp30$.

It can be seen from Figure 5.5 that the most common destinations overall from Ouagadougou are Centre and Southwest with the highest probability of migration seen to Centre under wet rainfall conditions. It is evident that the highest overall probability of migrating from Ouagadougou to Bobo Dioulasso, Sahel, Centre and International are highest under wet rainfall conditions. However, in the case of migration to Southwest, overall probabilities are highest under average rainfall. The least likely destination for migrants under any rainfall conditions is

Bobo Dioulasso with Sahel a close second. However, the increase in the sum probability of migration to these destinations increases considerably under wet conditions. Figure 5.6 displays the sum probability of all individuals originating in Bobo Dioulasso migrating to any destination under dry, average and wet rainfall conditions according to the current year's rainfall and migration data from 1970-1999 ($ppt.mp30$).

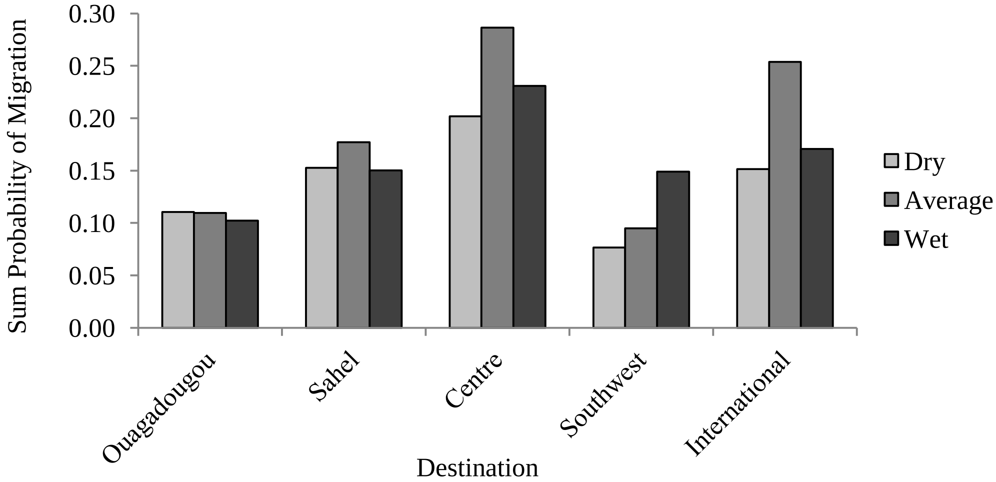

Figure 5.6: Sum probability of all individuals originating in Bobo Dioulasso migrating to alternative destinations in dry, average and wet rainfall years using $ppt.mp30$.

The overall highest scoring destination for migrants from Bobo Dioulasso is seen in Figure 5.6 to again be Centre, but this time under average rainfall conditions. The sum probability of migration from Bobo Dioulasso to Sahel, Centre and International is seen to be highest under average rainfall conditions with wet conditions resulting in the highest rate of migration to Southwest. The overall probability of any individual migrating to Ouagadougou shows the least difference between rainfall conditions. Figure 5.7 displays the sum probability of all individuals originating in Sahel migrating to any destination under dry, average and wet rainfall conditions according to the current year's rainfall and migration data from 1970-1999 ($ppt.mp30$).

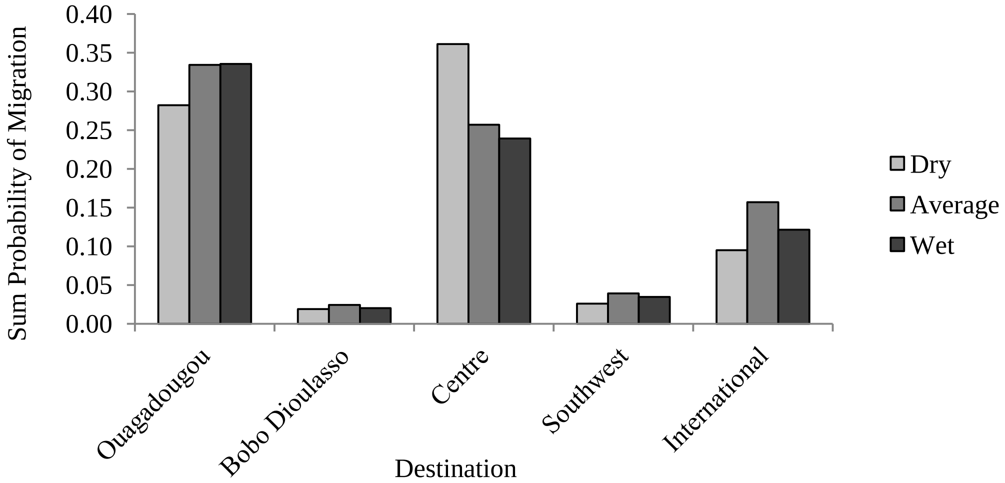

Figure 5.7: Sum probability of all individuals originating in Sahel migrating to alternative destinations in dry, average and wet rainfall years using $ppt.mp30$.

It can seen from Figure 5.7 that the sum probability of individuals migrating from Sahel to either Bobo Dioulasso or Southwest is low under any rainfall conditions. The highest sum probability destination is again seen to be Centre but under dry rainfall conditions. Migration to Ouagadougou is seen to be the second most probable option under either average or wet conditions. The highest overall probability of international migration from Sahel is seen to occur under average rainfall conditions. Figure 5.8 displays the sum probability of all individuals originating in Centre migrating to any destination under dry, average and wet rainfall conditions according to the current year's rainfall and migration data from 1970-1999 ($ppt.mp30$).

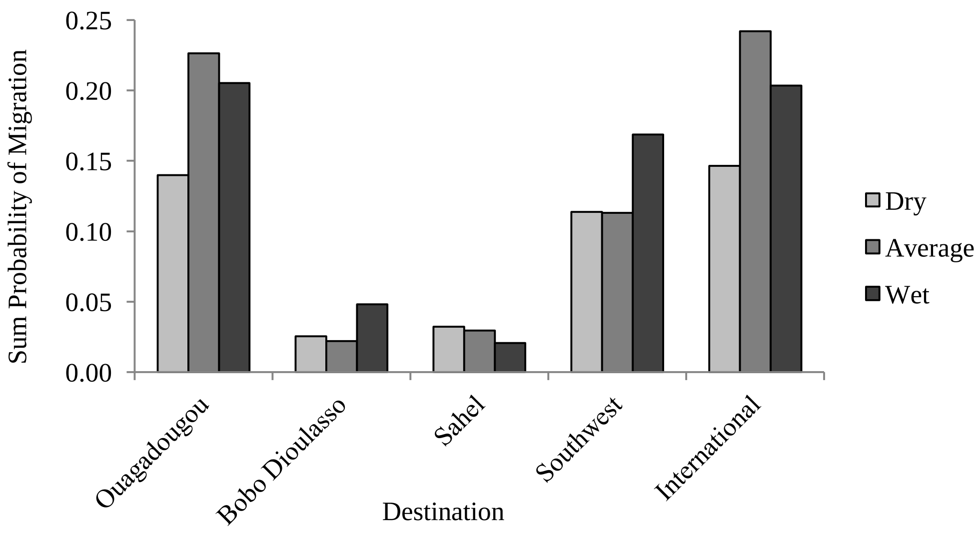

Figure 5.8: Sum probability of all individuals originating in Centre migrating to alternative destinations in dry, average and wet rainfall years using $ppt.mp30$.

The highest sum probability destination from Centre is seen in Figure 5.8 to be International under average rainfall. Such conditions also result in the highest sum probability of migration to Ouagadougou. While the highest sum probability of migrating to Southwest is seen as occurring under wet conditions, the probability of migration to either Bobo Dioulasso or Sahel is low under any rainfall conditions. Figure 5.9 displays the sum probability of all individuals originating in Southwest migrating to any destination under dry, average and wet rainfall conditions according to the current year's rainfall and migration data from 1970-1999 ($ppt.mp30$).

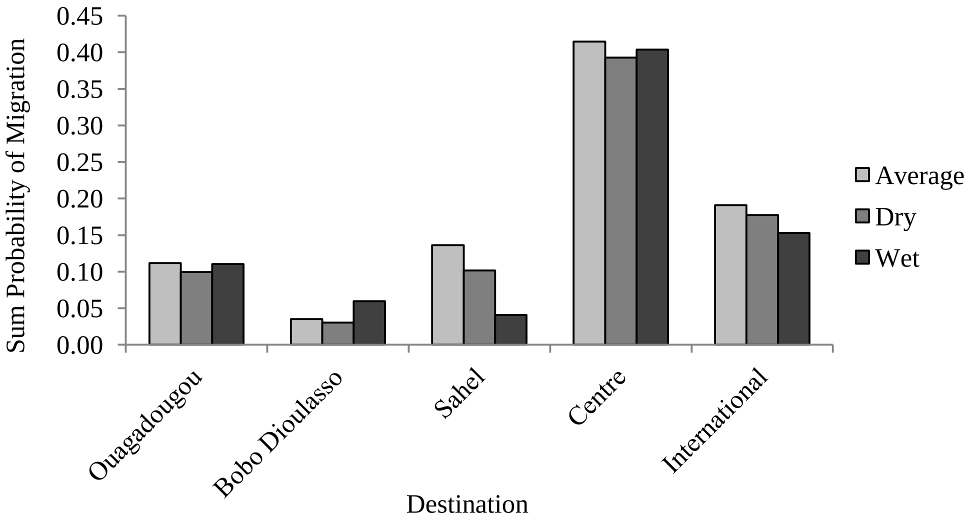

Figure 5.9: Sum probability of all individuals originating in Southwest migrating to alternative destinations in dry, average and wet rainfall years using $ppt.mp30$.

It can be seen from Figure 5.9 that the most probable destination for any migrant from Southwest under any rainfall conditions is Centre with relatively little variation in probability value between rainfall scenarios. The second most probable overall destination is seen to be International with, as in the case of migration to Centre, a marginally higher sum probability calculated for dry rainfall conditions. Once again, the probability of migrating to Bobo Dioulasso is low while the intermediate-level destinations of Ouagadougou and Sahel are seen to again have the greatest sum probabilities as destinations under dry rainfall conditions. In order to understand the general trend of relationships between rainfall and sum probability of migration from each zone, Figure 5.10 displays the total sum probability of individuals in each zone migrating to any destination.

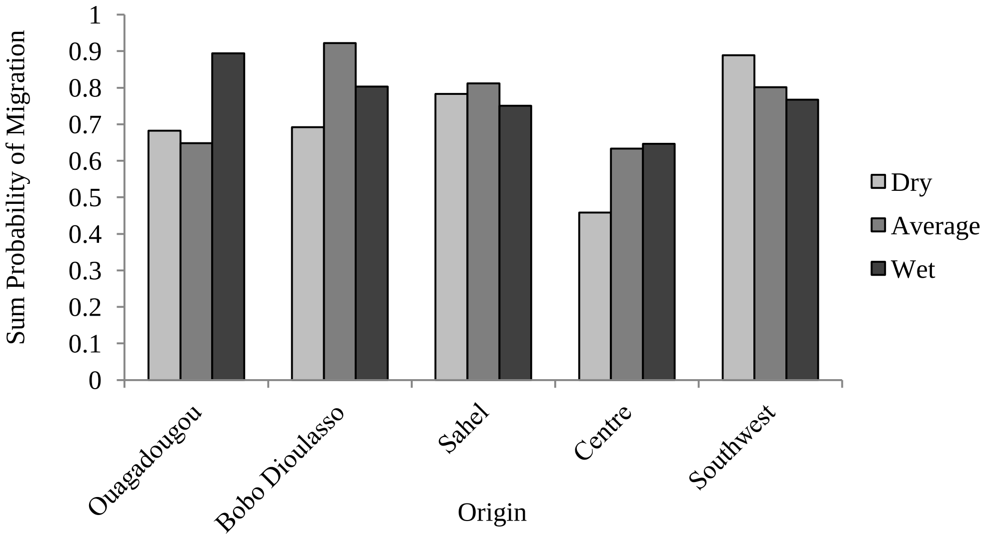

Figure 5.10: Sum probability of all individuals originating in each zone migrating in dry, average and wet rainfall years using $ppt.mp30$.

It can be seen from Figure 5.10 that the total sum trend in migration from Ouagadougou that is broken down into different destinations in Figure 5.5 results in a considerably higher sum probability of migration under wet rainfall conditions. Although the lowest sum probability can be seen to occur under average rainfall, the sum value for dry conditions is not dissimilar. By contrast, the sum probability of migration from Bobo Dioulasso is greatest under average rainfall with dry conditions resulting in the greatest decrease in sum probabilities away from the average maximum. Relatively little variation between the sum probability of migration away from Sahel is seen between the different rainfall conditions with average rainfall resulting in the greatest sum probability. In the case of migration from Centre, a significantly lower sum probability of migration is seen under dry conditions with the highest sum probability seen for wet conditions. Finally, in the case of migration from Southwest, the highest sum probability of migration is seen to result from dry conditions with the lowest value calculated for wet conditions.

It is evident from the above brief representation of the sum probabilities of all classes of agents from each of the five destinations migrating to any other zone that the nature of the empirically-derived likelihoods of migration vary considerably between origin, destination and rainfall conditions. Such multiple and varied statistical relationships between origins, destinations and rainfall are unlikely to even come close to capturing the full complexity of the real variety of relationships derived from the EMIUB data for each of the twelve agent classifications of age, gender and marital status. Such complex interrelationships between each of the variables included in these relationships contribute to the value of using agent-based modelling to investigate the role of these multiple factors upon individual attitudes towards migration and the interplay between such attitudes with the additional components of subjective norms and perceived behavioural controls. Despite the complexity of the multiple and varied relationships between rainfall and migration, it is interesting to identify the rainfall conditions that lead to the greatest sum probability of migration to any destination by any individual in all zones. Such propensity to migrate is displayed in Figure 5.11 using sum probabilities for all individuals and those suggested to be most likely to migrate by focus group participants (all males and females aged between 15 and 20 plus all males aged between 21 and 35).

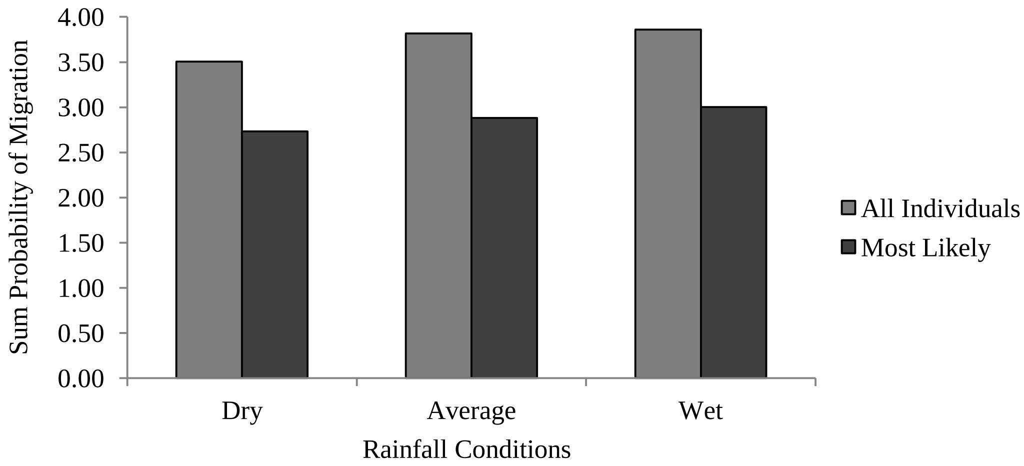

Figure 5.11: Sum probability of all individuals and those deemed the most likely migrants originating in all zones migrating to alternative destinations in dry, average and wet rainfall years using $ppt.mp30$.

It can be seen from Figure 5.11 that, whether considering the sum probability of migration on the basis of all individuals or only those considered most likely to relocate, propensity to migrate increases slightly with increased rainfall. Such a relationship represents the total overall pattern of migration that could be anticipated from a simplistic analysis of the impact of rainfall upon migration in Burkina Faso. Figure 5.12 divides the sum probability of all individuals migrating into internal and international destinations under dry, average and wet rainfall conditions.

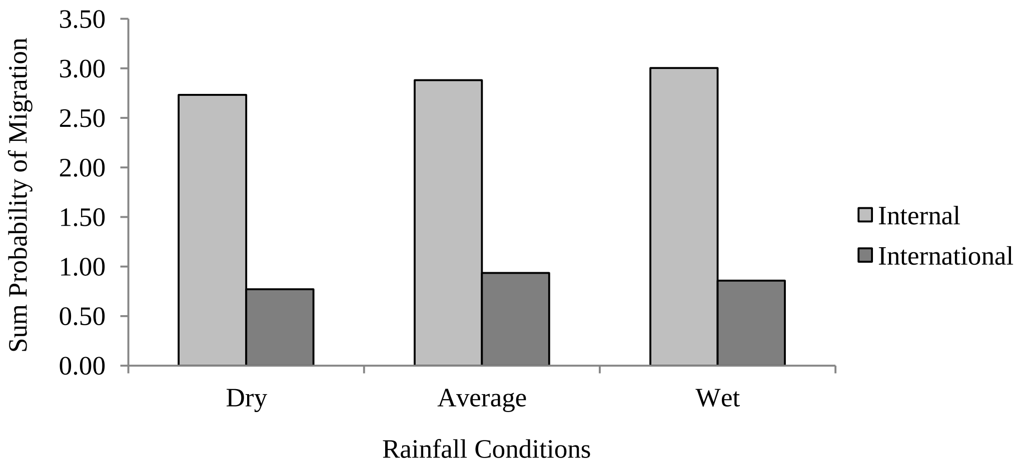

Figure 5.12: Sum probability of all individuals and those deemed the most likely migrants originating in all zones migrating to internal and international destinations in dry, average and wet rainfall years using $ppt.mp30$.

The sum probability of all individuals migrating under dry, average and wet rainfall is seen in Figure 5.12 to result in a pattern of increased migration with increased rainfall when considered on the basis of internal migration. However, when considered on the basis of international migration, the greatest sum probability of migration is seen to result from average rainfall conditions. Both an increase and decrease in rainfall away from average conditions is seen to result in a decreased sum probability of all individuals migrating to international destinations. Although not displaying the true complexity of the relationship between individual attributes and migration to different destinations under different destinations due to the vast array of probability values required for the modelled migration decision, the relationships between rainfall and migration shown in Figures 5.5 to 5.12 provide an interesting broad basis for later comparison with the migration flows simulated by the AMARC model. Differences between the trends displayed here and those modelled by the ABM that incorporates the additional components involved in the modelled migration decision can be used to indicate the additional value contributed by the agent-based modelling approach.

5.5 Subjective Norm

The purpose of the subjective norm component of an agent's decision to migrate is to incorporate the influence of an individual's peers upon their development of behavioural intentions. The ideal manner in which to derive the influence of an agent's peers would involve interrogation of a dataset that contained migration and social network information relating to a community of individuals such as those represented in the EMIUB data. In such a case a comparison could be made of the migration histories of individuals with the same age, gender, marital status, assets, and origin location but with unique social networks. From such an approach the influence of an individual's peers' migration histories upon their own could be inferred. However, due to the lack of availability of such data the calculation of a relationship/function linking the likelihood of an individual migrating to the number of people they know who have also migrated is derived through alternative means.

Working with the information and data available to this research the subjective norm component of the decision to migrate is therefore derived through an agent's consideration of the opinions of their networked peers (po) (Equation 10). In each simulation run each agent in the model is linked to an average of fifty others through a network defined at model startup. In a continuous 2-dimensional environment such as that used in the model, the network can be defined as random (agents are connected randomly), scale-free (some agents are social 'hubs' while others are 'hermits') or ring-lattice (each agent is connected to a given number of closest agents in a ring formation). Networked agents pass messages between themselves that inform one another of their most recent migration decisions. On the basis of the messages received by an agent from their peers, a scoring system is used to assign peer opinion values to each of the migration options being considered. However, as the number of peer messages an agent is likely to need to persuade them to migrate to a new location is dependent upon their individual circumstances, a multiplier function (f) is used to weight the values. For example, an agent migrating internally from the Sahel will have a different cultural norm affecting their behaviour to that of an agent considering the same migration but living in the Southwest.

$$SN = f(po)$$

(Equation 10)

Analysis of the EMIUB dataset reveals a range of probabilities of an agent migrating either internally or internationally in the top ten most populated locations in each of the five zones in 1990. The average probability of an individual migrating from each of these locations between 1990 and 1999 is used to suggest the range of the peer impact component (po) of the subjective norm. For example, the lowest average 1990-1999 probability of migrating internally from a location (individual village/town) within the Sahel is 0.040 while the maximum average 1990-1999 probability provided by another location within the zone is 0.102. By ranking the average 1990-1999 migration probability values for the top 10 most inhabited locations in the region in this manner and dividing each by the average 1990-1999 probability of migrating internally from the whole of the Sahel zone, a multiplier function can be developed. In doing so, the different migration trends of each location are derived as being a function of the influence of the migration history of individuals upon one another through the interactions of a social network.

Tables 5.1 to 5.10 display the internal and international 1990-1999 average migration probability and migration factor values for migrants from the top ten most populated locations within each of the five origin zones used in the ABM. Each table displays the data in ascending migration probability order. The probability of migration is defined as the average annual probability of any individual from the population of that location migrating out of the origin zone in the period 1990-1999. Migration factors are defined as the relevant location's probability of migration divided by the probability of an individual migrating from anywhere within the zone within the same time period.

INTERNAL MIGRATION FROM OUAGADOUGOU		
Location ID	Probability of Migration	Migration Factor
124	0.0083	0.1492
106	0.0317	0.5670
133	0.0324	0.5805
128	0.0425	0.7605
141	0.0446	0.7976
137	0.0602	1.0784
126	0.0749	1.3403
131	0.0768	1.3749
108	0.0819	1.4653
101	0.0842	1.5078

Table 5.1: 1990-1999 probability of internal migration and internal migration factors for the top ten most populated locations within Ouagadougou. Average 1990-1999 probability of internal migration from Ouagadougou = 0.0559

INTERNATIONAL MIGRATION FROM OUAGADOUGOU		
Location ID	Probability of Migration	Migration Factor
128	0.0059	0.3691
126	0.0083	0.5221
137	0.0095	0.5976
106	0.0103	0.6453
124	0.0138	0.8665
108	0.0201	1.2596
133	0.0202	1.2647
141	0.0243	1.5260
101	0.0314	1.9732
131	0.0463	2.8994

Table 5.2: 1990-1999 probability of international migration and international migration factors for the top ten most populated locations within Ouagadougou. Average 1990-1999 probability of international migration from Ouagadougou = 0.0159

INTERNAL MIGRATION FROM BOBO DIOULASSO		
Location ID	Probability of Migration	Migration Factor
208	0.0300	0.4909
219	0.0361	0.5910
226	0.0399	0.6529
240	0.0407	0.6664
237	0.0521	0.8523
220	0.0542	0.8871
210	0.0658	1.0758
224	0.0699	1.1429
215	0.0921	1.5063
203	0.1168	1.9102

Table 5.3: 1990-1999 probability of internal migration and internal migration factors for the top ten most populated locations within Bobo Dioulasso. Average 1990-1999 probability of internal migration from Bobo Dioulasso = 0.0611

INTERNATIONAL MIGRATION FROM BOBO DIOULASSO		
Location ID	Probability of Migration	Migration Factor
208	0.0000	0.0000
226	0.0000	0.0000
219	0.0067	0.4781
215	0.0083	0.5963
220	0.0113	0.8111
210	0.0132	0.9471
224	0.0171	1.2226
237	0.0225	1.6096
203	0.0239	1.7120
240	0.0383	2.7390

Table 5.4: 1990-1999 probability of international migration and international migration factors for the top ten most populated locations within Bobo Dioulasso. Average 1990-1999 probability of international migration from Bobo Dioulasso = 0.0140

INTERNAL MIGRATION FROM SAHEL		
Location ID	Probability of Migration	Migration Factor
436	0.0403	0.5963
424	0.0465	0.6887
440	0.0478	0.7077
415	0.0518	0.7673
426	0.0561	0.8297
409	0.0616	0.9112
411	0.0660	0.9768
423	0.0978	1.4471
408	0.0979	1.4487
407	0.1015	1.5025

Table 5.5: 1990-1999 probability of internal migration and internal migration factors for the top ten most populated locations within Sahel. Average 1990-1999 probability of internal migration from Sahel = 0.0676

INTERNATIONAL MIGRATION FROM SAHEL		
Location ID	Probability of Migration	Migration Factor
415	0.0000	0.0000
436	0.0000	0.0000
408	0.0000	0.0000
423	0.0051	0.3570
424	0.0077	0.5354
426	0.0079	0.5478
411	0.0162	1.1252
409	0.0168	1.1670
440	0.0189	1.3161
407	0.0358	2.4890

Table 5.6: 1990-1999 probability of international migration and international migration factors for the top ten most populated locations within Sahel. Average 1990-1999 probability of international migration from Sahel = 0.0144

INTERNAL MIGRATION FROM CENTRE		
Location ID	Probability of Migration	Migration Factor
606	0.0230	0.3664
712	0.0323	0.5141
505	0.0414	0.6589
528	0.0421	0.6694
503	0.0432	0.6873
533	0.0582	0.9251
502	0.0651	1.0351
727	0.0660	1.0498
729	0.0762	1.2119
615	0.0826	1.3137

Table 5.7: 1990-1999 probability of internal migration and internal migration factors for the top ten most populated locations within Centre. Average 1990-1999 probability of internal migration from Centre = 0.0629

INTERNATIONAL MIGRATION FROM CENTRE		
Location ID	Probability of Migration	Migration Factor
528	0.0000	0.0000
712	0.0029	0.1624
503	0.0074	0.4089
505	0.0099	0.5485
502	0.0148	0.8188
729	0.0185	1.0236
606	0.0243	1.3395
615	0.0261	1.4418
727	0.0317	1.7490
533	0.0335	1.8481

Table 5.8: 1990-1999 probability of international migration and international migration factors for the top ten most populated locations within Centre. Average 1990-1999 probability of international migration from Centre = 0.0181

INTERNAL MIGRATION FROM SOUTHWEST		
Location ID	Probability of Migration	Migration Factor
810	0.0203	0.2893
828	0.0318	0.4528
328	0.0352	0.5006
344	0.0532	0.7560
343	0.0569	0.8085
822	0.0690	0.9816
827	0.0714	1.0158
334	0.0716	1.0181
345	0.0736	1.0465
327	0.0748	1.0632

Table 5.9: 1990-1999 probability of internal migration and internal migration factors for the top ten most populated locations within Southwest. Average 1990-1999 probability of internal migration from Southwest = 0.0703

INTERNATIONAL MIGRATION FROM SOUTHWEST		
Location ID	Probability of Migration	Migration Factor
328	0.0000	0.0000
828	0.0000	0.0000
334	0.0000	0.0000
327	0.0100	0.6215
810	0.0106	0.6616
827	0.0202	1.2531
822	0.0202	1.2575
344	0.0232	1.4399
343	0.0261	1.6206
345	0.0515	3.2032

Table 5.10: 1990-1999 probability of international migration and international migration factors for top the ten most populated locations within Southwest. Average 1990-1999 probability of international migration from Southwest = 0.0161

Tables 5.1 to 5.10 provide the range of average internal/international migration probability values for the top ten most inhabited locations in each of the five model zones. The most inhabited locations have been used for this purpose based upon the assumption that a larger population presents a greater opportunity for an influential social network. The larger populations also give the average migration values greater significance due to the increased sample size.

Using the migration factor data presented above, the shape of the influence of subjective norm upon the migration decision can be inferred. However, rather than create an overly complex subjective norm function using regression equations that require further assumptions on the number of peers required to affect an individual agent's behaviour, migration factor values are interpreted using a more simplistic approach. From the range of migration factors calculated for each zone, the minimum, average and maximum values are used to develop the subjective norm used in the AMARC model. The mean migration factor for a zone is therefore used to represent the standard subjective norm function used if an agent in the model has been recommended a particular migration option by just one of their peers. In such an instance, the subjective norm value an individual would return on the basis of their peer opinions for that option would be 1, having no impact upon the relevant behavioural attitude value as per Equation 1.

If an agent has zero peers that favour migration to the option being considered, the agent uses the minimum relevant migration function ($MIN.mf$) for their zone but adjusted to represent the appropriate proportion of the average ($AVE.mf$) using Equation 11.

$$po = MIN.mf \ \times AVE.mf$$

(Equation 11)

For example, if the minimum internal migration function for the Sahel is 0.2893, and the average is 0.7932, due to the fact that the average has been used to represent the standard state of play and is the equivalent to a subjective norm of 1, the minimum migration function will be adjusted to be 0.2295 (0.2893 x 0.7932). In the same way, the maximum migration function ($MAX.mf$) is adjusted to be proportional to the average using Equation 12. If an agent has more than one networked peer that favours migration to the destination being considered the maximum peer opinion value, derived from the proportionally adjusted relevant maximum migration factor for the zone and destination will be used.

$$po = MAX.mf \ \times AVE.mf$$

(Equation 12)

Tables 5.11 to 5.20 display the minimum, average and maximum internal and international migration factor values calculated for each zone and the proportionally adjusted peer opinion values that represent the modelled subjective norm in the AMARC model.

Ouagadougou	Minimum	Average	Maximum
Internal Migration Function	0.1492	0.9621	1.5078
Proportional Internal Peer Opinion Value	0.1435	1.0000	1.4507

Table 5.11: Minimum, average and maximum migration functions and proportionally adjusted peer opinion values for internal migration destination options from Ouagadougou.

Ouagadougou	Minimum	Average	Maximum
International Migration Function	0.3691	1.1924	2.8994
Proportional International Peer Opinion Value	0.4401	1.0000	3.4570

Table 5.12: Minimum, average and maximum migration functions and proportionally adjusted peer opinion values for international migration destination options from Ouagadougou.

Bobo Dioulasso	Minimum	Average	Maximum
Internal Migration Function	0.4909	0.9776	1.9102
Proportional Internal Peer Opinion Value	0.4798	1.0000	1.8673

Table 5.13: Minimum, average and maximum migration functions and proportionally adjusted peer opinion values for internal migration destination options from Bobo Dioulasso.

Bobo Dioulasso	Minimum	Average	Maximum
International Migration Function	0.0000	1.0116	2.7390
Proportional International Peer Opinion Value	0.0000	1.0000	2.7707

Table 5.14: Minimum, average and maximum migration functions and proportionally adjusted peer opinion values for international migration destination options from Bobo Dioulasso.

Sahel	Minimum	Average	Maximum
Internal Migration Function	0.5963	0.9876	1.5025
Proportional Internal Peer Opinion Value	0.5889	1.0000	1.4839

Table 5.15: Minimum, average and maximum migration functions and proportionally adjusted peer opinion values for internal migration destination options from Sahel.

Sahel	Minimum	Average	Maximum
International Migration Function	0.0000	0.7538	2.4890
Proportional International Peer Opinion Value	0.0000	1.0000	1.8761

Table 5.16: Minimum, average and maximum migration functions and proportionally adjusted peer opinion values for international migration destination options from Sahel.

Centre	Minimum	Average	Maximum
Internal Migration Function	0.3664	0.8432	1.3137
Proportional Internal Peer Opinion Value	0.3089	1.0000	1.1077

Table 5.17: Minimum, average and maximum migration functions and proportionally adjusted peer opinion values for internal migration destination options from Centre.

Centre	Minimum	Average	Maximum
International Migration Function	0.0000	0.9341	1.8481
Proportional International Peer Opinion Value	0.0000	1.0000	1.7263

Table 5.18: Minimum, average and maximum migration functions and proportionally adjusted peer opinion values for international migration destination options from Centre.

Southwest	Minimum	Average	Maximum
Internal Migration Function	0.2893	0.7932	1.0632
Proportional Internal Peer Opinion Value	0.2295	1.0000	0.8433 (1)

Table 5.19: Minimum, average and maximum migration functions and proportionally adjusted peer opinion values for internal migration destination options from Southwest.

Southwest	Minimum	Average	Maximum
International Migration Function	0.0000	1.0057	3.2032
Proportional International Peer Opinion Value	0.0000	1.0000	3.2216

Table 5.20: Minimum, average and maximum migration functions and proportionally adjusted peer opinion values for international migration destination options from Southwest.

It can be seen from Tables 5.11 to 5.20 that the average migration functions generally fall close to 1. As such, the proportional peer opinion values are not all that far removed from those provided by the migration functions. Where a peer opinion value is calculated to be less than 1, the impact of the resulting subjective norm upon the behavioural intention calculated using Equation 1 will be negative, reducing the likelihood of migration to that destination. Conversely, a peer opinion value of greater than 1 will increase behavioural intention towards the relevant option. In all cases of internal migration, having zero peers that favour the option being considered reduces an agent's peer opinion value considerably. However, in the case of international migration, originating in any zone other than Ouagadougou and having no peers that favour international migration results in a peer opinion value of 0. An agent returning a peer opinion value of zero will also return a subjective norm value of zero which will, when applied to Equation 1, result in no chance of an International migration destination being selected. As a result, in order for a positive intention towards international migration to be developed by an agent from Bobo Dioulasso, Sahel, Centre or Southwest zones, at least one peer must already favour the option. Further to this nuance of the peer impact upon international migration, having more than one peer favour the option has a significant impact upon the likelihood of an agent selecting international migration as a result of the peer opinion value returned being almost 3.5 (in the case of international migration from Ouagadougou), more than tripling the intention towards this option.

At the start of each model run in 1970, each agent is initialised into the model with their relevant prior experience of migration as recorded in the EMIUB data. As such, agents in all zones can be networked with peers that have experience of International migration right from model startup in 1970. Such experience can feed into the peer opinions of agents in all zones and support future International migration despite the potential for a subjective norm value of zero being returned under a no-favouring-peers scenario. Furthermore, positive experience of migration from Ouagadougou to International destinations could potentially cascade through the system, increasing peer opinion strategies towards such migration through each agent's network of peers. Such interactions may give rise to previously unexpected flows of International migrants, an example of a potentially emergent property for which agent-based models are prized.

Although the subjective norm component of the AMARC modelled decision to migrate appears to recreate the approximately expected impact of peer opinions upon the migration decision through the use of a quantitative analytical approach, internal migration from the Southwest presents itself as a slight anomaly. Internal migration from the Southwest is the only migration flow for which the average and maximum migration functions combine to produce a peer opinion value of less than 1. Using Equation 12 the maximum peer opinion calculated is 0.8433, thereby still reducing an agent's intention towards internal migration despite the recommendation of numerous peers. In order to retain the value of the migration probability values calculated in the behavioural attitude component of the decision to migrate, this value is therefore rounded to 1. Such a result suggests that originating in the Southwest and knowing more than one person who favours a particular internal migration option has no additional impact upon the final decision to migrate in peer opinion terms. By contrast, having zero peers that favour internal migration from the Southwest still results in a clear decrease in peer opinion value and therefore subjective norm.

Because of the lack of data on peer impact and the crucial role of the number of peer opinions an agent needs to retrieve a subjective norm value that crosses the threshold from a negative to a positive peer impact, the values used in the AMARC model are simplified so that any more than 1 peer favouring an option produces the maximum peer opinion value. In a real-world social network different individuals may communicate with varying numbers of peers with varying powers of influence over their migration decision. In order to recreate some of this level of social interaction, agents within the model are each connected with up to 50 peers with whom they interact. Although 50 connected peers may be more than an average individual would realistically have, as a result of the manner in which the networks in the AMARC model are established, a proportion of these connected peers will be under the age of 15 and therefore not undertaking an independent migration decision themselves or contributing to the decisions of others. Thus, in reality, although a modelled agent's network may be made up of 50 peers, considerably fewer will be having an influential impact.

Using an artificially enlarged modelled network to account for non-influential peers and a simplified assumption as to the precise number of peers required to push an agent across the subjective norm threshold (where peer opinions have a positive rather than negative impact upon behavioural intention), the subjective norm component of the AMARC modelled decision to migrate is defined. This approach allows a peer's opinions to affect the behaviour of an agent, encouraging individual agency through communication with a unique social network. Such an approach to the inclusion of social factors has been undertaken as a result of the data shortage and uncertainty relating to the precise nature of the relationship between an individual's migration decision and the view of their peers in a modelled network in Burkina Faso.

5.6 Behavioural Intention

By calculating behavioural intention on the basis of Equation 1, each agent stores intention values relating to the five migration options available for their consideration. Comparing each of the intention values an agent has assigned to each of the migration options available to them and identifying the highest scoring option enables an agent to then make a behavioural choice. Starting with the highest scoring migration option considered, each agent 'rolls a dice' to see if their intention is realised. This dice roll is achieved through the generation of a random number between 0 and 1. If the number generated is less than the final intention score, the agent will follow that course of action. If however the random number is greater than the intention value the agent moves on to consider the next highest scoring migration option they have considered. Without this step agents would gravitate to the location for which they score the highest attitude value. While this is, in essence, the desired outcome, if agents with specific age, gender and marital status values retrieve an attitude score of, for example, 0.0075 for one migration option and 0.0074 for another, without this additional dice roll, disproportionately more agents would migrate to the marginally higher scoring location. Furthermore, the process outlined here is intended to satisfy Simon's (1957) notion of satisficing and the sub-optimal decision-making undertaken by humans.

In the AMARC models an agent will only ever migrate for a period of 7 months before they return to their origin location. For the sake of simplicity, the migration decision is undertaken by all agents in the month of August before actual migration occurs during September, post-harvest at the beginning of the dry season. Following migration in September, all agents then return to their home locations at the beginning of the wet season in May. Although this may not represent the full complexity of real world migration of all Burkinabé people, for the sake of model simplicity and transparency of results, this standard rule is applied to all agents. Field interviews conducted in Burkina Faso revealed that many people across the country reside and work at home for the duration of the wet season, only migrating following the harvest in August/September.

5.7 Model Cycles and Feedbacks

Through feedbacks built into the model, events that occur as it runs through each year of the simulation play a part in later events. As an agent goes through the process of ageing and getting married, their attributes change and the behavioural attitude they apply to each migration decision changes. Equally, as an agent gains experience of migration to various destinations, their perceived behavioural control value for repeating that action again increases. As these values change, so too do the messages that agents send to their peers regarding their preference for each option, therefore impacting the subjective norm values used by agents in their own decisions. It is these interacting components within the ABM that can produce emergent behaviour beyond that anticipated by a more linear statistical analysis. As time progresses in the model, the rainfall conditions affecting migrants also change. These changes in rainfall then play a part in affecting the migration decisions of individuals.

5.8 Summary

Following the conceptual model development described in Chapter 4, this chapter details the translation of the Simplified Model of Adaptation to Rainfall Change (SMARC) conceptual model into a working ABM. Through translation of the Theory of Planned Behaviour components into model functions and equations modelled agents can develop intentions towards migration behaviour on the basis of their quantified behavioural attitude, subjective norm and perceived behavioural control towards each option. Following a comparison of the intentions developed by an agent towards migration options, a favoured migratory behaviour is selected by an agent and undertaken. Using the model elements described above, Chapter 6 outlines the process undertaken to test the ability of the model to replicate the migration decision in Burkina Faso. This process is achieved by running the model for a period during which observed migration flow data is available for verification and validation of the modelled results.

Chapter 6

Model Validation and Testing

6.1 Introduction

Developed to simulate the migration decision of people living in Burkina Faso and elucidate the role of changes in rainfall variability in that decision, the AMARC model described in Chapter 5 is intended to both replicate past migration flows from 1970 to 1999 and simulate migration in the future under different rainfall scenarios. However, before either the role of rainfall or future migration patterns can be considered, the model must be assessed in terms of its ability to validly replicate past flows. The primary aim of this chapter is therefore to assess the validity of the ABM in terms of its ability to replicate past migration flows. This validity assessment can then be used to consider the authority of the model in its application to both determining the role of changes in rainfall variability in the migration decision and producing predictions of migration flows resulting from different rainfall scenarios in the future. The validation process described in this chapter includes a number of different levels of comparison of model outputs with observed data available from the EMIUB. All simulation results presented in this and later chapters are the result of five member ensembles: selected as adequate to incorporate a sufficient degree of variation between runs without demanding excessive computing power to complete.

6.2 Model Validation - AMARC1 (ppt.mp30)

Numerous versions of the AMARC model have been produced that can be used at different stages in the validation and analysis stages of this research. The first of these, AMARC1, initialises with all 4,449 individuals for whom there is 1970 data available in the EMIUB. In order to perform the most stringent validation test possible, the model is run with only these 4,449 agents present in the model until its completion in 1999. The EMIUB dataset provides migration history data for these individuals up to 1999, therefore permitting direct comparison of the model with the record, herein referred to as EMIUB1. As such, no agent birth or death is permitted within the model throughout its thirty year run time. As a very stringent means of analysis where the AMARC1 model is required to attempt an exact replication of the migration decisions made by 4,449 individuals over a thirty year period, results from this level of validation should not be expected to precisely replicate the EMIUB1 data but display similar migration patterns of migrants leaving each model zone.

Agents in the AMARC1 model are located in random networks where each agent has, on average, fifty networked peers. Rainfall patterns between 1970 and 1999 are gained from the historical Delaware rainfall data described in Chapter 4. Dry, average and wet rainfall years are defined according to the quartile values of the rainfall data for each zone over the thirty year period in question. Migration probability values for use in the agents' migration decisions are derived from analysis of 1970-1999 migration data while each year is assessed as average, wet, or dry on the basis of that year alone (therefore using weight matrices $ppt.mp30$).

Table 1 of Appendix 5 displays the observed EMIUB1 migration flow data used for validation. The average annual number of migrants from all five zones over the 30 year period from 1970 to 1999 is recorded by the EMIUB1 data as 191, or 4.30% of the total population, ranging from a low of 104 migrants (2.34%) in 1971 to a high of 284 (6.38%) in 1985. The largest number of these migrants (annual average of 45) originates in the most populated zone, Centre. However, when considered as a percentage of the population of each zone, Centre represents the zone with the lowest migration rate (annual average rate of 3.27%). When viewed as a percentage migration rate, the origin location with the highest rate of migration is Southwest (annual average of 4.68%). The year with the highest overall migration, 1985, sees a contrasting pattern with the highest migration rate that year from Sahel (7.46% of zone population) and lowest from Southwest (3.79% of zone population).

Table 2 of Appendix 5 displays the averaged results of five runs of the AMARC1 model over the period 1970 to 1999. The average annual number of AMARC1 modelled migrants from all five zones over the 30 year period from 1970 to 1999 is 244 (5.48%), compared to the EMIUB1 total of 191 (4.30%). The largest number of these migrants (annual average of 57) again originates in the most populated zone, Centre. Again, when considered as a percentage of the population of each zone, and in accordance with the EMIUB1 data, Centre displays the lowest migration rate (annual average rate of 4.15%). The location modelled as having the highest migration rate (annual average of 6.21%) is Ouagadougou although both Bobo Dioulasso and Southwest also show modelled migration rates of over 6%. The AMARC1 model zone with the lowest actual number of total migrants is Southwest (annual average of 38). Total migration peaks in the model data in 1990 at 373 migrants, 5 years later than witnessed in the EMIUB1. The highest absolute migration modelled in 1990 originates from Bobo Dioulasso with 88 migrants (9.82%) although the highest migration rate modelled that year originates from Ouagadougou at 10.64% (70 migrants). The EMIUB1 data year with the highest total migrants, 1985 (284 migrants across all zones), is modelled by AMARC1 as a year with a five model run average of 309 migrants. Of these, most (72 individuals) originate in Centre although the highest migration rate is modelled as occurring in Southwest (8.78% of total population).

When the migration patterns of the 4,449 agents recorded as alive in 1970 by the EMIUB1 data are followed in their migration histories both throughout their lifespan in the observed data and in the AMARC1 model, some inevitable discrepancies do occur. These discrepancies are, to some extent, to be anticipated due to the nature of the manner that the AMARC1 model works to isolate rainfall as the primary motive for migration. Within the EMIUB1 data, individuals will be migrating for numerous interconnected reasons. By contrast, the AMARC1 model uses rainfall as the only precursor to migration in its attempt to isolate and assess its role in the migration decision. This, the most stringent means of testing and validating the AMARC models against the observed data, can be best considered in terms of the general trend in the overall flow of migrants from the model and its comparison to the EMIUB1 data. Figure 6.1 displays the overall migration trend from all zones both from the EMIUB1 data and as a mean of five runs of the AMARC1 model.

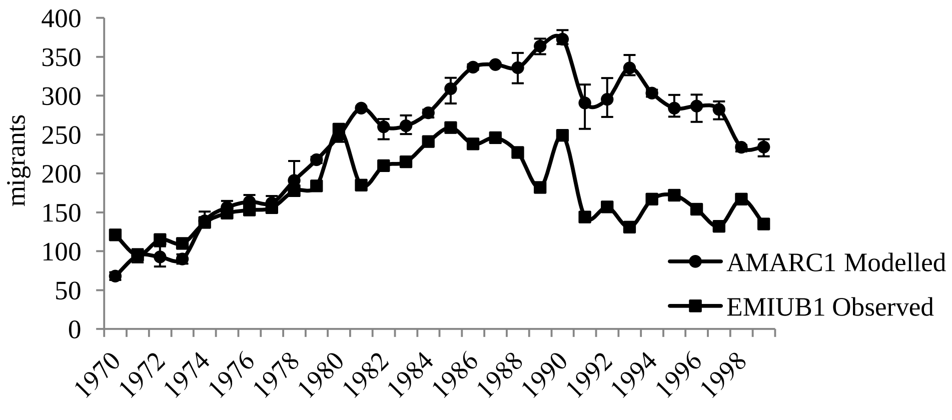

Figure 6.1: Total number of individuals alive in 1970 migrating from all zones each year from 1970-1999 in the EMIUB1 Data and the AMARC1 model five run mean. Correlation coefficient = **0.65**.

As can be seen from Figure 6.1, a considerable level of agreement is evident between the EMIUB1 data record of the 1970-1999 migration history of the 4,449 agents initialised into the model at start-up and the five run mean AMARC1 modelled migration for the same individuals over the same time period. The correlation coefficient of the two sets of data is 0.65 which, over the 30 data points, gives a significance value of greater than 0.995. Furthermore, the natural variance in the migration flows modelled by each of the five runs of the AMARC1 model are seen, from the small error bars, to be minimal and within a range that the difference between minimum and maximum five-run modelled migration flows do not alter the relationship evident between observed and modelled data.

It can also be seen from Figure 6.1 however that, while the EMIUB1 recorded migration peaks in 1985 at 284, the year of greatest AMARC1 modelled migration, 1990, is recorded by EMIUB1 as having the third highest number of migrants, 273. As a result, although from 1981 onwards modelled migration is consistently higher than that observed, the general patterns of migration shown are similar, resulting in the significant correlation value. The fact that both observed and modelled migration rates decrease after 1990 is likely due to the ageing of individuals towards 1999. As this most stringent form of model validation allows no birth or death of individuals, either in the data or the model, the population in question ages towards 1999 and therefore becomes less likely to migrate as a result of the general tendency of migration in Burkina Faso being the undertaking of younger generations, of whom there are increasingly few.

It is evident therefore that, at this most stringent level of validation, the AMARC1 model is, without the input of any demographic change other than ageing, able to relatively accurately simulate the migration history of the 4,449 agents initialised into the model. As can be expected however, differences between the observed and modelled data are evident. These can be largely attributed to the efforts made by the model in its construction to focus upon rainfall as the primary driver of migration when in truth the migration trends seen in the EMIUB1 data will have been motivated by multiple characteristics and circumstances of the physical, social and financial environment that individuals find themselves in. If, for example, a large number of people in the EMIUB1 data migrated in a particular year as a result of, for example, conflict in neighbouring Côte d'Ivoire or the discovery of gold in Essakan, 330 km north of Ouagadougou (both events that occurred between 1970 and 1999), this would not be reflected by the AMARC1 model. As such migration is unlikely to be linked in any significant way to rainfall, but will have been recorded by the EMIUB survey, the use of the EMIUB1 data as the migration record from which *behavioural attitude* values in the model are derived means that migration trends seen in the data that do not correlate with variations in rainfall will not be reflected in the model. Although using a dataset that records all migration, not just that caused by rainfall, over the validation period may seem illogical, it is this data that has shaped the development of the AMARC models. As a result, the model does not attempt to elucidate the precise quantitative impact of rainfall on migration but is intended to investigate the large-scale influence of changes in rainfall upon migration in general. Although many migrations within and from Burkina Faso for a variety of motives may be affected to some degree by rainfall, a non-rainfall contributory factor such as political activism or the discovery of gold is beyond the scope of the model and can only be identified as a point of contrast.

In order to look in more detail at the total migration figures displayed above, the migration flows from each origin location can be considered. Figures 6.2 to 6.6 display the total migration flows from each origin location according to both the EMIUB1 data and the AMARC1 model.

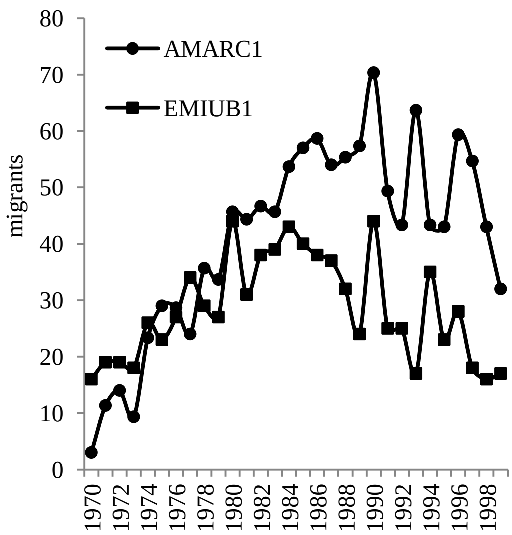

Figure 6.2: Number of migrants leaving Ouagadougou each year from 1970-1999 in the EMIUB1 data and in the AMARC1 model. Correlation coefficient for the two sets of data = **0.51**.

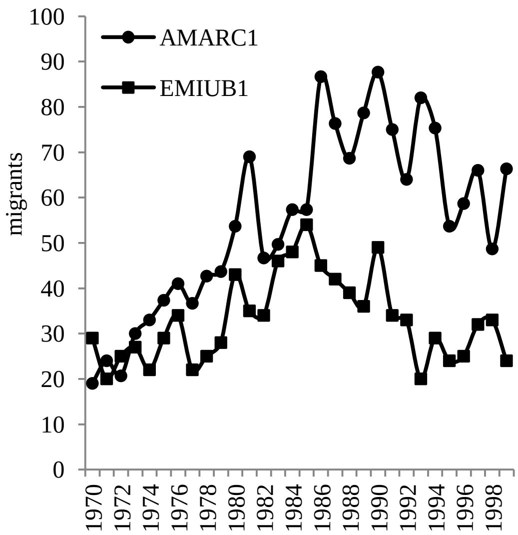

Figure 6.3: Number of migrants leaving Bobo Dioulasso each year from 1970-1999 in the EMIUB1 data and in the AMARC1 model. Correlation coefficient for the two sets of data = **0.44**.

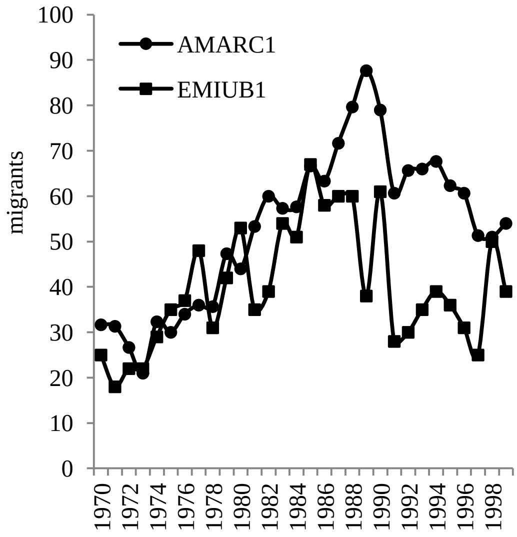

Figure 6.4: Number of migrants leaving Sahel each year from 1970-1999 in the EMIUB1 data and in the AMARC1 model. Correlation coefficient for the two sets of data = **0.56**.

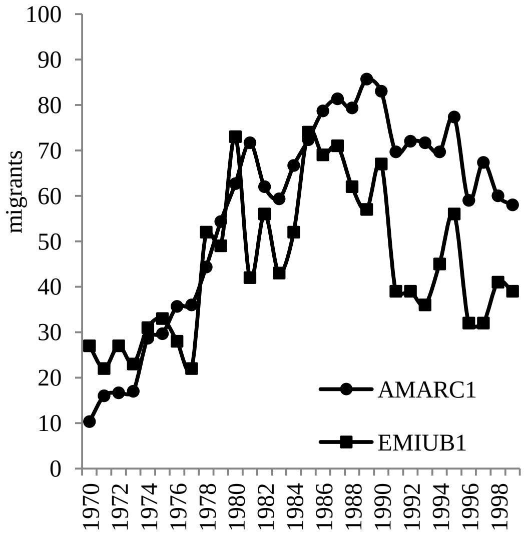

Figure 6.5: Number of migrants leaving Centre each year from 1970-1999 in the EMIUB1 data and in the AMARC1 model. Correlation coefficient for the two sets of data = **0.74**.

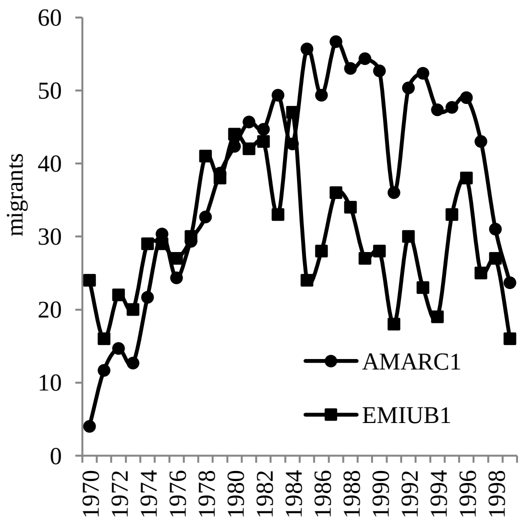

Figure 6.6: Number of migrants leaving Southwest each year from 1970-1999 in the EMIUB1 data and in the AMARC1 model. Correlation coefficient for the two sets of data = **0.40**.

All of the modelled flows of migrants from each of the five origin locations within AMARC1 show some level of agreement with the EMIUB1 data with even the lowest correlation value significant to 0.975. Correlation coefficient values range from 0.40 for Southwest to 0.74 for Centre. In all instances, the modelled migration rate is higher than the observed from about 1980 onwards. However, the general patterns of modelled migration shown in each of the

Figures 6.2 to 6.6 are similar to those observed by the EMIUB1, giving rise to the significant correlation values across all zones. The most notable difference between observed and modelled flows is evident in Figure 6.3 in the case of departures from Bobo Dioulasso. In this example, modelled flows are clearly higher than observed from 1986 onwards and fluctuate markedly over two or three year periods to the end of the simulation. Such an effect is likely to result from the manner in which rainfall has been broken down by this research. According to the dry, average, wet classification system used, rainfall in Bobo Dioulasso is seen to fluctuate regularly from 1986 onwards in Bobo Dioulasso with modelled peaks in migration tending to align with average rainfall and modelled troughs aligning with wet years.

Despite the possible limitation of categorising rainfall as within one of three classes (dry, average, wet), it is evident from the 0.975 significance between modelled and observed data that the AMARC1 model shows a good amount of agreement with the relevant EMIUB1 data at the most stringent level of model validation, at both national- and zone-scale resolutions. Although this level of correlation could be considered acceptable as a means of model validation (being at least 0.975 significant in all cases), there is evidently potential for improvement in the scale of accuracy with which the agent model represents the reality provided by the EMIUB record.

6.3 Model Validation - AMARC2 (ppt.mp30)

The central component missing from the AMARC1 model is the inclusion of demographic changes that affect the population of each zone. As a further means of model validation, the next version of the model, AMARC2, presents the same model processes as those of AMARC1 but with birth introduced as a further demographic process. The results of AMARC2 can then be compared to the full set of EMIUB data for further validation that incorporates those individuals surveyed in 2000 but born after 1970 (referred to herein as EMIUB2). By permitting birth within the AMARC2 model the population of each zone will increase each year as more agents are born and reach the age at which they are deemed to make their own migration decisions.

At this second stage of model validation, full demographic processes cannot be included in the ABM due to the fact that the EMIUB2 data contains no information on the death of individuals. This results from the retrospective nature of the survey. In order for an individual’s migration history to be recorded, that individual had to be alive and present in 2000 for interview. As a result, the AMARC2 model includes no function for agent death. Agents in the model are located in random networks where each agent has, on average, 50 networked peers. Agents use weight matrices $ppt.mp30$ in conducting their migration decisions.

Table 3 of Appendix 5 displays the EMIUB2 migration data for all surveyed individuals between 1970 and 1999, including those born after 1970. The EMIUB2 data records total migration from all zones in Burkina Faso as ranging from 121 in 1970 to 482 in 1999. The distribution of this overall migrant flow reveals that, in 1999, the zone from which the majority of migrants (140 migrants) originated was Sahel. In both 1970 and 1999 the EMIUB2 data records Ouagadougou as the zone with the lowest contribution (16 migrants and 60 migrants respectively).

Table 4 of Appendix 5 displays the averaged results from five runs of the AMARC2 model between 1970 and 1999. The AMARC2 five run averaged model outputs record total migration from all zones in Burkina Faso as ranging from 71 in 1970 to 409 in 1999. This compares well with the EMIUB2 observed total migration data which shows a low of 95 migrants in 1971 and a high of 482 in 1999. The distribution of the overall migrant flow modelled by AMARC2 reveals that, in 1999, the zone from which the majority of migrants originated was Sahel (140 individuals). This again corresponds well with the EMIUB2 data distribution which also shows Sahel as the zone that contributes the most migrants to the total flow, despite the larger overall population of Centre.

The two lowest migration flows modelled by AMARC2 originate in Ouagadougou and Southwest with flows in 1999 of 46 and 56 respectively. This again corresponds well with the observed trend as the smallest EMIUB2 migration flows in 1999 are seen to originate in Ouagadougou and Southwest with 60 and 62 migrants respectively. In order to further investigate the similarities between EMIUB2 observed and AMARC2 modelled migration flows, Figure 6.7 displays the EMIUB2 data migration record for all surveyed individuals between 1970 and 1999 (including those born after 1970) and the equivalent data averaged from five runs of the AMARC2 model.

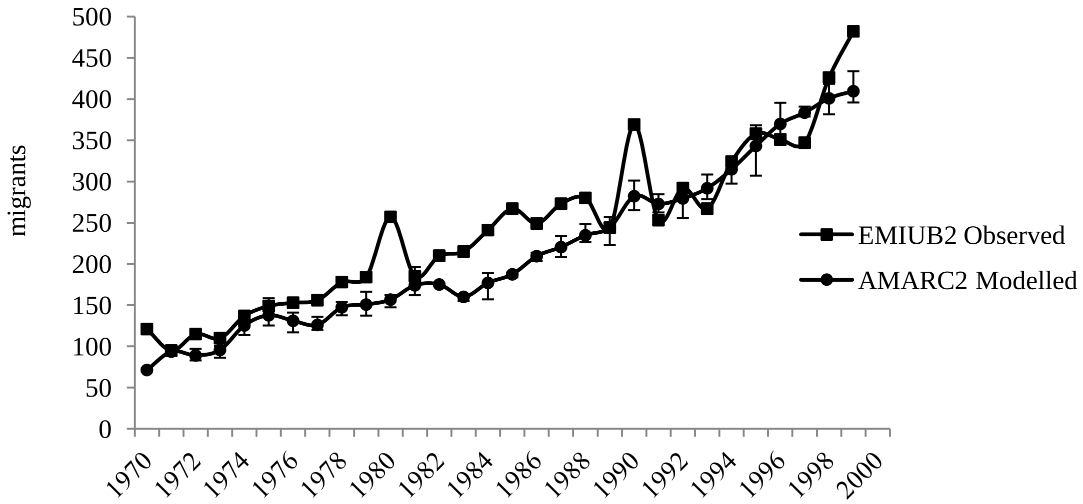

Figure 6.7: Total number of migrants leaving all zones each year from 1970-1999 in the EMIUB2 Data and the AMARC2 model. Correlation coefficient for the two sets of data = **0.94**. RMSD = **43 (12.7%)**.

Figure 6.7 shows that a considerably better correlation (correlation coefficient of 0.94) is evident between the AMARC2 model output and the EMIUB2 data than was seen in Figure 6.1 between AMARC1 and EMIUB1. The scale of the migration flows modelled by AMARC2 are similar to those of the EMIUB2 data with the highest migrant numbers both modelled and surveyed as occurring in 1999 (409 AMARC2 migrants compared to 489 in the EMIUB2 data). The five run error bars shown in Figure 6.7 also confirm that the degree of natural variation occurring between model runs is not large enough to alter the relationship between observed and modelled data. It appears therefore that adding the demographic component of birth into both the EMIUB data record and the AMARC model permits a closer statistical relationship between the modelled and observed data. A correlation coefficient of 0.94 is double that necessary to achieve 0.995 significance over the 30 data points from 1970-1999. Two clear peaks in the EMIUB2 observed migration flow seen in Figure 6.7 are evident in 1980 and 1990. Neither of these peaks are replicated by the AMARC2 modelled flow of migrants. As a result of the aim of the AMARC models to elucidate the role of changes in rainfall variability upon migration in Burkina Faso, it is therefore proposed that these clear peaks in observed migration result from historical events that would not be captured by an analysis that focuses on rainfall. Focus group participants mentioned the discovery of gold at Essakan in northern Burkina Faso as an historical event that triggered a considerable shift in the usual flows of migrants in the country. Although gold was first discovered at Essakan in 1985, mining activities did not start at the site until sometime later making it difficult to determine when a resulting change in migration flows may have occurred. However, the peak in migration flows may be more easily attributable, although not conclusively, to workers strikes across the country that led up to the overthrow of President Lamizana and perhaps increased labour migration.

As with the results of the AMARC1 model, it is useful to investigate the EMIUB2 data and AMARC2 outputs in more detail. Figures 6.8 to 6.12 display graphical comparisons of the numbers of migrants recorded by EMIUB2 and modelled by five averaged runs of AMARC2 as leaving each zone.

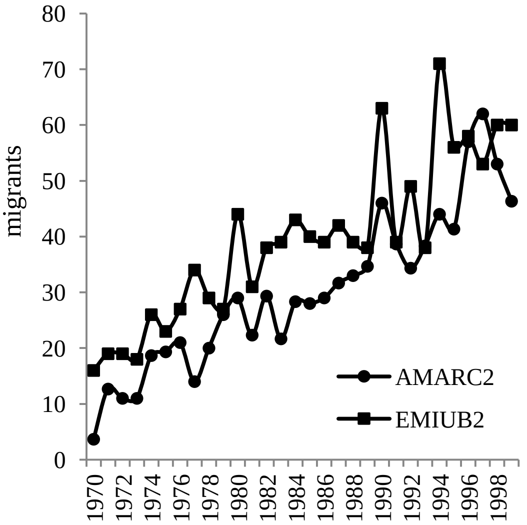

Figure 6.8: Numbers of migrants leaving Ouagadougou each year from 1970-1999 in the EMIUB2 data and in the AMARC2 model. Correlation coefficient for the two sets of data = **0.89**. RMSD = **11 (19.7%)**.

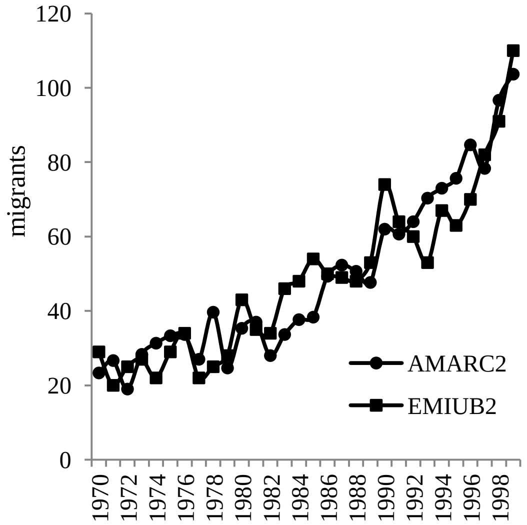

Figure 6.9: Numbers of migrants leaving Bobo Dioulasso each year from 1970-1999 in the EMIUB2 data and in the AMARC2 model. Correlation coefficient for the two sets of data = **0.93**. RMSD = **8 (9.9%)**.

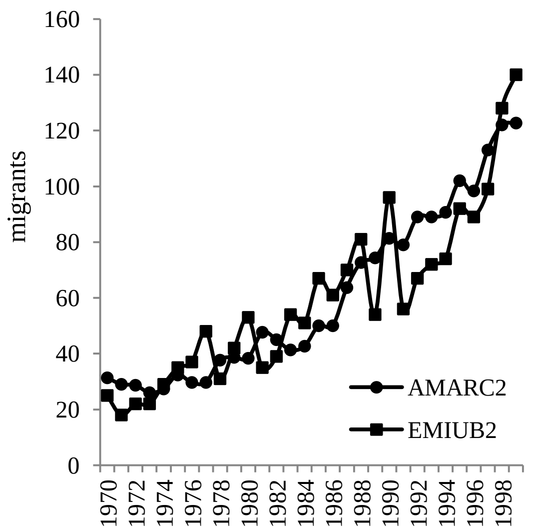

Figure 6.10: Numbers of migrants leaving Sahel each year from 1970-1999 in the EMIUB2 data and in the AMARC2 model. Correlation coefficient for the two sets of data = **0.91**. RMSD = **13 (13%)**.

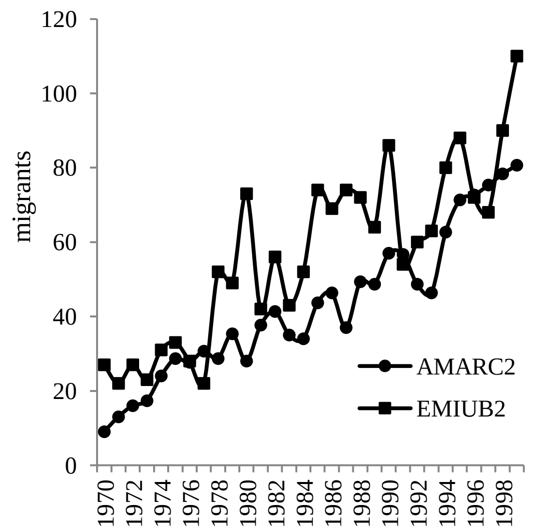

Figure 6.11: Numbers of migrants leaving Centre each year from 1970-1999 in the EMIUB2 data and in the AMARC2 model. Correlation coefficient for the two sets of data = **0.85**. RMSD = **19 (26.1%)**.

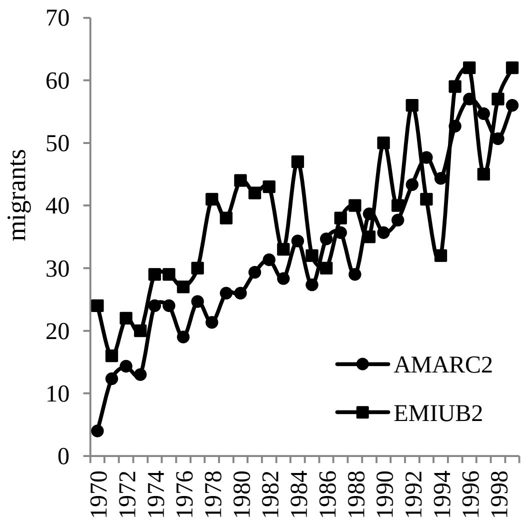

Figure 6.12: Numbers of migrants leaving Southwest each year from 1970-1999 in the EMIUB2 data and in the AMARC2 model. Correlation coefficient for the two sets of data = **0.82**. RMSD = **10 (18.8%)**.

The AMARC2 modelled flows of migrants from each of the five origin locations all show similarly good levels of agreement with the EMIUB2 data. The lowest correlation between the observed and modelled data is evident in the Southwest zone with a coefficient value of 0.82, still well into the realm of 0.995 significance. The highest correlation value is evident for Bobo

Dioulasso where observed and modelled flows produce a correlation coefficient of 0.94. Observed and modelled comparisons using EMIUB2 and AMARC2 data show considerable improvements in correlation values over those resulting from comparison of EMIUB1 and AMARC1 results. The peak in observed migration seen for total migrant flows in Figure 6.7 is replicated in departures from all zones but Southwest further suggesting the occurrence of some non rainfall related feature that caused increased migration almost nationwide.

Another means of assessing the ability of the modelled results to replicate the observed data is through the use of root-mean-square deviation (RMSD). The lowest deviation calculated is that for Bobo Dioulasso with five run averaged residuals of 8 (9.9%). By contrast, the highest deviation calculated is that for Centre with residuals calculated of 19 (26.1%), indicating relatively high individual differences between observed and modelled data points. While the RMSD values calculated between observed and modelled data for each zone combine to produce an overall RMSD for the total AMARC2 modelled migration of 43 (12.7%). There is no absolute criterion for a “good” RMSD value but this base provides an interesting platform from which to undertake comparisons of later model performance under different structural arrangements.

Correlation coefficient values calculated for the AMARC2 model results indicate that the model is able to accurately replicate the migratory trends seen in the EMIUB2 data across all five model zones. RMSD values however suggest that although the general trends are being accurately portrayed by the model, it is weaker at generating the level of annual variation in migration flows recorded by EMIUB2. For example, as displayed in Figure 6.11, observed migration from Centre varies greatly from year to year while maintaining a general pattern of increasing migration over the thirty year validation period. While the AMARC2 modelled migration follows the same pattern of increasing migration, the year-to-year variation in flows seen in the observed data is not replicated to the same extent resulting in the relatively high RMSD value. However, to expect the AMARC2 model to capture the full extent of the observed variation is unrealistic due to the nature of the model, and this research, in wishing to elucidate the role of changes in rainfall variability in the migration decision rather than capture the full migration decision which will, in reality, be influenced by numerous and interacting socio-economic factors, not all of which will be affected by rainfall.

6.4 AMARC2 - Destinations from Ouagadougou

It is evident that the AMARC2 model results, when compared with the EMIUB2 migration data from 1970-1999, produces considerably better correlations between observed and modelled data at all levels of analysis than were achieved by a comparison of the AMARC1 model results with the EMIUB1 data. Achieving a total migration correlation coefficient of 0.94 between AMARC2 modelled and EMIUB2 observed data gives considerable confidence in the ability of the AMARC2 model to replicate migration decision-making in the face of rainfall change. This is supported by the strong correlation coefficient values gained between modelled and observed data relating to the migration of individuals from each of the five model zones. However, in order to further assess the validity of the outputs of the AMARC2 model, the destinations of migrants from each of the five zones can be considered.

Table 5 of Appendix 5 shows the EMIUB data recorded destinations for migrants leaving Ouagadougou. Over the thirty year period from 1970 to 1999, the EMIUB2 data records a total of 1,173 migrants leaving Ouagadougou. The years of greatest migrant numbers are recorded as 1998 and 1999 when 60 migrants a year were seen to depart. The most common destination for migrants leaving Ouagadougou is recorded as Centre. Bobo Dioulasso is recorded as being by far the least likely destination for migrants leaving Ouagadougou with Sahel as the second least likely option. International migration away from Ouagadougou makes up 23% of the total flow away from the capital.

Table 6 of Appendix 5 shows the equivalent AMARC2 modelled destinations for migrants leaving Ouagadougou. The total number of migrants modelled as leaving Ouagadougou during the 30 year period from 1970-1999 is 905, 23% fewer than are recorded in the EMIUB data. The most frequented model destinations for migrants from Ouagadougou over the entire thirty year test period are Centre and International (41.90% and 39.58% of total migrants) with Southwest being the third most frequented destination (12.59% of total). This aligns relatively well with the observed EMIUB2 data which also finds Centre to be the most common destination from Ouagadougou (33.84%) with Southwest and International second and third most common (26.77% and 22.68% respectively. The least likely destination from Ouagadougou is both modelled and observed to be Bobo Dioulasso (modelled as 1.10% of total and observed to be 3.75%). Similarly, the Sahel is both modelled and observed to be an unlikely destination from Ouagadougou (4.82% and 12.96% respectively). Although not providing any information on the temporal nature of the destinations selected by migrants from Ouagadougou, a useful way to investigate the similarities between the observed EMIUB2 data and the modelled AMARC2 output is through Figure 6.13.

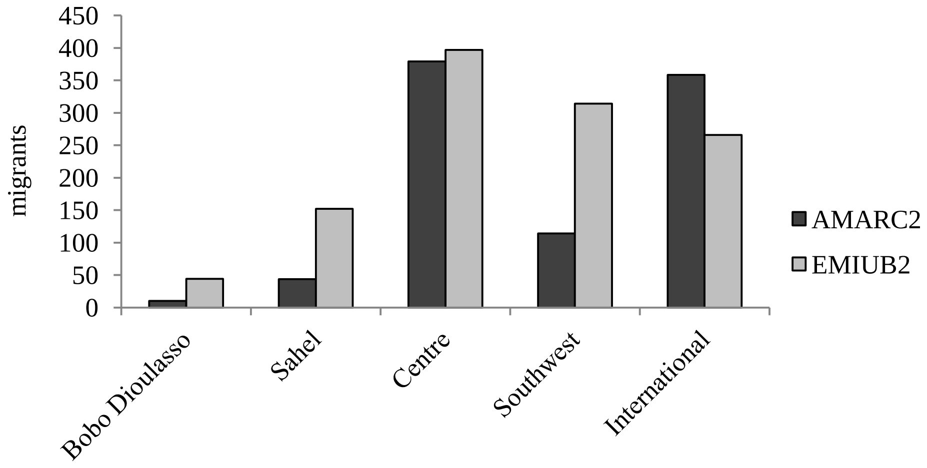

Figure 6.13: Destinations of the overall flows of migrants observed (EMIUB2) and modelled (AMARC2) as leaving Ouagadougou over the thirty year period 1970 to 1999.

Figure 6.13 shows that, in simulating the destinations of migrants leaving Ouagadougou between 1970 and 1999, the AMARC2 model shows good similarities with the observed data. The greatest discrepancies between observed and modelled results are evident for migrant numbers to Sahel and Southwest, both of which are underestimated by the AMARC2 model (by 71% and 64% respectively). Only in the case of International destinations does the AMARC2 model overestimate migration (by 35%). As a result of the manner in which agents select migration destinations (through rolls of a virtual dice that use a random numbers to determine whether a probabilistically defined threshold is exceeded) random effects play a part in any simulation outcome. On this basis, the discrepancies between observed and five run mean modelled destinations from Ouagadougou seen in Figure 6.13 may result from the interplay of randomness in each model run and the resulting calculation of a mean.

6.5 AMARC2 Destinations from Bobo Dioulasso

Table 7 of Appendix 5 shows the EMIUB2 data recorded destinations for migrants leaving Bobo Dioulasso. The total number of migrants recorded as leaving Bobo Dioulasso during the thirty year period from 1970-1999 is 1,453. The year of greatest overall migration is recorded as being 1999 when a total of 110 individuals migrated away from Bobo Dioulasso. Of these migrants, 34% (30 year total of 487) travelled to Centre, the most commonly chosen destination. The least frequented destination by migrants from Bobo Dioulasso, as recorded by the EMIUB2 data, is Southwest (282 or 12% of total migrants).

Table 8 of Appendix 5 shows the AMARC2 modelled destinations for migrants leaving Bobo Dioulasso. A total of 1,466 migrants are modelled as leaving Bobo Dioulasso between 1970 and 1999 by AMARC2, 1% more than were observed by EMIUB2. The most frequented destination is again modelled as Centre (36.79% of total). This corresponds well with the observed data, within which Centre is also the most frequented destination (33.53% of total). The modelled and observed data also share the least common destination, Southwest, with 8.54% of modelled migrants and 12.11% of observed. Figure 6.14 allows further investigation of the similarities between the observed EMIUB2 data and the modelled AMARC2 output for migrants from Bobo Dioulasso.

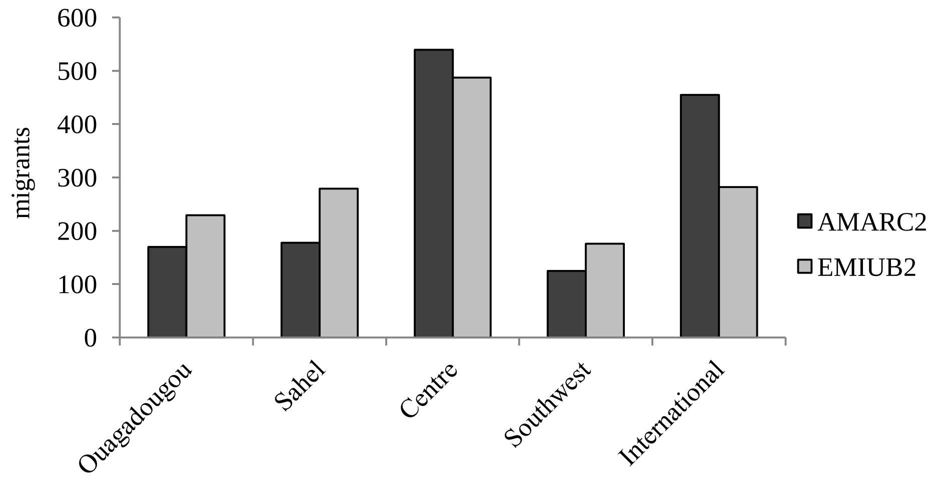

Figure 6.14: Destinations of the overall flows of migrants observed (EMIUB2) and modelled (AMARC2) as leaving Bobo Dioulasso over the thirty year period 1970 to 1999.

It can be seen from Figure 6.14 that, in simulating the destinations of migrants leaving Bobo Dioulasso between 1970 and 1999, the AMARC2 model shows good similarities with the observed data. While the modelled results overestimate migration to Centre (by 11%) and underestimate migration to Ouagadougou, Sahel and Southwest (by 26%, 37% and 29% respectively), the overall trends identified by the model match well with those observed by the EMIUB2 data. The greatest discrepancy is apparent in the case of migration to International destinations. In the same way as modelled International migration from Ouagadougou, International migrants from Bobo Dioulasso are significantly overestimated by the AMARC2 model (161% of observed).

6.6 AMARC2 Destinations from Sahel

Table 9 of Appendix 5 shows the EMIUB2 data recorded destinations for migrants leaving Sahel. A total of 1,786 migrants are recorded by the EMIUB2 data as leaving Sahel between 1970 and 1999. Of these, 44% (793 migrants) leave Sahel in order to travel to the capital, Ouagadougou. In addition, 575 individuals (32%) are recorded as migrating to Centre. By contrast, only 3% (71 migrants) leave Sahel in order to travel to the more distant city of Bobo Dioulasso. Similarly, only 6% of migrants (109 people) travel to the Southwest. A total of 238 migrants (13%) are recorded as leaving Sahel for International destinations over the thirty year period in question.

Table 10 of Appendix 5 displays the AMARC2 modelled destinations for migrants leaving Sahel. A total of 1,823 individuals are modelled by AMARC2 as leaving Sahel over the thirty year period from 1970-1999, 2% more than are recorded by the EMIUB2 data. Of these, the greatest proportion, 43.70%, migrate to Centre while the second greatest overall flow is to Ouagadougou (38.97%). This corresponds well with the EMIUB2 data which records Ouagadougou as the primary destination (44.40%) and Centre as the second most common (32.19%). The AMARC2 model shows Bobo Dioulasso to be the least common destination from Sahel (2.23%) with Southwest receiving second fewest migrants (4.11%). This again corresponds well with the EMIUB2 data which also records Bobo Dioulasso as the least frequented location (3.98%) and Southwest as the destination of second fewest migrants (6.10%). Figure 6.15 allows further investigation into the similarities between the observed EMIUB2 data and the modelled AMARC2 output for migrants from Sahel.

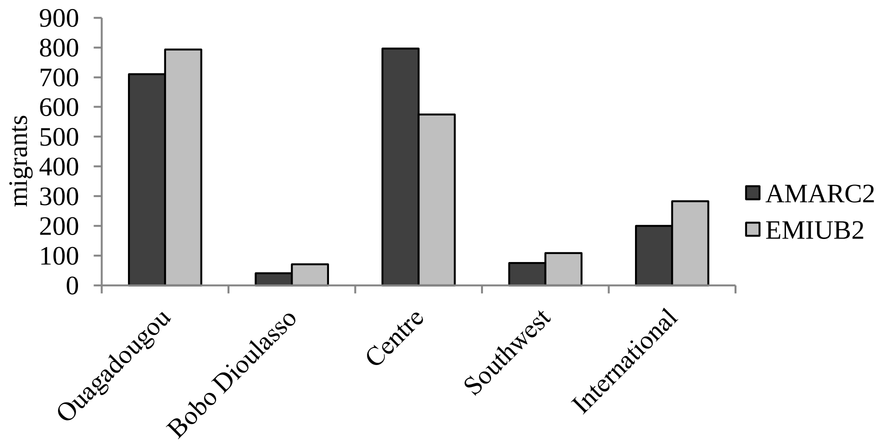

Figure 6.15: Destinations of the overall flows of migrants observed and modelled as leaving Sahel over the thirty year period 1970 to 1999.

It can be seen from Figure 6.15 that, in simulating the destinations of migrants leaving Sahel between 1970 and 1999, the AMARC2 model shows strong similarities with the observed data. The greatest difference is evident between observed and modelled migration from Sahel to Centre, overestimated by the model by 39%. Apart from this difference however, the modelled and observed flows of migrants align well. Unlike modelled International migration from both Ouagadougou and Bobo Dioulasso, migration to International destinations from Sahel is underestimated by the model by 29%.

6.7 AMARC2 Destinations from Centre

Table 11 of Appendix 5 shows the EMIUB2 data recorded destinations for migrants leaving Centre. A total of 1,703 migrants are recorded by the EMIUB2 data as leaving Centre between 1970 and 1999. Of these migrants, 35% (600 individuals) are recorded as having migrated from Centre to Ouagadougou. The second largest flow of migrants from Centre is to International destinations (33% or 556 migrants). By contrast, only 6% (102 individuals) of migrants leave Centre in order to migrate to Sahel. Similarly, only 7% (120 individuals) of migrants that leave Centre relocate to Bobo Dioulasso.

Table 12 of Appendix 5 shows the AMARC2 modelled destinations for migrants leaving Centre. A total of 1,281 agents are modelled by AMARC2 as leaving Centre in order to relocate to other destinations over the thirty year period from 1970-1999, 25% fewer than are recorded by EMIUB2. The greatest proportion of these migrants (40.70%) relocate to Ouagadougou with

International destinations the second most common choice (33.96%). This compares well with the EMIUB2 observed data which also records Ouagadougou as the most common destination (35.23%) and International as a close second (32.65%). The AMARC2 model shows Sahel and Bobo Dioulasso as the least likely destinations from Centre with just 4.37% and 4.87% of total 1970-1999 migrants respectively. This again compares well with the EMIUB2 data which records Sahel as the least likely destination (5.99%) and Bobo Dioulasso as the second least likely (7.05%). Figure 6.16 allows further investigation into the similarities between the observed EMIUB2 data and the modelled AMARC2 output for migrants from Centre.

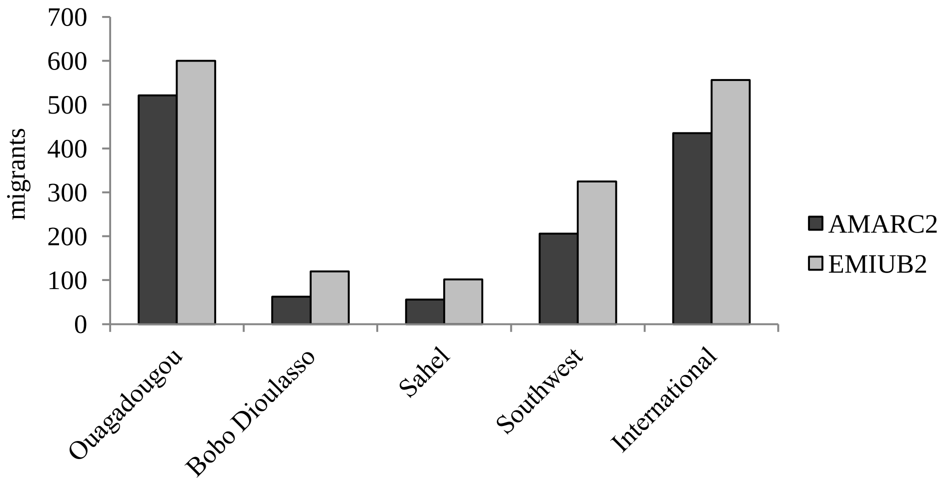

Figure 6.16: Destinations of the overall flows of migrants observed (EMIUB2) and modelled (AMARC2) as leaving Centre over the thirty year period 1970 to 1999.

Figure 6.16 reveals that, in simulating the destinations of migrants leaving Centre between 1970 and 1999, the AMARC2 model shows strong similarities with the observed data. In the case of each potential destination from Centre, the AMARC2 modelled results proportionally mirror those recorded by EMIUB2. However, the modelled thirty year flow of migrants to each destination is between 48% (in the case of Bobo Dioulasso) and 13% (in the case of Ouagadougou) less than the observed, leading to the overall number of AMARC2 modelled migrations between 1970 and 1999 being 25% less than the EMIUB2 observed record.

6.8 Destinations from Southwest

Table 13 of Appendix 5 displays the EMIUB2 data recorded destinations for migrants leaving Southwest. A total of 1,164 migrants are recorded by the EMIUB2 data as leaving Southwest between 1970 and 1999. Of these migrants, 49% (566 individuals) are recorded as having migrated from Southwest to Centre. The next largest flows of migrants from Southwest are to Ouagadougou (18% or 214 migrants) and International destinations (18% or 205 migrants). By contrast, only 7% (80 individuals) of migrants leave Southwest in order to migrate to Bobo Dioulasso. Similarly, only 9% of migrants (99 individuals) that leave Southwest relocate to Sahel.

Table 14 of Appendix 5 shows the AMARC2 modelled destinations for migrants leaving Southwest. A total of 977 agents are modelled by AMARC2 as leaving Southwest in order to relocate to other destinations over the thirty year period from 1970-1999, 16% fewer than are recorded by EMIUB2. The most common destination from Southwest modelled by AMARC2 is Centre (57.05% of migrants). This corresponds well with the EMIUB2 data which also shows Centre to be the most common destination (48.63% of migrants). The smallest modelled flows of migrants from Southwest are those to Bobo Dioulasso and Sahel with only 3.75% and 3.89% of total migrants respectively. Figure 6.17 allows further investigation into the similarities between the observed EMIUB2 data and the modelled AMARC2 output for migrants from Southwest.

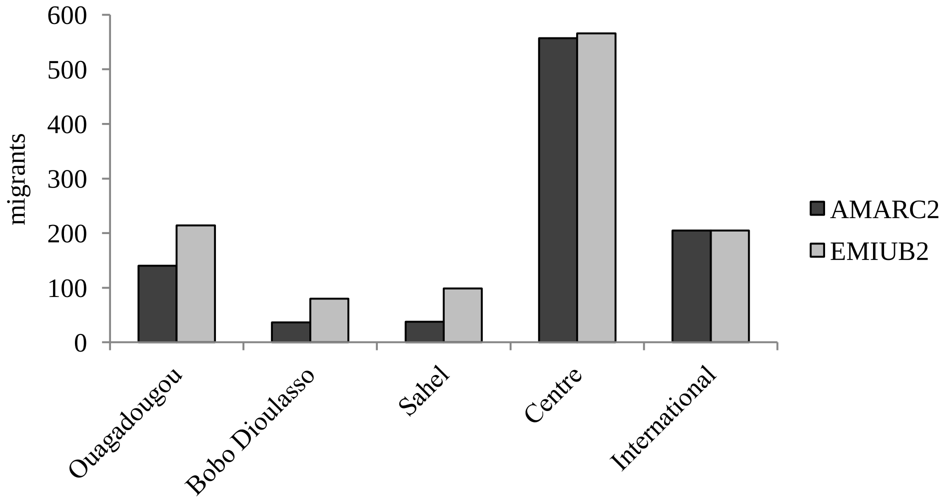

Figure 6.17: Destinations of the overall flows of migrants observed (EMIUB2) and modelled (AMARC2) as leaving Southwest over the thirty year period 1970 to 1999.

Figure 6.17 shows that, in simulating the destinations of migrants leaving Southwest between 1970 and 1999, the AMARC2 model shows strong similarities with the observed data. The most apparent of these similarities are evident for migration from Southwest to both Centre and International destinations. While the AMARC2 model underestimates observed migration to Centre by less than 2% (11 migrants over thirty years), migration to International is modelled to be the same as observed, 205 migrants. However, in proportional terms, due to the overall underestimation of migration from Southwest by the model, the modelled flow represents 20.95% of the total while the observed flow represents 17.61%. In the case of modelled migration from Southwest to Ouagadougou and Bobo Dioulasso both flows are underestimated by the AMARC2 model (by 45% and 54% respectively). The greatest disparity between observed and modelled flows is evident for Sahel where the number of AMARC2 modelled migrants over the thirty year period is 62% less than the observed, despite this difference only being 61 individuals in real terms.

By considering the destinations of migrants leaving each model zone throughout the validation period through a direct comparison of EMIUB2 observed and AMARC2 modelled flows, the AMARC2 model appears to relatively accurately replicate migration from all five zones in Burkina Faso. It can be expected that a certain amount of discrepancy would be evident between observed and modelled flows due to both the introduction of random effects into the model and the process by which AMARC2 is intended to extract the role of changes in rainfall variability in the migration decision rather than consider each of the multiple and interacting drivers of human migration. However, thus far it appears that the framework used to break down the migration decision and elucidate the role of changes in rainfall variability is permitting the AMARC model to accurately simulate Burkinabé migration decision-making.

6.9 AMARC2 Model Validation – Arrivals

It is evident that the averaged output of five runs of the AMARC2 model shows a highly significant correlation (0.94) with the observed EMIUB2 data when both are considered in terms of the total flow of migrants from all zones of Burkina Faso. When the AMARC2 outputs are considered at the next level of analysis, that of the number of migrants leaving each of the five zones of Burkina Faso, the correlation values generated (0.87, 0.93, 0.91, 0.85 and 0.82 for flows of migrants leaving Ouagadougou, Bobo Dioulasso, Sahel, Centre and Southwest respectively) suggest that the highly significant nature of the relationship between observed and modelled data remains. Furthermore, when the destinations of these migrants from each origin zone are considered, strong similarities exist between observed and modelled data. In order to further investigate the similarities between observed and modelled migrant flows, Tables 6.1

and 6.2 display the total numbers of migrants observed by EMIUB2 and modelled by AMARC2 as migrating from each origin to each destination between 1970 and 1999.

	Destination:					
Origin:	Ouaga.	Bobo.	Sahel	Centre	Southwest	International
Ouaga.	-	44	152	397	314	266
Bobo.	229	-	279	487	176	282
Sahel	793	71	-	575	109	238
Centre	600	120	102	-	325	556
Southwest	214	80	99	566	-	205
Total:	1,836	315	632	2,025	924	1,547

Table 6.1: 1970-1999 total numbers of migrants recorded by the EMIUB2 data as migrating from each of the five model zones to each destination option.

	Destination:					
Origin:	Ouaga.	Bobo.	Sahel	Centre	Southwest	International
Ouaga.	-	10	44	379	114	358
Bobo.	170	-	177	539	125	455
Sahel	710	41	-	797	75	200
Centre	521	62	56	-	206	435
Southwest	140	37	38	557	-	205
Total:	1,541	150	315	2,272	520	1,653

Table 6.2: 1970-1999 total numbers of migrants modelled by AMARC2 as migrating from each of the five model zones to each destination option.

If the flows of migrants leaving each zone are considered in terms of their destinations, as can be seen in Tables 6.1 and 6.2, the similarities between the observed EMIUB2 data and the AMARC2 modelled results suggest that modelled agents are able to replicate the variation of destinations selected by individuals. The total data displayed in Tables 6.1 and 6.2 are compared in Figure 6.18, below.

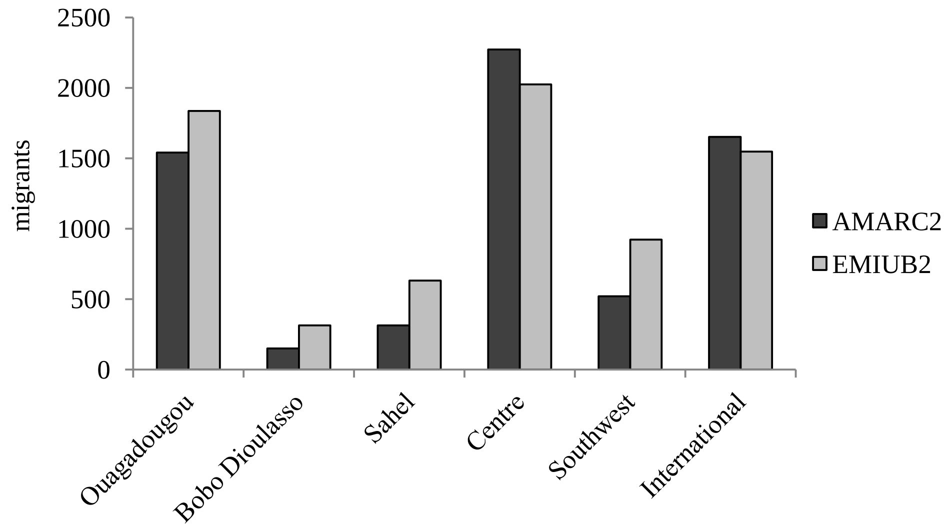

Figure 6.18: Comparison of the migrants observed (EMIUB2) and modelled (AMARC2) as arriving in each of the model zones over the thirty year period 1970 to 1999.

It is clear from Figure 6.18 that modelled arrivals in each of the zones closely parallel the relevant EMIUB2 data that records individuals arriving in each zone between 1970 and 1999. In the case of arrivals to Ouagadougou, Bobo Dioulasso, Sahel and Southwest the AMARC2 model consistently underestimates total arrivals. The most extreme example of these is Bobo Dioulasso where arrivals are underestimated by 52% (165 individuals). By contrast arrivals to both Centre and International destinations are overestimated by the model by 12% (702 individuals) and 7% (106 individuals) respectively. Despite these discrepancies, the general trends in arrivals produced by the AMARC2 model compare well with those observed by the EMIUB2. Through the model validation process outlined above it can therefore be concluded that not only does the AMARC2 model replicate observed migration flows to a 0.995 level of significance in terms of both total and zone-specific migrant departures, but that modelled agents are accurately replicating the destination choices of the individuals whose migration decisions they are intended to replicate.

6.10 Model Validation – Migrant Characteristics

From the results outlined above it is evident that, in analysing the outputs of the AMARC models, it is important to consider the modelled migrant flows in terms of both the total flow and the origins/destinations of migrants. As such it is reasonable to assume that consideration of the modelled flows at the next level of analysis, that of migrant characteristics, will provide further insight into the simulation potential of the ABM. Evidence that the migrants modelled by the AMARC2 model between 1970 and 1999 correspond approximately with the sum migration probability characteristics of each agent class in Chapter 5 will provide final proof of the valid nature of the model and the appropriateness of the migration outcomes simulated. The average numbers of agents from all origin zones with each combination of age, gender and marital status attributes modelled by five runs of AMARC2 as migrating between 1970 and 1999 are displayed in Table 6.3 and Figure 6.20.

15-20 Married Female	15-20 Married Male	15-20 Single Female	15-20 Single Male
1,107	114	289	1,084
21-35 Married Female	21-35 Married Male	21-35 Single Female	21-35 Single Male
1,178	1,470	1	209
35+ Married Female	35+ Married Male	35+ Single Female	35+ Single Male
397	610	1	0

Table 6.3: Average numbers of migrants with defined attributes modelled by AMARC2 as originating in all zones between 1970 and 1999.

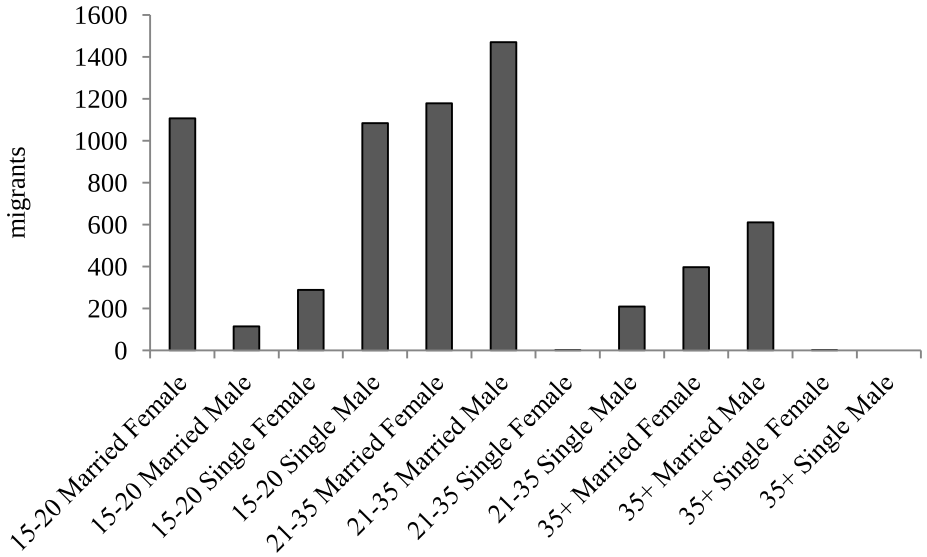

Figure 6.19: Average numbers of migrants with defined attributes modelled by AMARC2 as originating in all zones between 1970 and 1999.

The data displayed in Table 6.3 and Figure 6.20 reveal that the greatest proportion of migrants modelled by AMARC2 are 21-35 year old married males (1,470 between 1970 and 1999). The next most prolific migrants are modelled as being 21-35 married females. Analysis of the sum behavioural attitude probabilities presented in Figure 5.4 of Chapter 5 revealed that 15-20 year old married females had a high likelihood of migrating. This was attributed to marriage migration, despite the removal of specific reference to such migration from the EMIUB data. In accordance with this unexpected finding, Table 6.3 and Figure 6.20 display 15-20 year old married females as the third most prolific migrants from all zones over the 30 year validation period. Only single male agents over the age of 35 are modelled by AMARC2 as not migrating at all. However, five averaged runs of the model only show two single women aged 21 and over as having migrated over the 30 year validation period. As noted in Chapter 5 however, statistics relating to numbers of migrants must be considered in terms of the population. Figure 6.21 displays the 1970-1999 averaged annual percentage population structure of all agents in the AMARC2 model.

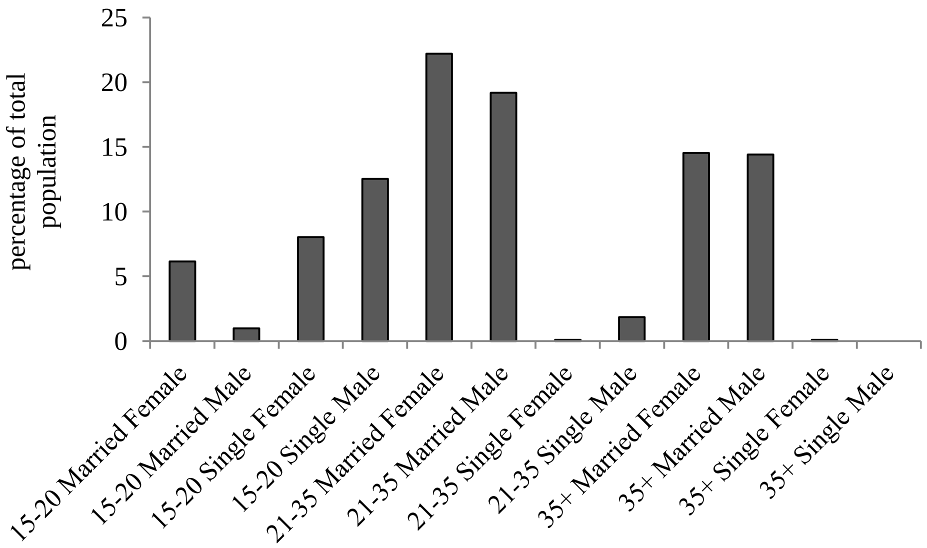

Figure 6.20: Averaged annual percentage AMARC2 population distribution of individuals from all origin locations between 1970 and 1999.

When Figures 6.20 and 6.21 are considered in parallel it is evident that zero or very few migrants could be anticipated to be 21-35 year old single females, over 35 year old single females or over 35 year old single males. A very small population of married male agents aged between 15 and 20 is also evident. The two largest populations of agents are 21-35 year old married males and females of the same age and marital status. Figure 6.21 shows that, of these two agent groups, there are slightly more 21-35 year old married females than males. However, despite this, and as a result of the behavioural attitude values generated by interrogation of the EMIUB data, more males within this age and marital status category migrate than females. Although it is somewhat surprising that only 209 21-35 year old single male agents are shown to migrate between 1970 and 1999 in Figure 6.20, such a statistic is put into perspective when considered in parallel with Figure 6.21. On average, only 2% of the total annual model population fall within the 21-35 year old single male category. Despite this, such migrants make up more than 3% of modelled migrants, indicating that the propensity of such modelled agents towards migration is strong despite the small population of such individuals recorded by the EMIUB2 data.

It can be concluded from Figures 6.20 and 6.21 that the AMARC2 model is able to effectively apply the SMARC theoretical model in the construction of an agent based model of the migration decision in Burkina Faso. The fact that the migrants modelled by the AMARC2 model are found to be effectively distributed across the agent classes reflects both the success of the model in simulating the migration decision and the ability of the model to replicate the appropriate demographic phenomena controlling population growth within the simulated population.

Strong correlations between observed and modelled data for the total modelled flow of migrants and the origins of those migrants, combined with the evidence presented above that confirms the appropriate implementation of the conceptual basis used in the development of the ABM, affirms the value of the AMARC2 model and its ability to simulate migration flows in Burkina Faso as a result of changing rainfall conditions. It is therefore concluded that the AMARC2 model is externally valid in its simulation of both demographic processes and migration decision-making in Burkina Faso and can be legitimately used further by this research in order to investigate the role of change in rainfall variability in the migration decision.

6.11 Model Validation – Probability Calculations

As described in section 5.4 of Chapter 5, two different approaches to calculating the probability values used as the behavioural attitude component of the decision to migrate are available to this research. One uses the notion of data-fitting to calculate as accurately representative probability values as possible using all of the EMIUB migration data available (30 years of data from 1970-1999). The other restricts the data used (10 years from 1990-1999) to calculate probability values that can be used to conduct an alternative means of validation. As such, 1970-1989 migration can be modelled by the AMARC2 model without 1970-1989 EMIUB2 migration data having had any impact upon the probability values used in the migration decision of modelled agents. Although deemed unnecessary by a data-fitting approach, testing the model using this restricted data approach permits further external validation of the AMARC2 model. The results of five runs of the AMARC2 model using the restricted-data approach (AMARC2.ppt.mp10) can be compared with those of both the EMIUB2 data and the AMARC2 model that used the data-fitting approach (AMARC2.ppt.mp30) over the periods 1990-1999 (the restricted-data calculation period) and 1970-1989 (the restricted-data validation period).

Table 15 of Appendix 5 displays the annual populations of agents modelled by the AMARC2.ppt.mp10 model as leaving each origin zone between 1970 and 1999. By 1999 a total of 394 migrants are modelled by the AMARC2ppt.mp10 model as leaving all zones. This compares to 482 recorded by the EMIUB2 data and 409 by the AMARC2.ppt.mp30 model. Figure 6.22 displays a comparison of the EMIUB2 observed total migration data and the migrants modelled by both the AMARC2.ppt.mp10 and AMARC2.ppt.mp30 models.

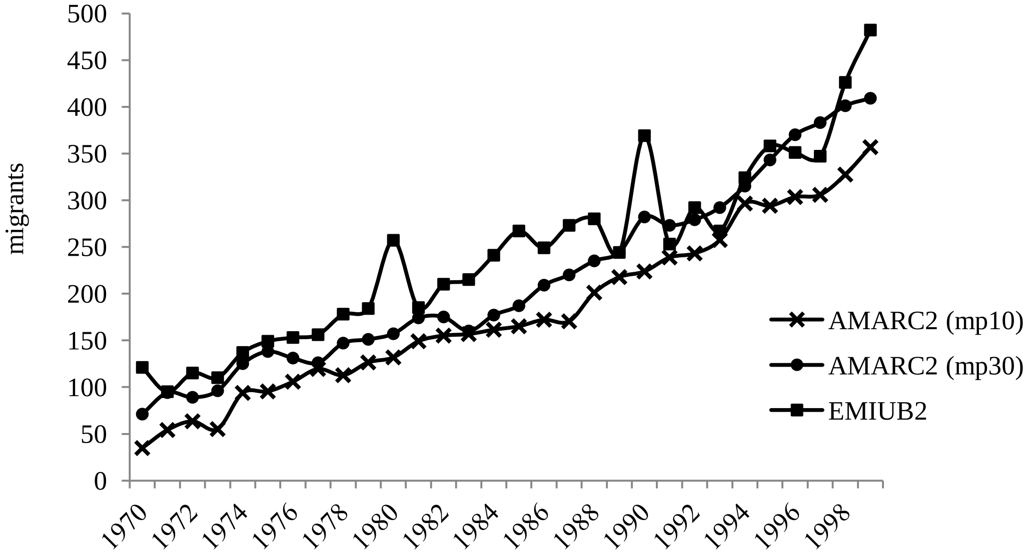

Figure 6.21: Total number of individuals observed (EMIUB2) and modelled (AMARC2(mp10) and AMARC2(mp30)) as migrating from all zones each year from 1970-1999. 1970-1999 correlation coefficient for EMIUB2 and AMARC2.10 data = **0.94**. RMSD = **71** (22.1%).

It can be seen from Figure 6.22 that throughout the period 1970-1999 the AMARC2.ppt.mp10 modelled total flow of migrants falls below that of both the AMARC2.ppt.mp30 modelled and EMIUB2 observed total flows. Despite this, the 1970-1999 correlation coefficients calculated for both versions of the AMARC2 model when compared with the EMIUB2 data equal 0.94, well within the realm of 0.995 significance. A statistical difference between the two modelled flows of total migrants can be identified using a root mean squared deviation (RMSD) analysis.

While AMARC2.ppt.mp30 gives RMSD residuals of 43 (12.7%), the AMARC2.ppt.mp10 version gives a considerably higher residuals score of 71 (22.1%), indicating greater differences between observed and modelled results.

If the data used to inform the behavioural attitude probability values is restricted to 1990-1999 the resulting correlation coefficient and RMSD values calculated are interesting. It could reasonably be anticipated that the version of the AMARC2 model constructed using 1990-1999 probability values (AMARC2.ppt.mp10) might perform better over that period but display a lesser correlation between 1970 and 1989 when compared with the results of the model constructed using 1970-1999 data (AMARC2.ppt.mp30). Despite this anticipated outcome, results from the AMARC2.ppt.mp10 model produce a correlation coefficient of 0.76 and RMSD of 76 (57.3%) when compared with the EMIUB2 data over the 10 year period from 1990-1999. By contrast, results from the AMARC2.ppt.mp30 model produce a considerably better correlation coefficient of 0.81 and RMSD of 41 (30%) over the same period giving a significance level of 0.995.

It appears therefore that, despite 1990-1999 being the precise period used to produce the migration probability values used in the AMARC2.ppt.mp10 model, the AMARC2.ppt.mp30 model performs better over this period both in terms of a higher correlation coefficient and lower RMSD. In further contrast to the anticipated outcome, the AMARC2.ppt.mp10 model is found to perform almost as well as the AMARC2.ppt.mp30 version over the period 1970-1989. While AMARC2.ppt.mp30 gives a correlation coefficient value of 0.91 and RMSD of 44 between 1970 and 1989, the AMARC2.ppt.mp10 model also gives a correlation coefficient of 0.91 but RMSD residuals of 67 when compared to the EMIUB2 observed data.

Despite the unexpected outcomes of correlation and RMSD values calculated for the two versions of the AMARC2 model, it is evident that overall, the model version that uses thirty year derived probability values performs better, albeit by a margin only really identified through the use of RMSD residual values. While the AMARC2.ppt.mp10 model is therefore proven to be externally valid as a result of the restricted-data approach (1990-1999 data), the greater accuracy of the model in simulating the migration decisions of agents when using probability values calculated from the data-fitting approach (1970-1999 data) leads this research to adopt the latter process both in the detailed examination of validation in this chapter and in later use of the AMARC2 model. Investigating the role of changes in rainfall variability in the modelled decision to migrate with probability values of lesser representative value would restrict the potential value that may be derived from later results.

6.12 Summary

In this chapter different versions of the AMARC model were thoroughly investigated in order to identify the external validity of the models to replicate the migration decision in Burkina Faso. Using the observed EMIUB2 data as the primary source of comparative validation, migration rates modelled by AMARC2 have been found to correlate with the observed data at a 0.995 significance level at both total migration and zone-migration levels of analysis. Furthermore, the destinations of the modelled migrants and their arrivals in alternative locations have been found to correlate well with observed data while the different classes of model agents have been seen to produce migration flows that appropriately represent the statistical tendencies of their groups towards migration. Following on from the successful validation process outlined above, Chapter 7 develops the AMARC2 model into an appropriate version for simulating future migrant flows before investigating the role of changes in rainfall variability in the modelled migration decision.

Chapter 7

The Role of Changes in Rainfall Variability, Demography & Networks in the Modelled Migration Decision

7.1 Introduction

The initial AMARC model results presented in Chapter 6 show that the AMARC2 ABM accurately replicates past migration flows from Burkina Faso when rainfall is used as the primary precursor to relocations countrywide and to international destinations. Using the high degree of confidence attributed to the model as a result of this validation process, the models can thus be used to investigate both the influence of rainfall on the modelled migration decision and the future levels of migration simulated as occurring in Burkina Faso under different rainfall scenarios. The following chapter addresses the first of these concepts through the use of further versions of the AMARC models.

7.2 AMARC3

In the previous chapter the AMARC2 model was used for a validation process that permitted direct comparison with the EMIUB2 data. However, in order to validate against the EMIUB2 dataset (a retrospective survey conducted in the year 2000 that required all respondents to be alive at the time of the survey) the AMARC2 model did not include a function for agent mortality. In order to investigate the role of changes in rainfall variability in the modelled migration decision, the AMARC3 model is therefore used. AMARC3 uses the same initial population, birth, marriage and ageing functions and migration decision-making process as AMARC2 but incorporates an additional function that, in accordance with the UN recorded rate of demographic change, causes agents to die. As with all other versions of the AMARC model, AMARC3 only permits agents to migrate, and the impact of rainfall upon that migration to be felt. As the impact of rainfall upon total migration is the focus of the research, agents contained within the model are not undertaking a climate change adaptation per se but are undertaking their annual migration decision-making process under changing rainfall conditions in different rainfall zones of Burkina Faso.

Table 1 of Appendix 6 shows the five run average number of agents simulated by AMARC3 as leaving each zone throughout the modelled period 1970-1999. The model simulates total migration from all zones in Burkina Faso as ranging from 65 migrants in 1970 to a maximum of 315 migrants in 1990. This compares to ranges of 131 to 482 for the EMIUB2 data and 161 to 453 by the AMARC2 model. A 1990 peak in total migration flow simulated by AMARC3 and a comparatively low migration flow evident towards the end of the model validation period result from the inclusion of agent mortality in the AMARC3 model. Although no migration validation data is available for direct comparison with the outputs of AMARC3, all demographic components must be included into the ABM to provide the 1970-1999 base migration model that can then be used in later analysis.

The distribution of the overall migrant flow modelled by AMARC3 reveals that the zone from which the majority (26.30%) of total migrants originated over the thirty year validation period was Sahel. By contrast, Ouagadougou is recorded as the lowest contributor to the overall migration flow between 1970 and 1999 (14.83%). As could be anticipated, these proportional migration patterns are very similar to those modelled by AMARC2 and align well with the EMIUB2 observed data. It appears therefore that inclusion of the additional demographic component of agent death marginally decreases the modelled flows of migrants without dramatically affecting the nature of the origins, destinations and characteristics of migrants themselves. In order to further understand the modelled impact of agent mortality upon total migration flows Figure 7.1 displays a comparison of the total migration rates observed by the EMIUB2 data and modelled by the AMARC2 and AMARC3 models between 1970 and 1999.

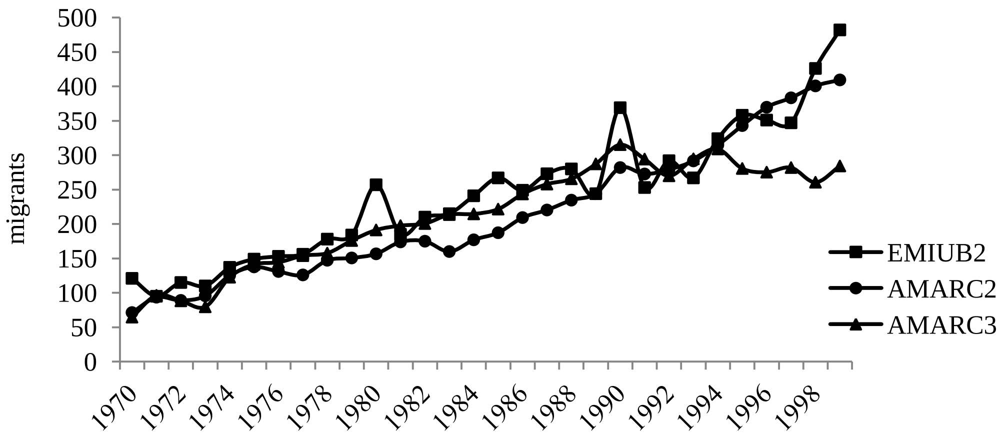

Figure 7.1: Total numbers of migrants observed by the EMIUB2 data and modelled by the AMARC2 and AMARC3 models as leaving all zones in Burkina Faso between 1970 and 1999. Correlation coefficient between EMIUB2 and AMARC3 data = **0.85**. RMSD = **59**.

It is evident from Figure 7.1 that the inclusion of agent mortality into the AMARC models results in a marginal reduction in the total number of individuals seen to migrate towards the end of the thirty year validation period. By 1999 the total number of migrants modelled by AMARC3 is 41% less than those recorded by the EMIUB2 data and 31% less than are modelled by AMARC2. As the only change in the model from AMARC2 to AMARC3 is the addition of agent mortality, it can be assumed that the reduced migration flows logically result from the demographic changes that occur in the model. Interestingly, between 1975 and 1990, the AMARC3 model appears in Figure 7.1 to correspond better with the EMIUB2 data than the AMARC2 model. Although the precise reason behind this apparent better fit is not clear, it is evident that the ABM output is sensitive to changes in parameters such as agent mortality.

One possible explanation for the closer fit of the AMARC3 modelled migration flow to that recorded by EMIUB2 is the change to agent networks and communication that result from the death of agents. The resulting removal of older individuals from an agent's network will cause the network places that become free to be populated with younger agents. A peer network made up of younger agents with greater tendencies towards migration could potentially increase an agent's own tendency towards migration through peer-peer communication, thereby explaining the higher modelled migration flow resulting from the addition of agent mortality in AMARC3. As a result of the model validation process described in the previous chapter and the positive conclusions drawn as to the ability of the AMARC models to replicate observed migration flows within and from Burkina Faso over the period 1970 to 1999, the AMARC3 model is used as the basis from which further investigation can be performed.

7.3 Interpreting Rainfall Data

The standard version of both the AMARC2 and AMARC3 models run using behavioural attitude values retrieved from a series of weight matrices that represent the probability of a particular agent class originating in a particular location migrating to a given destination on the basis of the rainfall characteristics of that year. The data-fitting performed on the EMIUB data gave migration probability values that defined each year between 1970 and 1999 as dry, average or wet according to the total rainfall of the year in question (ppt). A single year of relatively high rainfall could therefore potentially have a considerable impact upon modelled migration.

Using the final full-demographic AMARC3 model an alternative approach to analysing the EMIUB migration data was also employed to provide another means of investigating the role of changes in rainfall variability. Rather than calculating migration probability values where each model year is defined as dry, average or wet according to the total rainfall of the year in question (ppt), the alternative approach classes each year on the basis of the year in question and the two previous years ($ppt3$). A single year of relatively high rainfall could therefore have potentially little impact upon modelled migration if it was preceded by two years of below average rainfall. Using a three year rainfall trend such as this acknowledges the longer-term, slow-onset, cumulative nature of the impacts of rainfall change upon subsistence farmers such as the majority of individuals represented in the EMIUB data. Furthermore, Henry et al. (2004a) use a three year rainfall precursor in their study of the influence of rainfall upon migration in Burkina Faso. In order to further investigate the role of changes in rainfall variability in the migration decision, the AMARC3 model is run using the $ppt3$ behavioural attitude weight matrices. In both the data fitting process and model runs, each year is therefore defined as dry, average or wet according to the rainfall of the year in question and the two preceding years.

Table 2 of Appendix 6 displays the averaged results of five runs of the AMARC3 model using 3 year rainfall weight matrices. When directly compared to elucidate the impact of using one-year and three-year rainfall matrices upon modelled migration, the data show very little disparity. A total of 6,409 agents are modelled as migrating between 1970 and 1999 by the AMARC3.ppt3.mp30 model, less than 1% more than are modelled by the version of the model that uses the standard ppt weight matrices (AMARC3.ppt.mp30. Similarly, the proportional breakdown of these total flows shows very similar zonal distributions of migrants. Figure 7.2 displays the total numbers of migrants modelled by both versions of the AMARC3 model between 1970 and 1999.

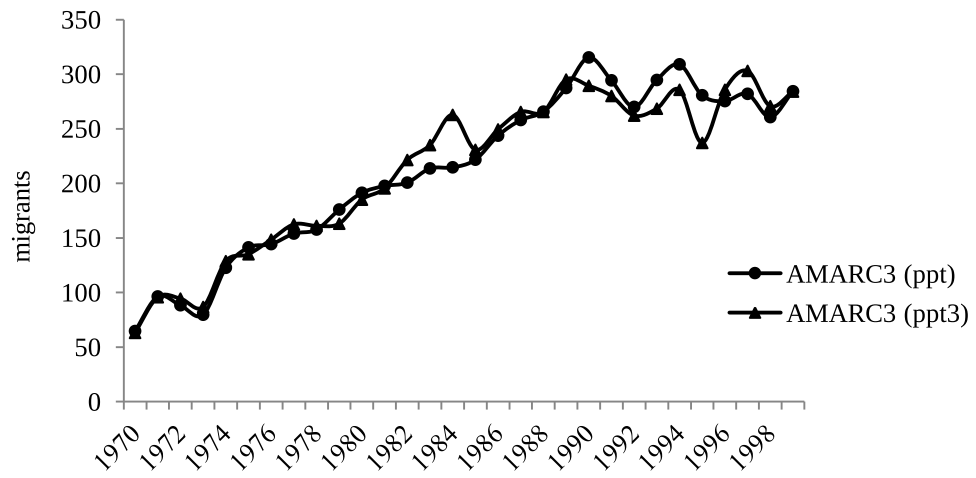

Figure 7.2: Annual populations of agents modelled by the one-year (ppt) and three-year ($ppt3$) rainfall classification versions of AMARC3 model as leaving each origin zone between 1970 and 1999. RMSD = **17 (7.07%)**.

It can be seen from Figure 7.3 that there is little difference between the total migration flows simulated by the two rainfall classifications of the AMARC3 model, particularly for the first 12 years (1970-1982). The RMSD residuals calculated between the two sets of data are only 17 (7.07%) over the thirty data points. In order to further investigate the nature of the two modelled flows, Figures 7.4 to 7.8 display the migration flows simulated from each of the five origin zones over the period 1970 to 1999.

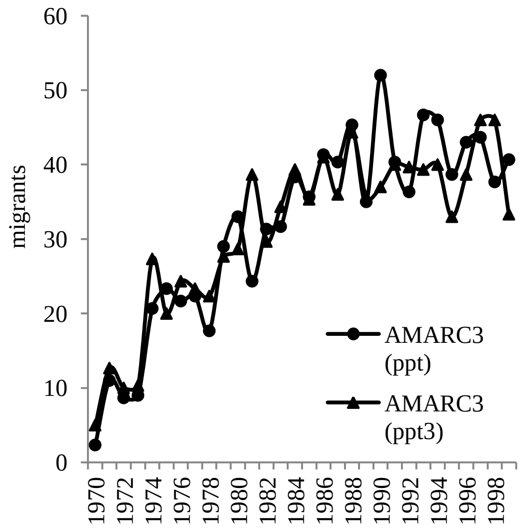

Figure 7.3: Flows of migrants originating in Ouagadougou as modelled by AMARC3 using ppt and $ppt3$ weight matrices. RMSD = **5 (13.07%)**.

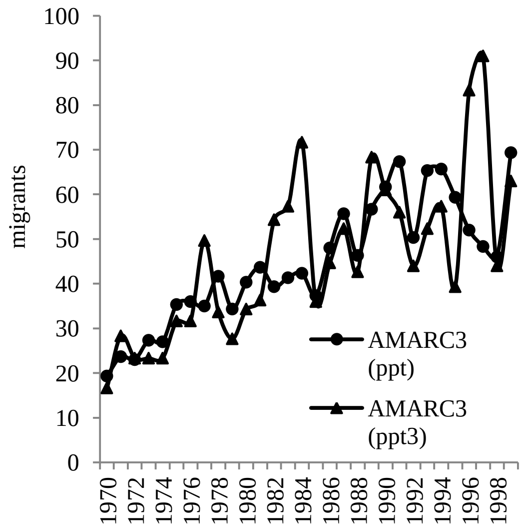

Figure 7.4: Flows of migrants originating in Bobo Dioulasso as modelled by AMARC3 using ppt and $ppt3$ weight matrices. RMSD = **14 (18.51%)**.

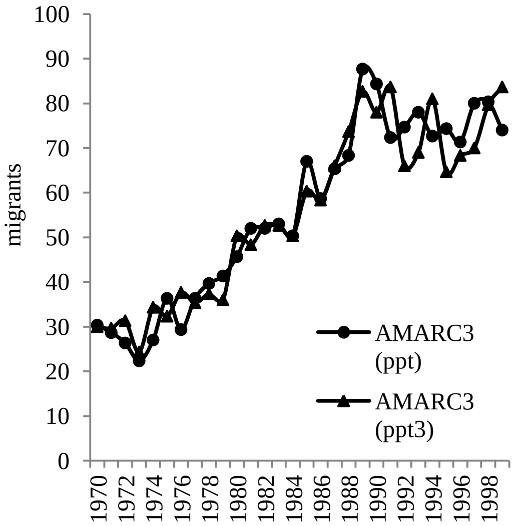

Figure 7.5: Flows of migrants originating in Sahel as modelled by AMARC3 ppt and $ppt3$ weight matrices. RMSD = **6 (9.87%)**.

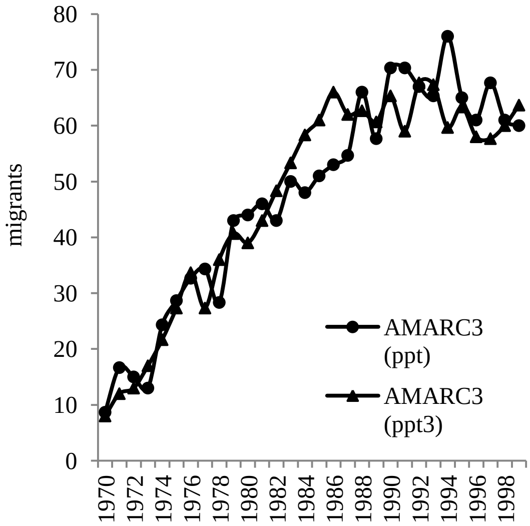

Figure 7.6: Flows of migrants originating in Centre as modelled by AMARC3 using ppt and $ppt3$ weight matrices. RMSD = **6 (10.77%)**.

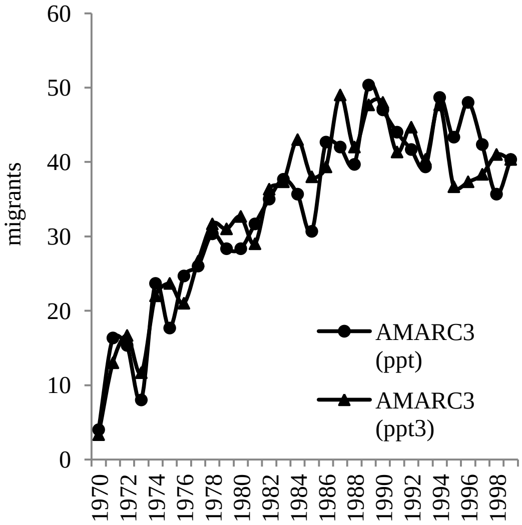

Figure 7.7: Flows of migrants originating in Southwest as modelled by AMARC3 using ppt and $ppt3$ weight matrices. RMSD = **4 (9.10%)**.

Each of the migrant flows displayed in Figures 7.3 to 7.7 reveal a slightly different pattern when one-year and three-year rainfall classifications are compared. The ppt and $ppt3$ AMARC3 modelled flows appear very similar with RMSD residuals between the two sets of data ranging from 4 to 6 (9.10% to 13.07%) in all zones apart from Bobo Dioulasso where the RMSD is 14

(18.51%). It is evident therefore that in the case of all zones apart from Bobo Dioulasso the difference between the AMARC3 ppt and $ppt3$ modelled flows is small. In the case of Bobo Dioulasso, two periods of significantly increased migration are modelled by the $ppt3$ version of the model compared to the ppt standard. The differences evident in the modelled migration of Bobo Dioulasso occur during the periods 1982 to 1984 and 1996 to 1997.. Although no such clear differences appear to be present in modelled migration flows from Ouagadougou or Sahel, the migration flows modelled from Centre and Southwest also show increased $ppt3$ modelled migration during the early to mid eighties (1984 and 1985 in Centre and 1984 in Southwest). Furthermore, modelled migration from Southwest using the $ppt3$ weight matrices appears to be lower than the ppt equivalent throughout the period 1995 to 1997. Figures 7.8 to 7.12 display the classification of each model year in each zone as dry (1), average (2) or wet (3) under the ppt and $ppt3$ classifications.

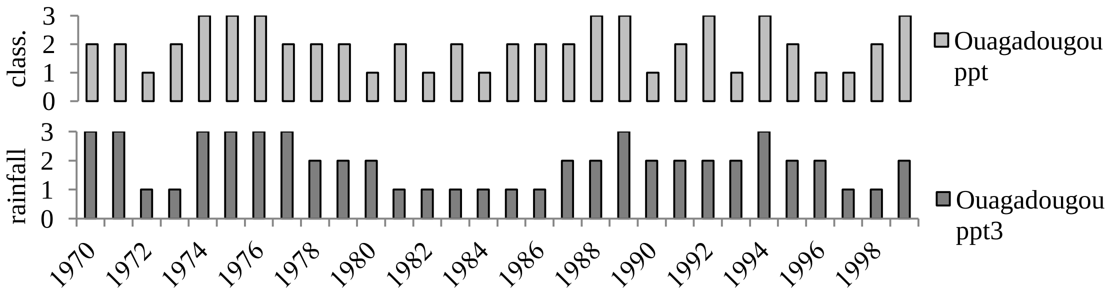

Figure 7.8: 1970-1999 ppt and $ppt3$ Ouagadougou rainfall classifications. Years with rainfall of below average/dry = 1, average rainfall = 2, and above average/wet = 3.

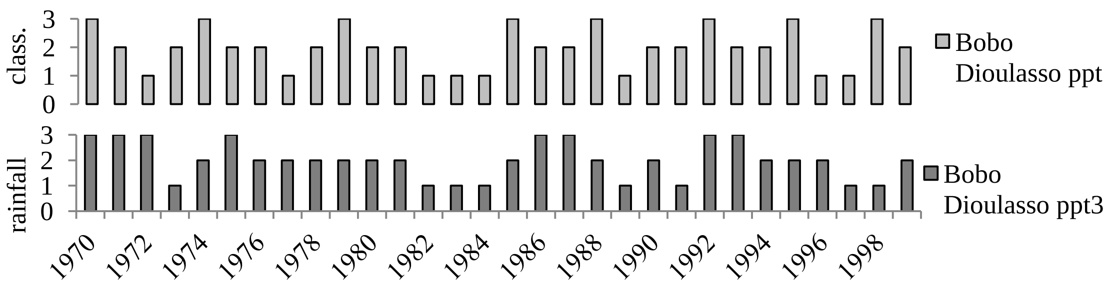

Figure 7.9: 1970-1999 ppt and $ppt3$ Bobo Dioulasso rainfall classifications. Years with rainfall of below average/dry = 1, average rainfall = 2, and above average/wet = 3.

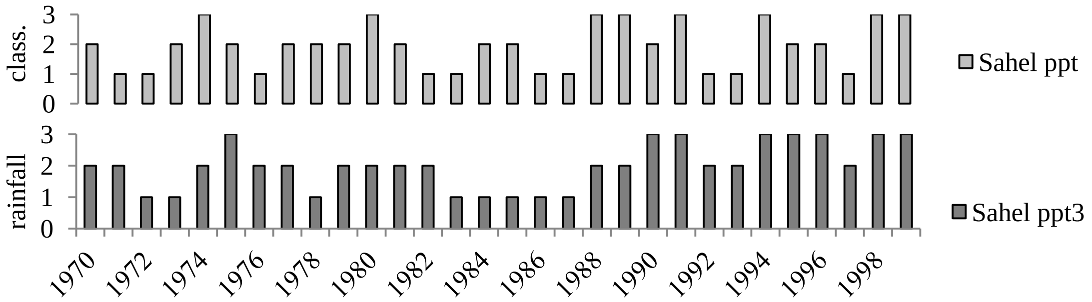

Figure 7.10: 1970-1999 ppt and $ppt3$ Sahel rainfall classifications. Years with rainfall of below average/dry = 1, average rainfall = 2, and above average/wet = 3.

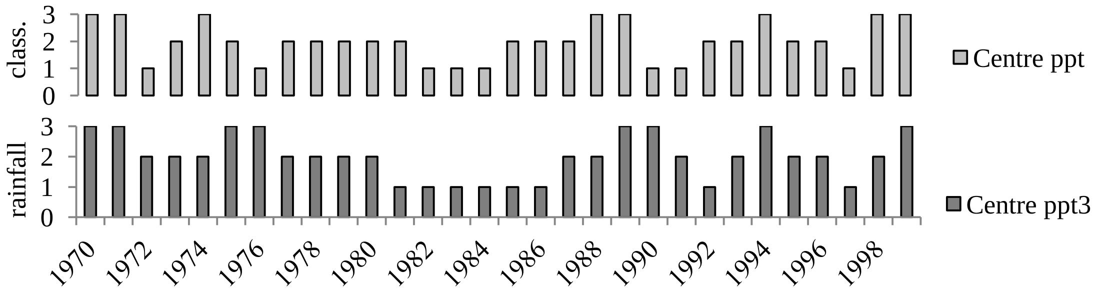

Figure 7.11: 1970-1999 ppt and $ppt3$ Centre rainfall classifications. Years with rainfall of below average/dry = 1, average rainfall = 2, and above average/wet = 3.

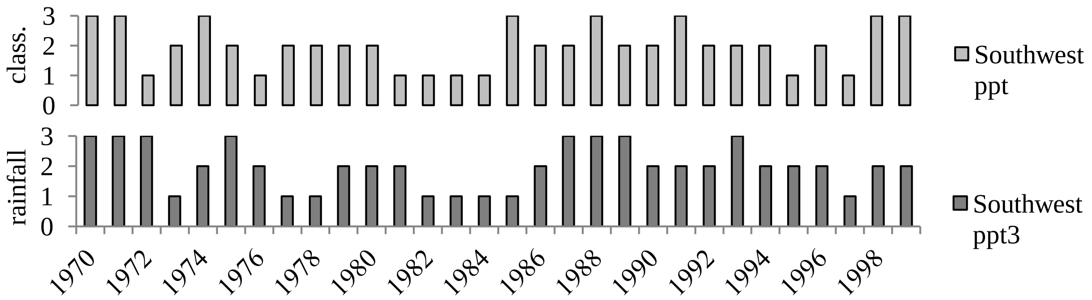

Figure 7.12: 1970-1999 ppt and $ppt3$ Southwest rainfall classifications. Years with rainfall of below average/dry = 1, average rainfall = 2, and above average/wet = 3.

By considering the different approaches to rainfall classification used by the ppt and $ppt3$ versions of the AMARC3 model it is possible to investigate the origin of some of the slight differences between the two sets of modelled migration flows. Differences between the migration flows modelled using the two distinct rainfall approaches have been identified as being most evident in Bobo Dioulasso, Centre and Southwest during the early to mid eighties (between 1982 and 1985). Across all five zones both ppt and $ppt3$ rainfall approaches record some or all of this period as below average rainfall. In the case of Bobo Dioulasso, both rainfall approaches categorise the years 1982-1984 as below average rainfall. However, the $ppt3$

version classes the preceding six years (1976-1981) as having average rainfall while the ppt version identifies these same years as being a mix of average, above and below. As the specific years during which different migration patterns are evident have been categorised as experiencing the same class of rainfall by both versions of the model, the different migration flows in Bobo Dioulasso can likely be attributed to the different levels of migration experience of agents leading up to this period of drought and the different tendencies to migration being communicated by each agent's networked peers following different drought precursors.

In Centre and Southwest, the other two zones within which migration patterns are seen to be different during the extended period of drought witnessed across Burkina Faso in the early 1980s, similar causal components are thought to be at play. While the ppt model identifies the years 1982-1984 as having below average rainfall, the $ppt3$ version identifies this drought period as extending from 1981 to 1986, likely impacting upon the migration flows modelled. While the drought periods identified by the two models in Southwest are of the same duration, the dry period finishes later in the $ppt3$ version of the model perhaps leading to the lower migration flows modelled by that version in 1985.

Not only is each year in the 1970-1999 running period of the AMARC3 model interpreted on a different basis by the two different versions of the model, the probability values used to calculate the likelihood of migration used by agents in forming their behavioural attitude towards migration options are different. As it could potentially take a longer or more extreme period of low rainfall to result in a specific year being categorised as below average under the model conditions imposed within the $ppt3$ version, it could be anticipated that the modelled migration flows might be more sensitive to such prolonged or extreme periods of drought. Such an occurrence is however only loosely evident from the five run averaged results displayed above. As a means to further understand the role of changes in rainfall variability upon the migration decision and therefore migration modelled as occurring in Burkina Faso the different ways of interpreting model rainfall as average, wet or dry are further considered.

7.4 The Role of Changes in Rainfall Variability - Departures

One of the crucial model components central to the inclusion of rainfall in the AMARC models is the classification of each model year as dry, average or wet. As identified above, the precise nature of this classification has some impact on the modelled outcomes in terms of whether the rainfall value to be classified represents the precipitation of the current year only or the inclusion of the two previous years as well. However, using a standard definition of a rainfall year (ppt) and a standardised means of classifying each year as dry, average or wet (relevant quartile threshold values) in both the analysis of the EMIUB data and each model run allows rainfall to provide a uniform modelled external precursor to migration. As rainfall is therefore used in the same manner in each version of the AMARC3 model, it is difficult to elucidate from model results the precise role of that rainfall plays in the migration decisions of agents.

In an attempt to clarify how rainfall affects the modelled migration decision of agents, three alternative versions of the AMARC3 model are used. AMARC3_Dry runs in the same 'full model' manner as AMARC3 but, no matter what the rainfall value of a year, always defines it as below average/dry. As a result, the behavioural attitude values retrieved by agents when making their migration decisions are only ever those calculated from the EMIUB data as being for a below average rainfall year. Similarly, the rainfall assets retrieved for the perceived behavioural control component are only ever average. Models AMARC3_Ave and AMARC3_Wet both have the same core model structure as AMARC3_Dry but define every year as average or above average/wet respectively. As such, only behavioural attitude and rainfall asset values for average and wet years are used respectively. By performing five runs of each of the three AMARC3 dry, average and wet models and comparing the averaged results it is possible to further investigate the role of changes in rainfall variability upon the modelled migration decision. Effectively using three fabricated historical rainfall scenarios, the results from the three models can provide further information on the likely role of changes in rainfall variability in migration decision in Burkina Faso.

Table 4 of Appendix 6 displays the averaged results of five runs of the AMARC3_Dry model. A total of 5,583 migrants are modelled as leaving all zones over the thirty years from 1970-1999 under an artificially dry scenario. Total migration is seen to peak in the AMARC3_Dry model results in 1989 at 264 migrants. Of these, the majority originate in the most populated zone, Centre. The fewest migrants that year meanwhile originate in Ouagadougou.

Table 5 of Appendix 6 displays the five model averaged results from the AMARC3_Ave model. A total of 6,688 migrants are modelled as leaving all zones between 1970 and 1999 under an artificially average rainfall scenario, 20% more than are modelled by the artificially dry scenario. The year of greatest overall migration modelled by the AMARC3_Ave model is 1990 with 300 migrants. Unlike the modelled results from the dry rainfall scenario run, the majority of these originate in the northernmost zone, Sahel. However, in parallel with the results of the AMARC3_Dry model, the lowest migrant flow that year is modelled by AMARC3_Ave as that originating in Ouagadougou.

Table 6 of Appendix 6 displays the five model averaged results from the AMARC3_Wet model. A total of 6,192 migrants are modelled as leaving all model zones between 1970 and 1999 under an artificially wet rainfall scenario, 7% less than under the artificially average rainfall scenario and 11% more than the dry. The year of greatest overall migration modelled by AMARC3_Wet is 1989 with 290 migrants. In accordance with the average rainfall version of the model, the majority of these 1989 migrants originate in Sahel while the smallest proportion originates in Ouagadougou. In order to further investigate the role of changes in rainfall variability in the modelled migration decision, Figure 7.13 displays a direct graphical comparison of the total flows of migrants modelled by each version of the AMARC3 model including the ‘full-rainfall’ version.

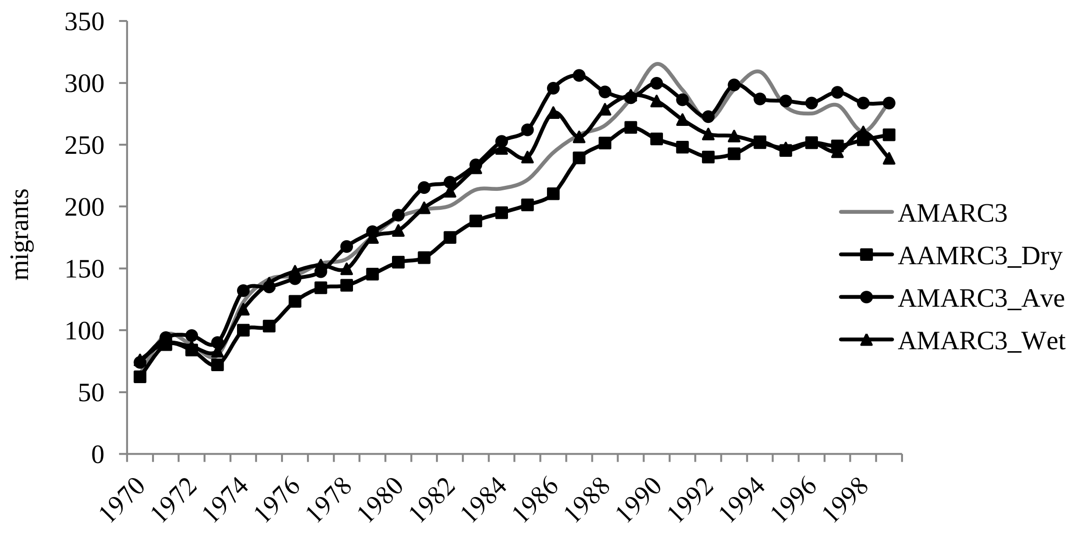

Figure 7.13: Annual populations of agents modelled by the standard and three rainfall versions of the AMARC3 model as leaving all origin zones between 1970 and 1999. RMSD away from AMARC3 = dry: 30 (15.08%), average: 20 (8.61%) and wet: 22 (10.43%).

Figure 7.13 displays the total migration flows modelled as occurring from all model zones by the three artificial rainfall scenario versions of the AMARC3 model. Between 1970 and 1994 it can be seen that the dry scenario results in the lowest level of total modelled migration.

However, from 1994 onwards the dry and wet rainfall scenarios show very similar modelled migration flows. The largest total migration flow is modelled by the average rainfall scenario of the AMARC3 model and represents a considerable increase in migration over both the dry and wet scenarios from 1993 onwards.

Results from the standard ‘full-rainfall’ version of the AMARC3 model show consistently higher levels of migration than those modelled under the dry scenario. By contrast, the average and wet rainfall scenarios show modelled total migration flows closer to those of the full model. Calculating RMSD values that compare migration modelled by the standard version of AMARC3 with each of the artificial rainfall scenario versions show residuals of 30 (15.08%), 20 (8.61%) and 22 (10.43%) for the dry, average and wet scenarios respectively. This suggests that the greatest influence of one rainfall scenario upon total modelled migration in Burkina Faso results from the dry version which models a significant decrease in migration over much of the thirty year test period. As might be anticipated from use of the 1970-1999 rainfall data to define dry, average and wet rainfall conditions, the lowest RMSD residuals score is evident for the average rainfall scenario. Interestingly, towards the end of the model period, total migrant flows modelled by the dry and wet scenarios start to display closer similarities. By the end of the test period the wet scenario modelled flows result in the lowest modelled total migration.

Total modelled migration flow results displayed in Figure 7.13 suggest that, from the approach used to isolate the role of changes in rainfall variability on the migration decision in Burkina Faso, the rainfall conditions that result in the largest overall modelled migration flows are those that are average. Any deviation away from average conditions appears to result in a reduction in migration flows, generally greater throughout the test period under below average rainfall conditions. It appears therefore that the overall flow of migrants in Burkina Faso marginally decreases under wet conditions. In the context of Burkina Faso this could be hypothesised to result from a rainfall-related increase in harvest yield that enables more households to survive the duration of the dry season without having to rely upon migration as a livelihood strategy to support household income. As such, migration becomes more of a choice than a necessity, an occurrence likely replicated in the *behavioural attitude* values agents in the AMARC model develop towards migration options.

While increased rainfall beyond average conditions is modelled to result in a marginal decrease in total migration, a decrease in rainfall to below average is seen to result in a further reduction in total migration. Rather than acting to increase the need for migration to support household income, dry conditions can be proposed therefore to reduce migration rates by limiting the ability of some households to invest in the initial expenditure required to undertake migration. In the context of the AMARC models, this would be reflected in the assets available to an individual agent and their formation of a *perceived behavioural* control score towards migration options. Such an occurrence would accord with the general trends of migration recently recorded in the literature (Black et al., 2011a) and can be tested by introducing increased assets into the model. In order to explore the proposed influence of assets and agent's perceptions of their capacity to migrate upon the low level of migration modelled under dry conditions, Figure 7.14 displays the modelled impact of the artificial addition of 50% extra assets to the entire model population (overlain on the modelled flows shown in Figure 7.13).

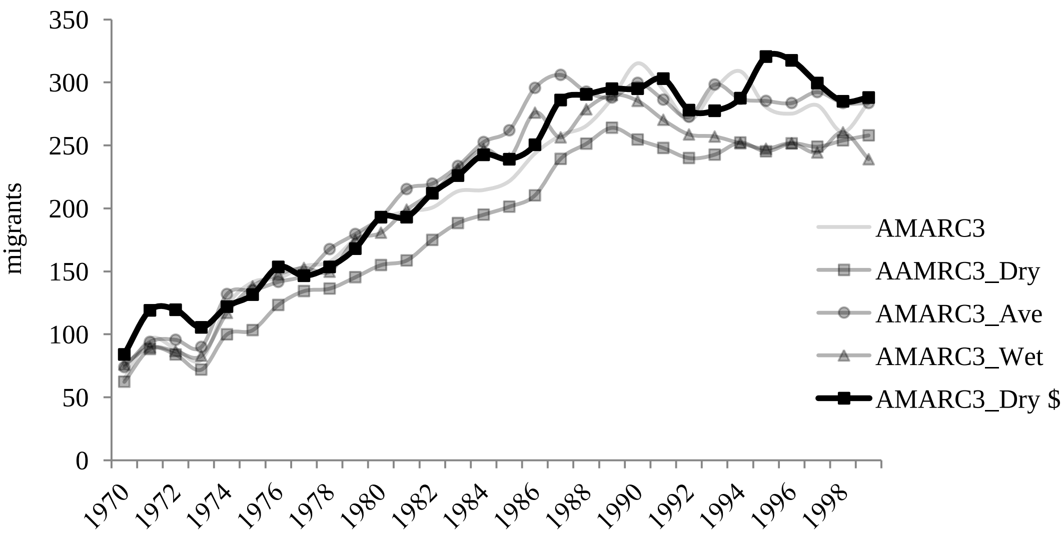

Figure 7.14: Annual populations of agents modelled by the standard and three rainfall versions of the AMARC3 model as leaving all origin zones between 1970 and 1999 overlain with an increased asset version of AMARC3_Dry, entitled, 'AMARC3_Dry $'.

By comparing the AMARC3_Dry $ modelled migration with that of a standard AMARC3_Dry run in Figure 7.14, it can be seen that modelled impact of increased assets results in an increased flow of migrants. On this basis, the notion that reduced migration under dry conditions is brought about by reduced access to the capital necessary for an agent to perceive themselves capable of migration, is supported. As such, an individual agent's 'need' to migrate to improve their financial situation during the time of hardship is outweighed by their reduced capacity to invest in migration. In order to further investigate the role of changes in rainfall variability on the modelled migration decision in Burkina Faso, Figures 7.15 to 7.19 display the changes in migration from each origin zone for the three artificial rainfall scenario versions of the AMARC3 model and the standard ‘full-rainfall’ version.

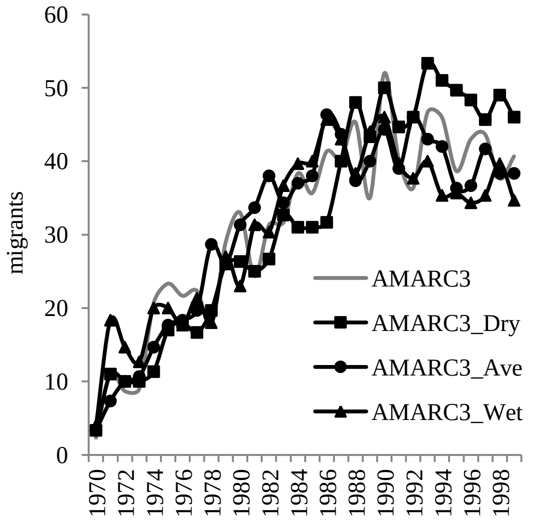

Figure 7.15: Flows of migrants modelled by the standard and artificially dry, average and wet AMARC3 rainfall scenarios as originating in Ouagadougou. RMSD away from AMARC3 = 5.9 (dry), 5 (ave.) and 5.4 (wet).

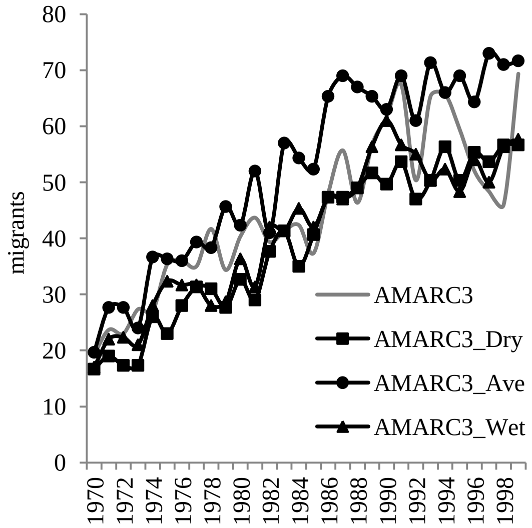

Figure 7.16: Flows of migrants modelled by the standard and artificially dry, average and wet AMARC3 rainfall scenarios as originating in Bobo Dioulasso. RMSD away from AMARC3 = 8.3 (dry), 11 (ave.) and 7.1 (wet).

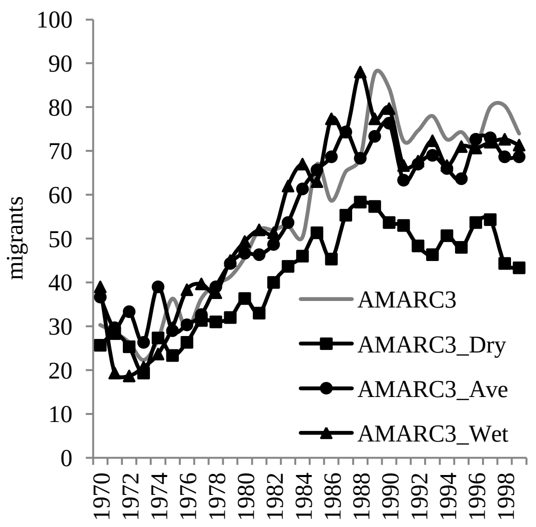

Figure 7.17: Flows of migrants modelled by the standard and artificially dry, average and wet AMARC3 rainfall scenarios as originating in Sahel. RMSD away from AMARC3 = 18.3 (dry), 7.2 (ave.) and 8.2 (wet).

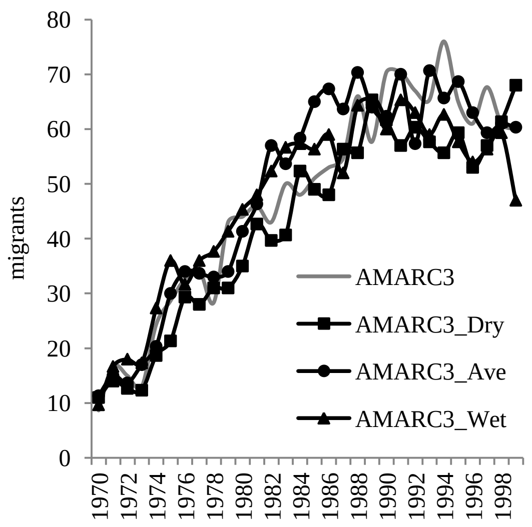

Figure 7.18: Flows of migrants modelled by the standard and artificially dry, average and wet AMARC3 rainfall scenarios as originating in Centre. RMSD away from AMARC3 = 7.7 (dry), 6.8 (ave.) and 6.6 (wet).

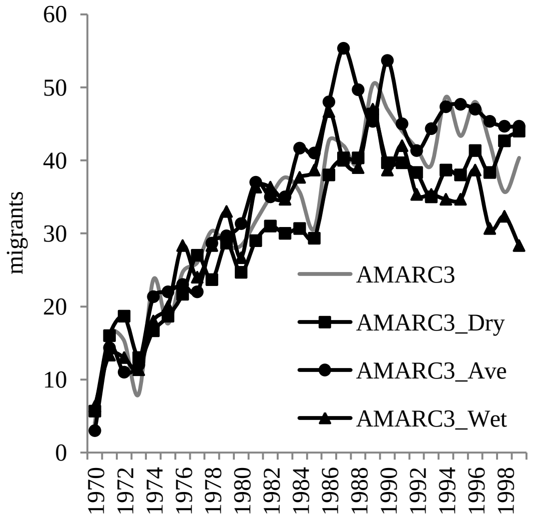

Figure 7.19: Flows of migrants modelled by the standard and artificially dry, average and wet AMARC3 rainfall scenarios as originating in Southwest. RMSD away from AMARC3 = 4.7 (dry), 5.2 (ave.) and 5.9 (wet).

When the comparison of artificially dry, average and wet rainfall scenarios reaches the level of analysis at which modelled migrant numbers leaving each zone are considered, the role of changes in rainfall variability upon the migration decision in each zone can be seen to be different. Figures 7.15 to 7.19 reveal that the nature of the comparisons that can be drawn between each of the rainfall scenario versions of AMARC3 vary between origin zones. The flows of migrants modelled as leaving Ouagadougou tend to show relatively little deviation from the standard version of the AMARC3 model, at least until 1993 when migration flows under the dry scenario are seen to be consistently higher than the average, wet and 'full-rainfall' versions. Calculating RMSD values that compare migration modelled by the standard version of AMARC3 with each of the artificial rainfall scenario versions show residuals of 5.8, 5 and 5.4 for the dry, average and wet scenarios respectively. It is clear therefore that, although little variation between the artificial rainfall scenarios is evident in Ouagadougou, the largest deviation away from the standard version of AMARC3 is evident for the dry rainfall scenario.

The flows of migrants modelled as leaving Bobo Dioulasso (Figure 7.16) show considerably more variation than is evident in the case of Ouagadougou. Throughout the majority of the thirty year test period, the average rainfall scenario results in consistently higher rates of migration than both the dry and wet scenarios and the ‘full-rainfall’ version of AMARC3. Migrant flows modelled by the dry and wet scenarios meanwhile appear to show little overall difference while also fitting closer to the migrant flow modelled as leaving Bobo Dioulasso under the ‘full-rainfall’ model. RMSD values calculated show the deviation of artificial rainfall scenario migrant flows away from those modelled by the ‘full-rainfall’ version as ranging from a low of 7.1 for the wet scenario to 11 for the average. It appears therefore that the greatest deviation away from the standard version of AMARC3 is evident under the average rainfall scenario in Bobo Dioulasso.

It can be seen that the greatest difference in modelled migrant flows from Sahel in Figure 7.17 result from dry conditions, modelled as producing consistently fewer migrants from 1978 onwards. By contrast, artificially average and wet conditions in Sahel appear to result in little change in overall modelled migration away from that modelled by the ‘full-rainfall’ model. The RMSD calculated between AMARC3 and AMARC3_Dry modelled migration flows from Sahel show residuals of 18.3, considerably more than those calculated for the average and wet scenarios (RMSD of 7.2 and 8.2 respectively). It appears therefore that while average and wet rainfall conditions have little impact upon overall migration flows in Sahel, dry rainfall conditions result in a clear decrease in modelled migrant numbers.

It can be seen from Figure 7.18 that, while a relatively clear impact of rainfall upon migration in both Bobo Dioulasso and Sahel can be inferred, such an impact is not as evident in the case of modelled migration from Centre. Although artificially dry rainfall conditions appear to result in a slight decrease in modelled migration between 1977 and 1986, the trend is not as apparent throughout the remainder of the test period. When RMSD values are compared it is evident that the dry rainfall scenario shows slightly more deviation (residuals of 7.7) away from the ‘full-climate’ version of AMARC3 than is calculated for both average (residuals of 6.8) and wet (residuals of 6.2) conditions. It appears therefore that, although not as clearly evident as in the case of Sahel, dry conditions result in decreased modelled migration from Centre.

In the case of modelled migration from Southwest, it can be seen from Figure 7.19 that, particularly from 1990 onwards, average rainfall conditions result in higher rates of migration than both the dry and wet alternatives. Furthermore, the average rainfall scenario appears to generally follow both the scale and pattern of migration modelled by the ‘full-rainfall’ version of AMARC3. Over this same period (1990-1999) the artificially wet rainfall scenario appears to result in the lowest level of modelled migration from Southwest. RMSD values calculated to compare each of the rainfall scenario modelled outputs with that of the standard version of AMARC3 reveal that the lowest level of deviation away from the 1970-1999 AMARC3 flow is that for the dry scenario (residuals of 4.7). The largest is evident for the wet scenario (residuals of 5.9) while the average scenario shows a median level of deviation (residuals of 5.2). It can be seen therefore that the impact of the artificial rainfall scenarios upon modelled migration from Southwest appear to have no consistent relationship across the entire thirty year test period. While the lowest modelled migration throughout the 1980s appears to result from the dry rainfall scenario, throughout the 1990s the lowest flow appears to result from wet rainfall conditions.

The impact of rainfall upon modelled migration flows is evidently different in each of the origin zones. While dry rainfall conditions result in increased modelled migration from Ouagadougou, the same conditions result in a significant reduction in migrant numbers from Sahel and, to a lesser extent, Centre. Meanwhile, average rainfall conditions in Bobo Dioulasso and, to a lesser extent Southwest, result in increased modelled migration. The fact that these differences in modelled migration trends are evident across the model zones suggests that different environmental, social, economic and cultural drivers are at play in each location across Burkina Faso, making a simple analysis of a trend in total migration alone somewhat flawed. The notional basis of agent-based modelling as permitting the inclusion of both structure and agency in considering the migration decision is therefore supported by the presence of different and contrasting migrant trends across the five zones.

Although trends in modelled migration vary with changing rainfall in each of the five model zones, a general tendency of greatest modelled migration under average conditions and lowest modelled migration under dry conditions appears to be emerging. Such a pattern is evident in both the total modelled flows seen in Figure 7.13 and, to varying degrees, the flows modelled from each zone. In Figure 7.14, evidence was presented that supported the hypothesis that decreased assets under below average rainfall conditions were restricting agents' perceptions of whether or not they were capable of migrating. In the asset-poor Sahel model zone, migrant flows modelled under dry conditions show the greatest reduction away from average or wet flows and likely contribute considerably to the reduction in total modelled flows seen under dry conditions in Figure 7.13. Such evidence further supports the power of changes in assets in determining modelled migration. However, it is interesting to observe that the converse increase in assets that is modelled as occurring under above average/wet rainfall conditions does not lead to modelled migration flows beyond those seen under average conditions. Only in the case of Sahel do the increases in assets following wet conditions result in modelled migration beyond that seen under average conditions.

As a result of the mode of analysis implemented in this section, migration across Burkina Faso is modelled by AMARC to be generally greatest under average rainfall conditions. Evidence has been presented that links a decrease in modelled migration under dry conditions with the reduction in assets that agents require to perceive themselves more capable of migrating. By contrast, the slight reduction in migration modelled under wet rainfall conditions appears to result from the reduced tendencies towards migration of subsistence households under advantageous agricultural conditions where they retain the option of remaining in-situ and farming their own land rather than having to migrate in search of additional income. As such, the migration seen in the model is considered to be more of a wealth development strategy than the survival migration seen under drought conditions. Although Lilleør and Van den Broeck (2011) refer to evidence in the current literature of a negative relationship between migration and rainfall (decreased rainfall resulting in increased migration and vice versa), they suggest that there is only very limited evidence as to what drives it. In accordance with Lilleør and Van den Broeck's paper that focuses on income variability as one of two major drivers of migration in Less Developed Countries (the other being income level differentials between origin and destination), the AMARC model finds that the change in income resulting from below average rainfall affects migration, but not in the direction that the majority of the literature suggests. In accordance with Black et al.'s (2011a) notion of 'trapped populations', decreased rainfall is reducing household assets, particularly in the already asset-poor Sahel, and contributing to a decrease in modelled migration. Meanwhile, above average rainfall is seen to result in generally little change in modelled migration when compared with that seen under average conditions.

7.5 The Role of Changes in Rainfall Variability - Arrivals

Analysis of the role of change in rainfall variability on the migration decision thus far has revealed the nature of both the overall migrant flows modelled under each rainfall scenario and the breakdown of those flows into their respective origins. The AMARC models were found in Chapter 6 to be appropriately portraying migration in Burkina Faso to the level of accuracy where simulations of the total flow of migrants and the breakdown of that flow into both origin and destination locations were deemed valid. With the aim of further investigating the role of changes in rainfall variability while using a level of model simulation detail classed as externally valid, it is possible to consider arrivals modelled at each of the model zones, including International. Understanding both the origins and destinations of migrants simulated by the three artificial rainfall scenarios used as AMARC3 model versions provides further detail that can be used to understand the nature of rainfall in the modelled migration decision.

Table 7 of Appendix 6 displays the five run averaged annual arrivals modelled for each zone by AMARC3_Dry. Over the 30 year modelled period the AMARC3_Dry model simulates International destinations as being the most popular with a total of 1,785 migrants relocating to such destinations between 1970 and 1999. Ouagadougou and Centre are also modelled as popular destinations under the artificially dry scenario with 1,379 and 1,571 arrivals respectively. The least frequently chosen destination is modelled as being Bobo Dioulasso with only 83 arrivals over the thirty year test period.

Table 8 of Appendix 6 displays the five run averaged numbers of migrants modelled as arriving in each destination zone by AMARC3_Ave. In accordance with the migration flows simulated by AMARC3Dry, the most common destination for migrants in the AMARC3_Ave model is International. However, the 2,674 migrants modelled as arriving in International destinations represents an increase of 50% over the total thirty year flow modelled by the artificially dry scenario. In further agreement with the AMARC3_Dry modelled migration flows, the least common destination is seen to be Bobo Dioulasso with just 100 arrivals modelled by AMARC3_Ave between 1970 and 1999.

Table 9 of Appendix 6 displays the five run averaged numbers of migrants modelled as arriving in each destination zone by AMARC3_Wet. Under the artificially wet rainfall scenario once again the most common modelled destination is International with 1,963 modelled arrivals between 1970 and 1999, 10% more than modelled by AMARC3_Dry. However, the AMARC3_Wet model shows Centre to be almost as popular a destination as International with 1,923 arrivals, 22% more than are simulated by the dry version of the model. The least frequented destination for migrants under the artificially wet scenario is again shown to be Bobo Dioulasso with 125 arrivals modelled over the thirty years from 1970-1999. In order to further investigate the nature of the flows of migrants modelled as arriving in each of the destination options available in the AMARC models, Figures 7.20 to 7.25 display comparisons of the number of arrivals modelled by each of the three artificial rainfall scenario versions of the AMARC3 model.

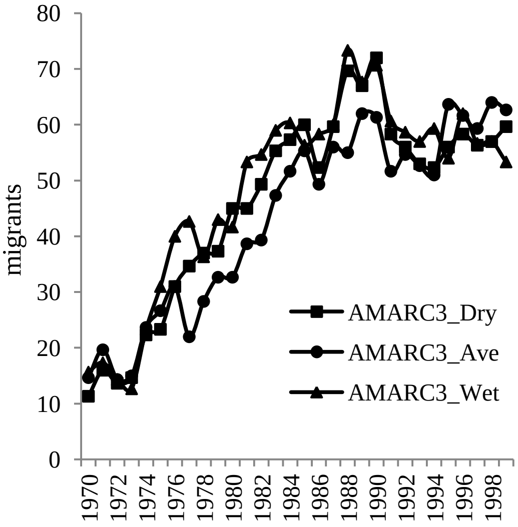

Figure 7.20: Flows of migrants modelled by the three artificial rainfall scenarios of the AMARC3 model as arriving in Ouagadougou.

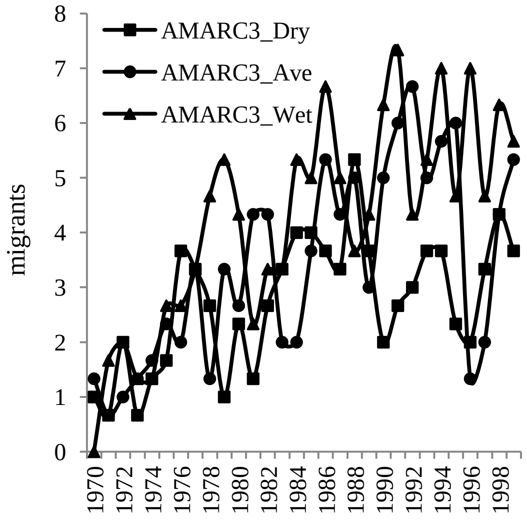

Figure 7.21: Flows of migrants modelled by the three artificial rainfall scenarios of the AMARC3 model as arriving in Bobo Dioulasso.

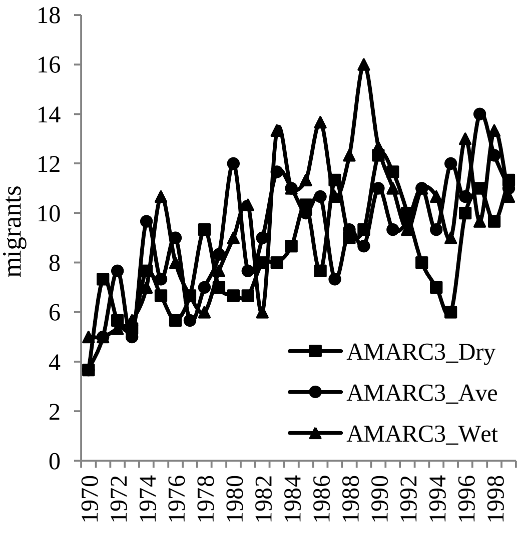

Figure 7.22: Flows of migrants modelled by the three artificial rainfall scenarios of the AMARC3 model as arriving in Sahel.

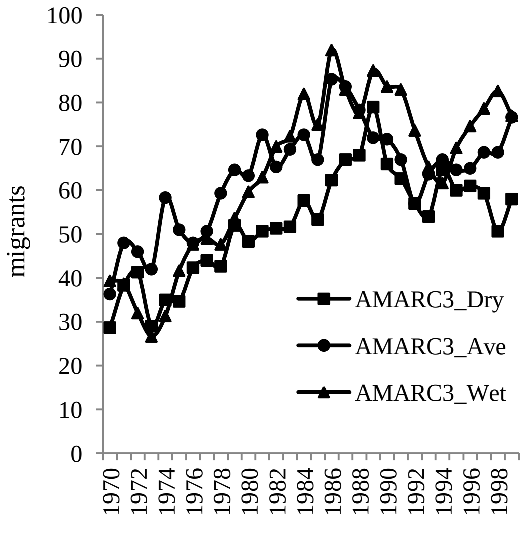

Figure 7.23: Flows of migrants modelled by the three artificial rainfall scenarios of the AMARC3 model as arriving in Centre.

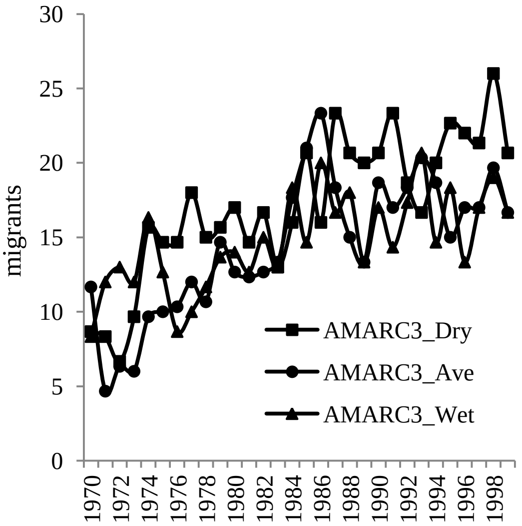

Figure 7.24: Flows of migrants modelled by the three artificial rainfall scenarios of the AMARC3 model as arriving in Southwest.

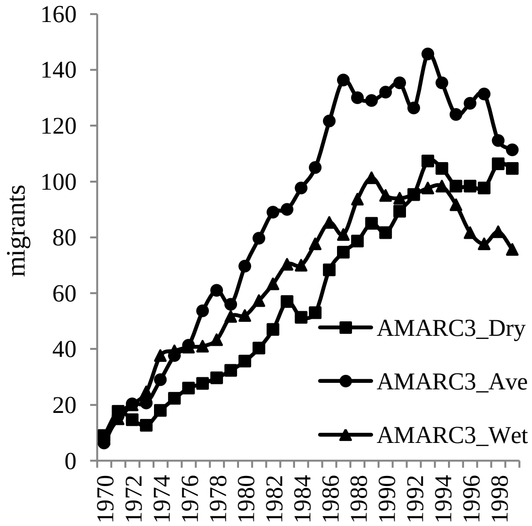

Figure 7.25: Flows of migrants modelled by the three artificial rainfall scenarios of the AMARC3 model as arriving in International.

It is evident from Figures 7.20 to 7.25 that, in the case of the five internal destinations available to migrants in Burkina Faso, relationships between modelled artificial rainfall scenario and migration are neither immediately apparent nor consistent across all five zones. However, some relationship between modelled rainfall scenario and level of modelled migration can be identified for arrivals in most zones. In the case of arrivals to Ouagadougou, between 1977 and 1991 average rainfall conditions appear to result in a low arrival rate while dry and wet conditions result in marginally higher arrivals. However, this trend appears to reverse towards the end of the test period. Migrants modelled as choosing Bobo Dioulasso as a destination are so few in all modelled scenarios that no reliable results are considered to be identifiable.

Arrivals in Sahel are not clearly distinguishable between rainfall scenarios although, of the four notable peaks in modelled arrivals, one occurs under average rainfall conditions (1980) while the three others occur under the wet rainfall scenario (1983, 1986 and 1989). By contrast, the lowest arrival rates in Sahel are seen largely as occurring during dry rainfall conditions. Throughout the test period, modelled arrivals in Centre appear to be consistently lower under dry conditions. By contrast, both average and wet conditions appear to result in similarly high arrival rates in Centre. In a similar fashion, arrivals in Southwest appear to be comparable under average and wet rainfall conditions. However, unlike arrivals in Centre, the dry scenario results in a slight increase in modelled arrivals in Southwest, particularly from 1993 onwards.

Identifying differences between the arrivals modelled for each internal destination under the dry, average and wet rainfall scenarios in Figures 7.20 to 7.24 is at times difficult due to the similarity between modelled arrivals and the changes in arrival patterns seen across the thirty year test period. By contrast, a clear and fairly consistent difference between modelled arrivals to International destinations is evident across dry, average and wet rainfall scenarios. It can be clearly seen from Figure 7.25 that the average rainfall scenario results in considerably higher modelled arrivals to International destinations. The wet scenario meanwhile results in clearly reduced modelled arrivals while the lowest International arrival rate is evident under the dry rainfall scenario between 1970 and 1993, beyond which point the wet scenario shows lower modelled flows.

From the results of the artificially dry, average and wet AMARC3 rainfall scenarios presented above it can be inferred that dry rainfall conditions result in low rates of arrival to Sahel, Centre and International destinations but increased rates of arrival in Southwest and, to a lesser extent, Ouagadougou. Average rainfall conditions meanwhile appear to result in low rates of arrival in Ouagadougou and Southwest but a significantly increased arrival rate in International and, to a lesser extent, Centre. Finally, wet conditions are modelled as resulting in relatively high rates of arrival in Ouagadougou, Sahel, Centre and Southwest while arrivals to International destinations are contrastingly seen to be relatively low.

Modelled arrivals to each of the internal destinations available to agents show arrival rates that appear in many cases to change over time as well as between rainfall scenarios. Arrivals in Ouagadougou for example are modelled as being significantly lower under average rainfall conditions between 1977 and 1991. However, for the remainder of the test period, such a pattern is not so evident. In order to further investigate the role of changes in rainfall variability on the migration decision and work towards a relationship between migration and rainfall as clear as that evident for International arrivals in Figure 7.25, this research turns to an analysis of the migrant numbers modelled by the ‘full-rainfall’ version of AMARC3 during model years recorded as dry, average and wet.

7.6 Migration in Dry, Average and Wet Years

The process of comparing modelled migration in years between 1970 and 1999 and classed as dry, average or wet should shed light on the tendency of the modelled agents in each zone to migrate in the face of less consistent historic rainfall precursors. As identified in Chapter 4, 1970-1999 rainfall data for the AMARC models comes from the Delaware data and has been retrieved from the global dataset using the latitude and longitude coordinates for each of the five modelled zones. Due to this zone-based approach to rainfall retrieval, each model zone has its own definition of dry, average and wet years, calculated using quartiles for the relevant rainfall data. As a result, one particular year may be defined as average in one zone but wet or dry in others. This approach therefore acknowledges the spatial reality of rainfall patterns which may induce drought in one location and a relative abundance of water in another nearby.

Used to derive the probability values that make up each agent's behavioural attitude towards each migration option and their rainfall related assets, the annual rainfall classifications inform model development and are a central component in each model run. The following analysis is therefore used to investigate how the combination of rainfall dependent components of the migration decision result in actual modelled migration under each rainfall classification. Figures 7.26 to 7.28 display the classification of the rainfall experienced in each modelled zone between 1970 and 1999 as average, wet or dry on the basis of the *ppt* approach. Dry years are given a value of 1, average years a value of 2, and wet years a value of 3.

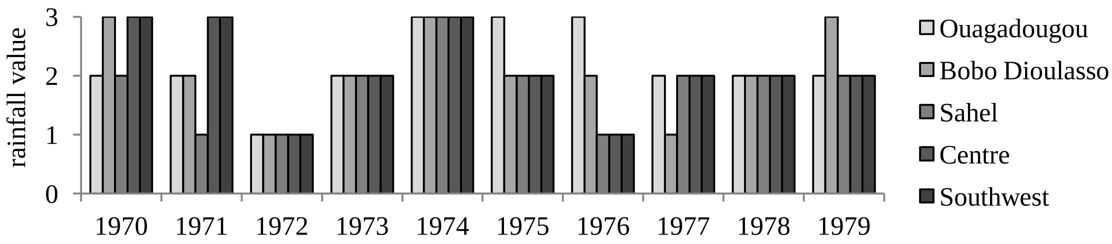

Figure 7.26: Rainfall classifications by year for all model zones from1970 to 1979. Below average/dry rainfall = 1. Average rainfall = 2. Above average/wet rainfall = 3.

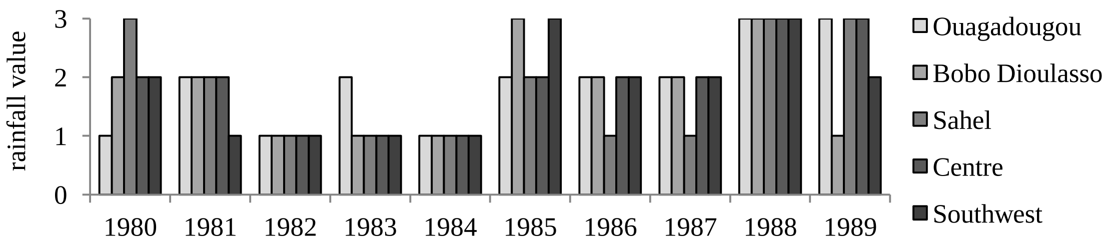

Figure 7.27: Rainfall classifications by year for all model zones from1980 to 1989. Below average/dry rainfall = 1. Average rainfall = 2. Above average/wet rainfall = 3.

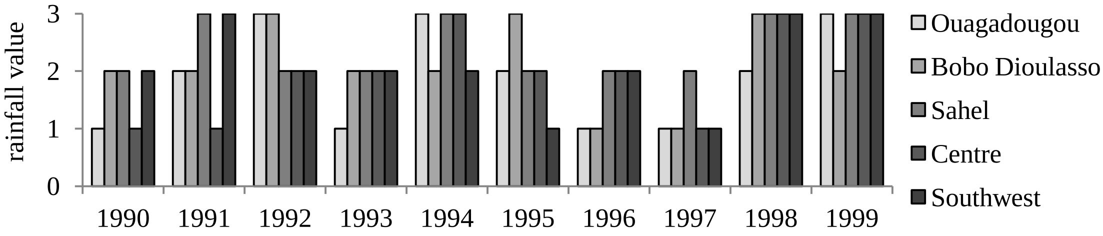

Figure 7.28: Rainfall classifications by year for all model zones from1990 to 1999. Below average/dry rainfall = 1. Average rainfall = 2. Above average/wet rainfall = 3.

It can be seen from Figures 7.26 to 7.28 that each AMARC model zone has its own 1970-1999 rainfall history in terms of the occurrence of dry, average and wet years. Only seven of the thirty modelled years show the same rainfall classification across all five model zones. In field interviews conducted across Burkina Faso, numerous mentions were made by interviewees to the worst droughts experienced in living memory being those that affected the whole of Burkina Faso and the surrounding region. Such droughts were reported by interviewees to have occurred in both the early 1970s (frequent specific mentions of 1972) and early 1980s (common mentions of 1984). Both of these periods show evidence of agreement in terms of rainfall classifications across the model zones. The primary example of this is evident in Figure 7.27 for the period from 1982 to 1984. In both 1982 and 1984 all five model zones are recorded as experiencing rainfall conditions classed as dry, while four out of five zones also recorded 1983 as dry. This period of both prolonged and widespread below average rainfall was mentioned by interviewees across Burkina Faso as one of particular hardship.

Due to the spatial variation in rainfall across Burkina Faso, the impact of dry, average and wet years upon migration must be considered in the context of each individual zone. Figure 7.29 displays the migration rate modelled by AMARC3 as occurring in Ouagadougou from 1970-1999 and the model rainfall classifications for the same time period. The migration rate is calculated as the percentage of a zone’s entire population that the five run averaged modelled migration from that zone represents in a given year. Rainfall classifications follow the pattern described above where dry conditions are classed as 1, average rainfall as 2, and wet conditions as 3.

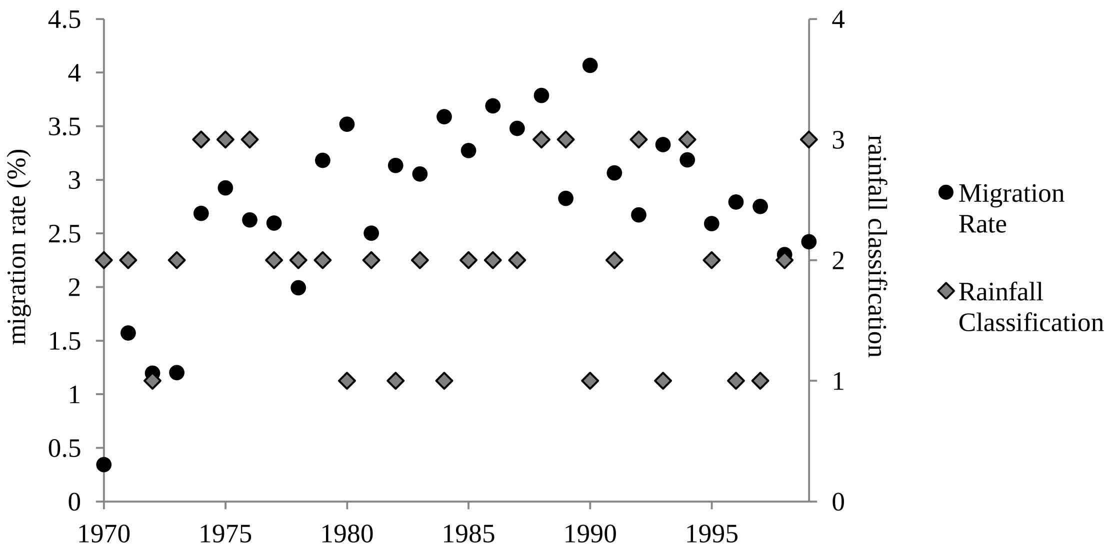

Figure 7.29: Scatter plot of AMARC3 (ppt) modelled migration rate and rainfall classifications for Ouagadougou from 1970-1999. Correlation coefficient = **-0.07**.

It can be seen from Figure 7.29 that no clear relationship between rainfall classification and modelled migration rate appears evident in Ouagadougou. Despite this, it can be loosely suggested that below average/dry rainfall years (such as 1980 and 1990) appear to result in slight increases in the modelled migration rate. The correlation coefficient between the two sets of data suggests a slight but insignificant negative relationship (-0.07). However, for a link between migration rate and rainfall to produce a significant correlation value, migration rate would need to increase or decrease in a continuous manner across the three-point rainfall scale used (e.g. lowest migration in dry years and highest in wet years or vice versa). Although the means of presentation seen in Figure 7.29 is a useful way to clearly display both rainfall classification and migration rate data from a location, it appears not to provide insight into what may be a subtle relationship between modelled migration and rainfall, particularly in the urban centre, Ouagadougou. In appreciation of the necessity for a more subtle means of analysis, Figure 7.30 displays the average migration rates modelled in Ouagadougou during dry, average and wet years.

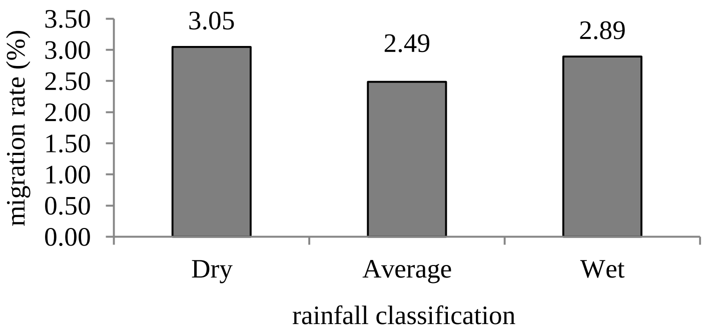

Figure 7.30: AMARC3 modelled 1970-1999 average migration rates for dry, average and wet rainfall years in Ouagadougou.

The difference between the average migration rates displayed in Figure 7.30 suggests that, as anticipated, the migration rates modelled for Ouagadougou in average wet and dry years show relatively little difference. However, in accordance with the suggested findings from Figure 7.29, and in accordance with later (1988 onwards) modelled migration flows from Ouagadougou displayed in Figure 7.15, the average rate of migration modelled during dry years is greater (3.05%) than that for both average (2.49%) and wet (2.89%) years. Figure 7.31 displays the migration rate and rainfall classification data for Bobo Dioulasso.

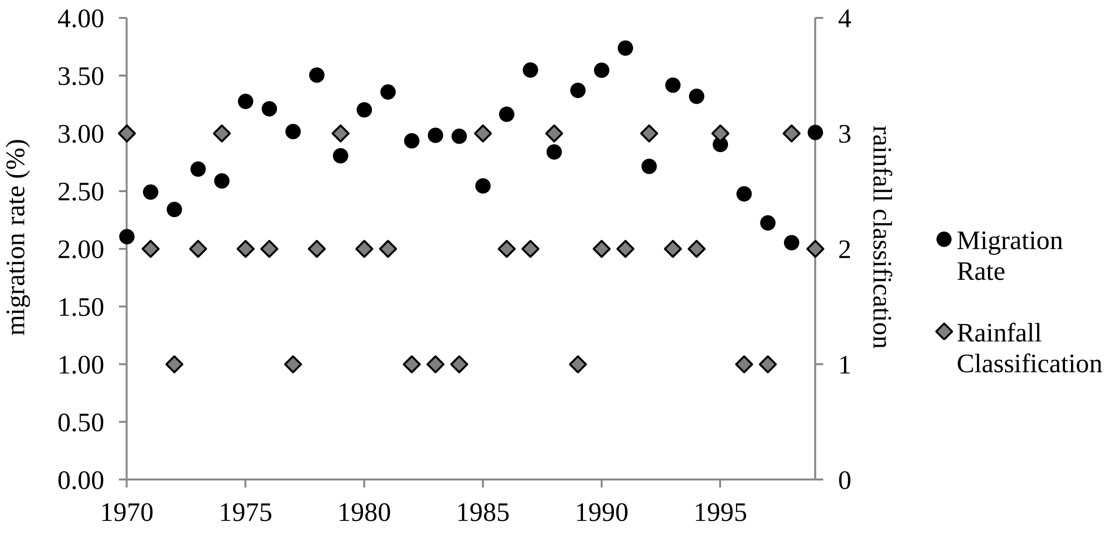

Figure 7.31: Scatter plot of AMARC3 modelled migration rate and rainfall classifications for Bobo Dioulasso from 1970-1999. Correlation coefficient = **-0.18**.

Similar to Ouagadougou, no clear relationship between migration rate and rainfall classification can be immediately seen in Figure 7.31 for Bobo Dioulasso. A negative but not significant correlation is again identified between migration rate and rainfall classification (-0.18). However, on closer inspection it can be proposed that model years with average rainfall correspond with increases in the modelled rate of migration from Bobo Dioulasso. Examples of this pattern can be seen across the thirty year test period with the most obvious occurrences in 1978, 1987 and 1991 when the modelled migration rate shows significant peaks in excess of 3.5%. Furthermore, while dry years can be seen to result in moderate levels of modelled migration, wet years appear to correspond well with low rates of migration, as can be clearly seen in the model years 1985, 1988, 1992 and 1998. These results correspond well with those presented in Figure 7.16 where the artificially induced dry rainfall scenario resulted in a higher rate of modelled migration than both dry and wet scenarios. In order to further investigate the relationship between rainfall classification and modelled migration rate in Bobo Dioulasso Figure 7.32 displays a comparison of the average migration rate modelled for dry, average and wet model years.

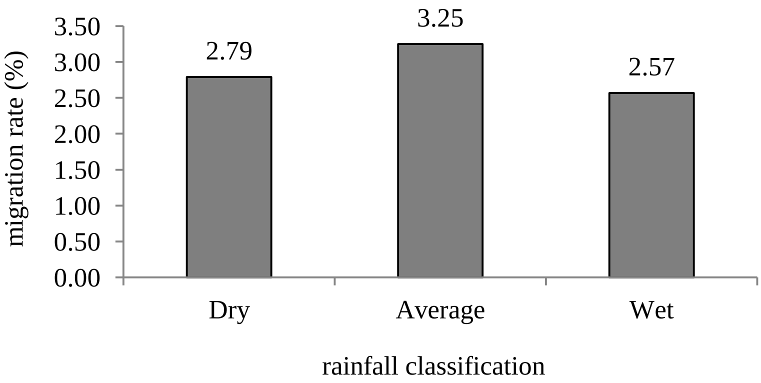

Figure 7.32: AMARC3 modelled 1970-1999 average migration rates for dry, average and wet rainfall years in Bobo Dioulasso.

The initial findings reported above on the basis of Figure 7.31 are supported by those displayed by Figure 7.32. The highest average modelled migration rate (3.25%) is shown to result from average rainfall conditions while the lowest (2.57%) are seen to result, on average, from wet conditions. Furthermore, in accordance with the earlier findings from Figure 7.16, dry rainfall conditions result in an intermediate level of migration rate that falls closer to those modelled under wet conditions. It is therefore evident that, in the case of the two urban centres of Burkina Faso, average rainfall conditions result in the lowest modelled migration rate from one (Ouagadougou) and the highest from the other (Bobo Dioulasso). Furthermore, while dry rainfall conditions in the capital are modelled to correspond with the highest rate of migration from there, such conditions correspond with a significant reduction in modelled migration from

Bobo Dioulasso. The contrast between modelled migration rates from these two urban zones may result from migration tendencies resulting from the urban lifestyles of individual inhabitants or be linked to the different average rainfall conditions that the two cities' experience in their respective locations within the rainfall gradient seen across Burkina Faso. Figure 7.33 displays the modelled migration rate and rainfall classification data for the northernmost model zone, Sahel.

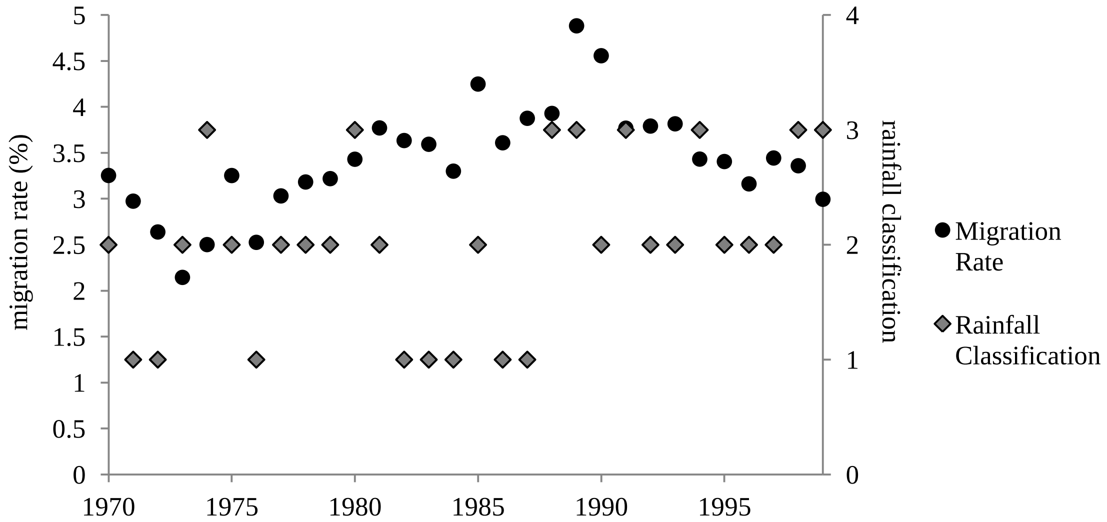

Figure 7.33: Scatter plot of AMARC3 modelled migration rate and rainfall classifications for Sahel from 1970-1999. Correlation coefficient = **0.17**.

Although a slight positive correlation is evident between modelled migration rate and rainfall classification in Sahel, no clear relationship can be derived from Figure 7.33. Two significant peaks in the modelled migration rate occur in 1985 and 1989. While the first of these appears to correspond with a single average rainfall year in a period of prolonged below average conditions, the second corresponds with a wet year. The driest of the five model zones, migration from Sahel might be anticipated to show the strongest relationship with rainfall. In the earlier comparison of model results under artificially dry, average and wet rainfall scenarios, Figure 7.17 showed migration from Sahel as being considerably lower under the dry rainfall scenario. However, the findings presented in Figure 7.33 do not clearly support such a relationship. In order to further investigate the relationship between migration rate and rainfall, Figure 7.34 displays the average migration rates modelled by AMARC3 for Sahel during dry, average and wet model years between 1970 and 1999.

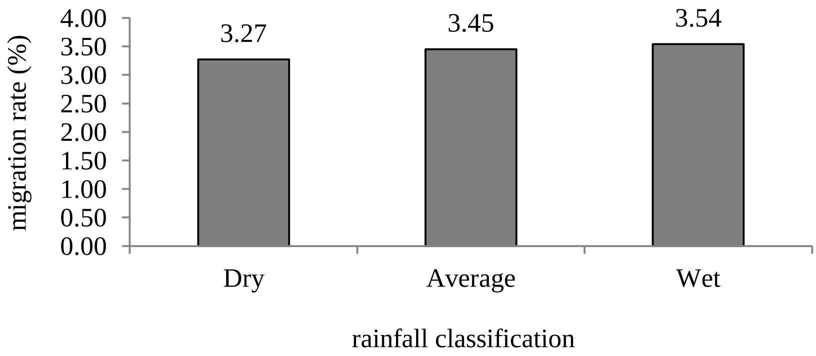

Figure 7.34: AMARC3 modelled 1970-1999 average migration rates for dry, average and wet rainfall years in Sahel.

It can be seen from Figure 7.34 that the low migration rate displayed in Figure 7.17 as resulting from dry conditions is, to some extent, replicated. So too is the presence of higher rates of migration under wet conditions. However, the extent of the relationships identified in Figure 7.17 are not seen as clearly in Figure 7.34. Both average and wet rainfall conditions are shown in Figure 7.34 to result in higher rates of migration (3.45% and 3.54% respectively) that could result in the peaks in migration reported from Figure 7.33, particularly in the case of the 1985 peak that occurred between dry years. The presence of such a clear relationship with rainfall in Figure 7.17 and the presence of the same, if weaker, relationship in Figure 7.34 suggests that increasing rainfall in the Sahel zone may lead to increased rates of migration away from the zone. Figure 7.35 displays the modelled migration rate and rainfall classification data for Centre.

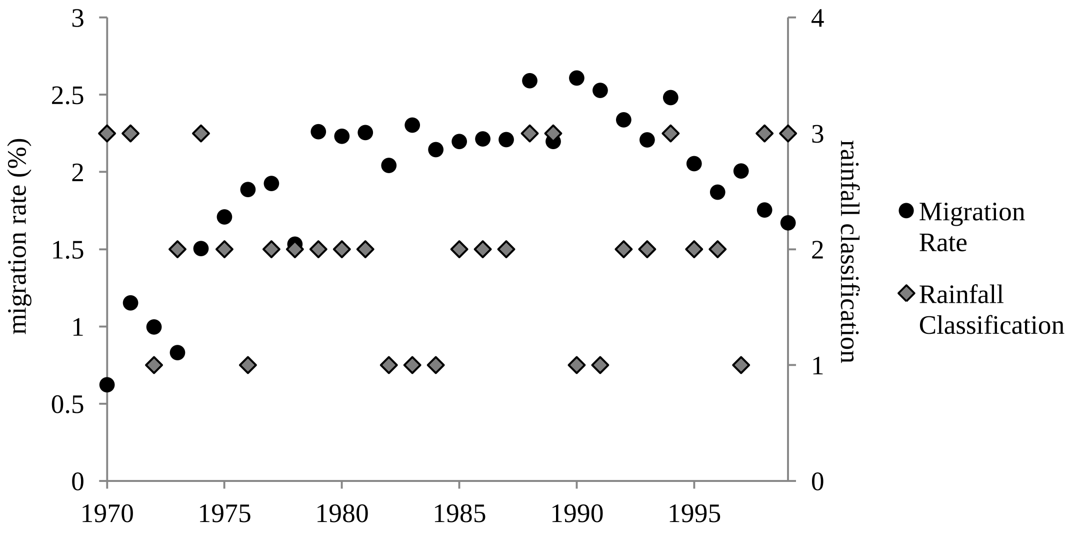

Figure 7.35: Scatter plot of AMARC3 modelled migration rate and rainfall classifications for Centre from 1970-1999. Correlation coefficient = **-0.23**.

In the case of migration modelled as occurring from Centre, no clear relationship between migration rate and rainfall is evident in the AMARC3 modelled results. Earlier analysis, presented in Figure 7.18 suggested that lower rates of migration were loosely linked to below average rainfall during at least some of the thirty year test period. However, such a relationship is not clearly visible from Figure 7.35. A slight but insignificant negative correlation between migration rate and model rainfall is however seen. Figure 7.36 displays the average migration rate from Centre modelled for each rainfall classification.

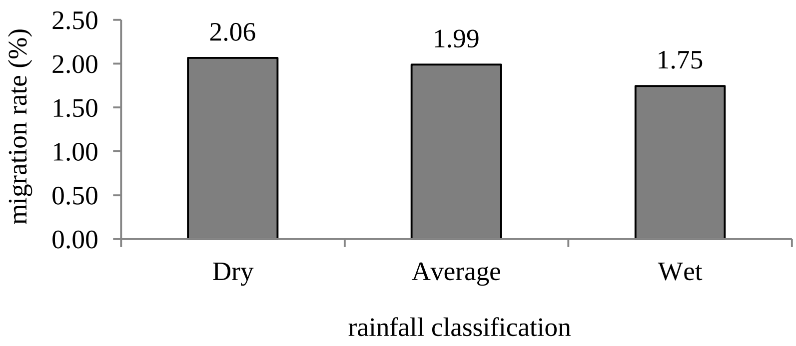

Figure 7.36: AMARC3 modelled 1970-1999 average migration rates for dry, average and wet rainfall years in Centre.

In slight contrast to the approximate findings made from Figure 7.18, dry rainfall years are modelled as, on average, resulting in a marginally higher migration rate (2.06%) than that modelled for average and wet years. The lowest migration rate (1.75%) modelled by AMARC3 is seen to occur, on average, under wet rainfall conditions. However, the differences between the average migration rates modelled for each rainfall classification vary over a relatively small range. Figure 7.37 displays the modelled migration rate and rainfall classification data for Southwest.

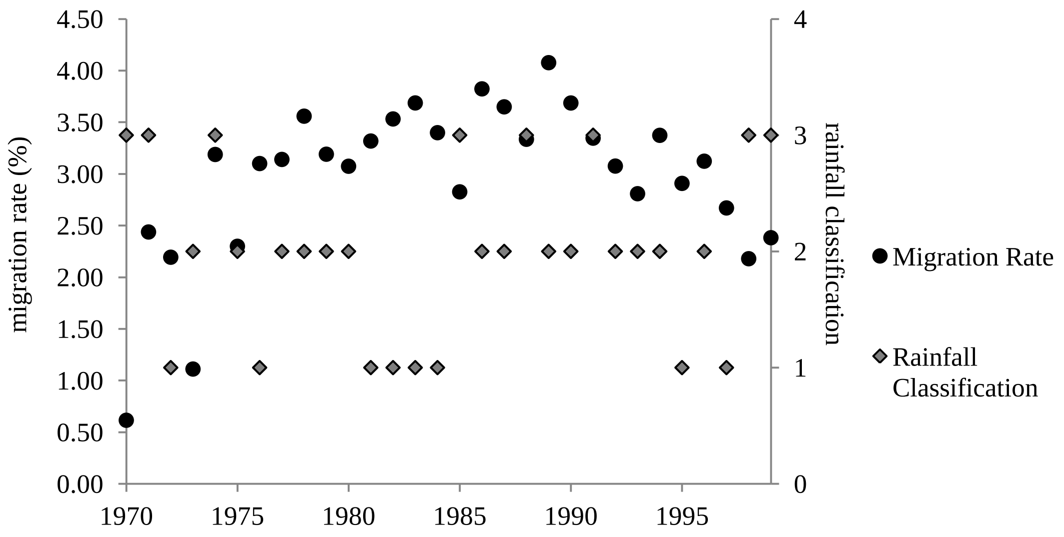

Figure 7.37: Scatter plot of AMARC3 modelled migration rate and rainfall classifications for Southwest from 1970-1999. Correlation coefficient = **-0.28**.

Figure 7.37 displays little evidence of a relationship between modelled migration rate from Southwest and model rainfall. Wet years for example appear to link to both peaks (e.g. 1974) and troughs (e.g. 1985) in modelled migration rate. However, in order to further investigate this relationship, Figure 7.38 displays the average migration rates calculated as modelled from Southwest during dry, average and wet years between 1970 and 1999.

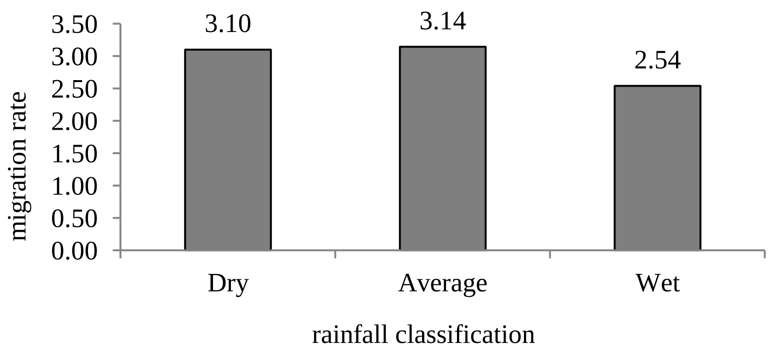

Figure 7.38: AMARC3 modelled 1970-1999 average migration rates for dry, average and wet rainfall years in Southwest.

It can be seen from Figure 7.38 that the rainfall classification for which average modelled migration rates are, by a narrow margin, highest in Southwest are average years (3.14%). By contrast, the lowest modelled average migration rate is seen for wet years (2.54%). Despite this apparent relationship between migration rate and rainfall classification, no such pattern is evident in the migration rate results displayed in Figure 7.37.

Figures 7.29 to 7.38 present the migration flows modelled by the ‘full-climate’ version of AMARC3 as migration rates. These rates represent the percentage of the total relevant population that migrate. Modelled migration flows are presented in this manner in an attempt to place modelled migration flows within the context of the demographic change occurring in each model run. The relationships between rainfall classification and migration rate described above share many similarities with those identified in section 7.4 which compared modelled migration flows from artificially generated dry, average and wet scenarios. The only significant difference between the findings of these two means of analysis is evident in the case of migrants modelled as leaving Sahel. As a result of the artificial rainfall scenario analysis it was found that modelled migration from Sahel was considerably lower under the dry rainfall scenario. By contrast, the migration rate modelled from Sahel during dry years is only marginally lower than those identified for average and wet years (Figure 7.34).

The method of analysis used in this section to identify the different migration rates modelled as occurring during dry, average and wet years in each of the five model zones has therefore generated results that, in general, support those of the earlier artificial rainfall scenario versions of the AMARC3 model. The relationships between rainfall and migration thus identified across Burkina Faso reveal the differing nature of the impact of rainfall in each zone. Figure 7.39 displays the average migration rates modelled for each rainfall classification in each zone identified through the above analysis.

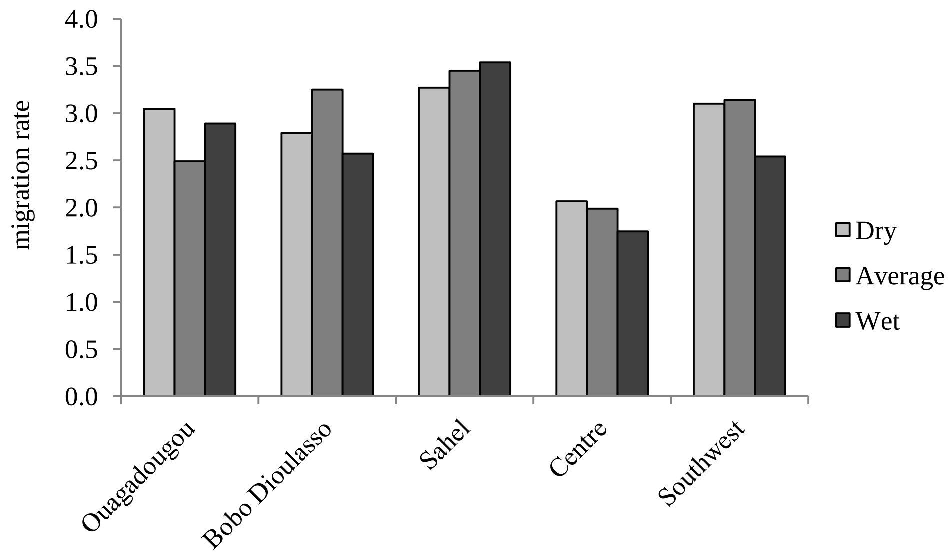

Figure 7.39: AMARC3 modelled 1970-1999 average migration rates for dry, average and wet rainfall years in all model zones.

It can be seen from Figure 7.39 that Sahel is modelled as having the highest rate of migration of all five zones in dry, average and wet rainfall conditions. Migration rates within Sahel are also the only ones modelled to increase with increasing rainfall. The lowest migration rates meanwhile are modelled as occurring in Centre under all rainfall classifications. The overall trend in modelled migration flows resulting from the artificial rainfall scenarios used in section 7.4 identified the dry scenario as resulting in the lowest modelled migration, and the average rainfall scenario as resulting in the highest. Such a relationship between rainfall and migration rate is not reflected in any of the individual zones presented in Figure 7.39. In fact, average rainfall conditions are only modelled to result in the highest migration rate in Bobo Dioulasso. Furthermore, only in Sahel do dry rainfall years result, on average, in the lowest migration rate. Figure 7.40 displays the combined migration rates for all five model zones in dry, average and wet rainfall years.

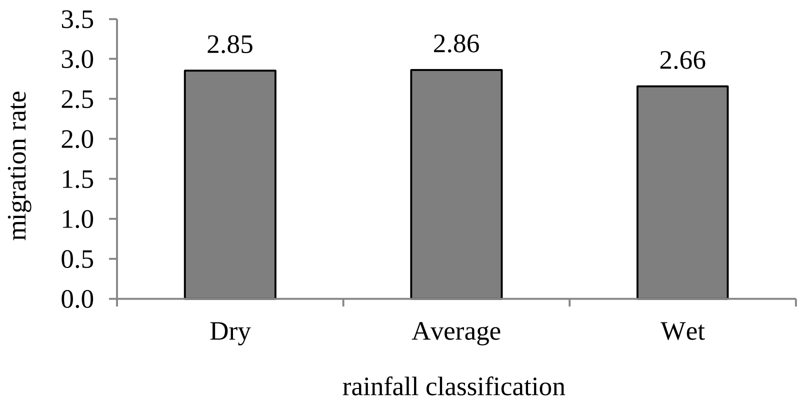

Figure 7.40: AMARC3 modelled 1970-1999 migration rates for dry, average, and wet rainfall years in Burkina Faso.

When each of the average migration rates for each zone presented in Figure 7.32 are combined to produce an overall picture of the migration rates simulated across the whole of Burkina Faso, another perspective is gained on the modelled relationship between rainfall and migration. It can be seen from Figure 7.40 that the overall modelled relationship between rainfall and migration displayed in Figure 7.14 is not entirely replicated. Although average rainfall conditions again result in the highest migration rate (2.86%), the rate modelled for dry rainfall years is only marginally less (2.85%).Wet rainfall conditions meanwhile result in the lowest rate of migration with, on average, only 2.66% of the population migrating. It is therefore evident that analysing the role of changes in rainfall variability in the modelled migration decision in terms of the departure rates modelled as occurring in each zone during different rainfall years gives marginally different results to the artificially induced rainfall scenario approach.

The presence of marginally different modelled relationships between rainfall and migration that result from the two methodological approaches used in this chapter (artificial scenarios and annual rainfall classifications) are considered to largely result from the contrast between those methodologies. The artificial scenarios used in section 7.4 gave a clearer definition between migration rates modelled as occurring under each scenario. However, such artificial scenarios represent a somewhat extreme approach to identifying the role of changes in rainfall variability in the migration decision by defining every model year between 1970 and 1999 as dry, average or wet. By contrast, the more analytical approach used in this section addresses each individual model year as dry, average or wet on the basis of the actual rainfall experienced.

On the basis of the findings of the two approaches, the more extreme rainfall scenario method appears to result in more extreme relationships between rainfall and migration. Permitting a rainfall scenario to continue for an extended period will result in a particular migration trend recurring throughout the population of modelled agents across the entire model period as a result of the use of one ‘type’ of behavioural attitude and rainfall asset values (linked only to dry, average or wet conditions) in the migration decision. The migration trend modelled following the use of these values in agent decisions will then affect their migration experience thereby also affecting perceptions of their ability to migrate. If, for example, dry rainfall conditions cause lower rates of migration, such a tendency towards migration will be reinforced as the model progresses due to the smaller number of agents with experience of migration that can both boost their own perceived behavioural control and reinforce the migration behaviour of others through the consideration of peer opinions.

In contrast, the ‘full-rainfall’ version of the AMARC3 model uses different types of behavioural attitude and rainfall asset values, causing different levels of migration each year and affecting each agent’s experience of migration in a different manner. While, for example, dry rainfall conditions may result in lower tendencies of the model population towards migration (as seen in Figure 7.14), the occurrence of average or wet rainfall years before the occurrence of a dry year is seen to reduce the potential impact of dry conditions on total migration (Figure 7.40). As a result, no single tendency towards migration appears to exist for long enough under the changing rainfall conditions to be notably reinforced.

From the results of the two approaches to investigating the role of changes in rainfall variability in the migration decision, it can be hypothesised that the AMARC3 model appears sensitive to rainfall both in terms of the occurrence of certain rainfall conditions and the duration of that occurrence. As a result of the potentially contrasting relationships identified between rainfall and migration in this chapter, it is difficult to identify the precise impact of rainfall upon total migration flows. However, Figures 7.14 and 7.40 agree that, in the context of total migrant flows in Burkina Faso, average rainfall conditions appear to result in the highest modelled migration while both dry and wet conditions result in a reduction in total modelled flow. This pattern is directly replicated in both Bobo Dioulasso and Southwest (Figure 7.39) but contrasts significantly with modelled migration from Ouagadougou which is shown to decrease during average rainfall years.

7.7 The Influence of Demography

As well as investigating the impact of rainfall upon modelled migration, it is important to understand the role of other influential components, namely demography and social networks. The first of these, demography, has long been identified as a component with considerable influence upon migration. In a nation such as Burkina Faso where migration is considered to be firmly rooted as an inherent component of the lives of much of the populace, an increase in population size is likely to have a significant impact upon migration flows simply due to the increase in the number of people of 'migrating age'. A certain proportion of the increased migration flows modelled as occurring as time progresses in the AMARC models will therefore inevitably result from the rate of demographic change implemented in the model on the basis of the UNPD crude birth and death rates. As such, the AMARC3 model is used to test the impact of the rate of demographic change upon migrant flows modelled between 1970 and 1999 through the use of a new version (AMARC3_birthDeath). The AMARC3_birthDeath model runs using a birth rate that is equal to the UNPD defined death rate also employed. By limiting the birth of agents to the rate at which they die, zero demographic change occurs in the model except ageing.

Table 10 of Appendix 6 displays the averaged results of five runs of the AMARC3_birthDeath model. A total of 6,060 migrants are modelled by AMARC3_birthDeath as leaving all zones throughout the thirty year test period, 5% less than modelled by the standard version of AMARC3. Of these migrants, those leaving Bobo Dioulasso, Sahel and Centre are shown to be of approximately the same scale (22.99%, 22.69% and 22.44% of total respectively) while significantly fewer migrants are modelled as leaving Ouagadougou and Southwest (15.99% and 15.89% respectively). Although more uniform, these modelled flows approximately represent the proportional distribution of migrant departures modelled by AMARC3. While it is interesting to note that the proportional distribution of migrants across the five origin zones is approximately the same as that modelled by the full demographic version of the AMARC3 model, the real value to be gained from the results of AMARC3_birthDeath is through direct temporal comparison of the evolution of the modelled migration flows. Figure 7.41 displays a graphical representation of the averaged results of five runs of the AMARC3 and AMARC3_birthDeath models between 1970 and 1999.

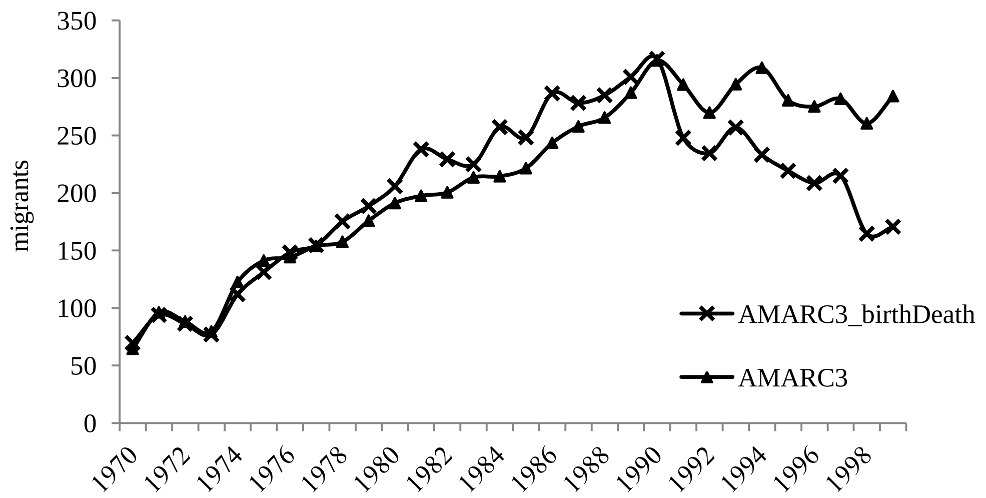

Figure 7.41: Comparison of the averaged results of five runs of the AMARC3 and AMARC3_birthDeath models.

It can be seen from Figure 7.41 that the impact of equal birth and death rates upon AMARC3 modelled migration is to reduce the numbers of migrants simulated as leaving their origin locations towards the end of the thirty year model period. After 1990 AMARC3_birthDeath modelled migration is consistently lower than that modelled by AMARC3. From 1970 to 1990, the migration flows modelled by AMARC3 and AMARC3_birthDeath show higher levels of migration under the zero population change demographic scenario. Likely resulting from a similar phenomenon to that identified in Figure 7.1, the introduction of fewer newborn agents into a migrating agent's network will act to increase their likelihood of migrating as their peer network will consist of a greater proportion of actively migrating agents that communicate positive intentions towards migration.

Although a similar pattern of migration is simulated by both models, from 1991 to the end of the model run period AMARC3_birthDeath total migration is consistently lower. The fact that the impact of zero demographic change only becomes apparent in the data from about 1990 onwards suggests that the alternative age structure of the AMARC3_birthDeath model population does not manifest itself in terms of its impact upon migration until the agents born into the model post-startup begin to reach migration age (defined as 15 years and up). Death rate in the AMARC3_birthDeath model is the same as that used in the standard version of AMARC3. The contrast between the two models occurs in the form of a different birth rate, set in AMARC3_birthDeath to equal agent death. As such, it will take 15 model years before the smaller number of agents born into the AMARC3_birthDeath model reach migration age and actively reduce migrant numbers. If time were permitted to progress beyond 1999 in the model we would likely see a further contrast between the level of migration simulated by the two models emerging as the demographic structures of the two populations of Burkina Faso diverged over time.

Demographic change can thus be seen in Figure 7.41 to have a clear impact upon the overall level of migration modelled as occurring within and from Burkina Faso. It stands to reason that a larger population of agents will, under the same structural precursors as a smaller population, generate a larger flow of migrants. A direct comparison between the post-1990 modelled migration flows of the two contrasting demography versions of the AMARC models provides insight into the extent of the impact of demography upon migration. In the model year 1991 (the first that shows a clear difference between modelled migration), the five run averaged AMARC3 modelled total migration stands at 294. By contrast, the five run averaged AMARC3-birthDeath modelled migration stands at 248, a difference of 46 individuals or reduction of 16%. By the end of the model period, 1999, the difference between the modelled migration flows is 113 individuals, a reduction of 40%. According to these results therefore, the impact of zero demographic change upon modelled migration is to reduce the overall rate of migration, a phenomenon seen to increase as the contrast between populations of migration age agents diverge over time. As a result of these findings, the notion that demographic factors within the AMARC models must be strictly monitored and controlled is supported.

7.8 The Influence of Social Networks

Agent-based models benefit from their ability to incorporate concepts of both agency and structure. Inherent to the process of individual agency is social interaction and the communication that occurs between agents that leads to such emergence-inducing processes as being influenced by and learning from the behaviour of others. In order for the agents within the AMARC models to interact with one another, each agent is networked with up to 50 peers with whom they share information on their migration decision. In the standard version of the AMARC models, agents are connected randomly across all model zones. However, the AnyLogic software also provides the opportunity for agents to be linked through scale-free or ring-lattice networks. In a scale-free network some agents are made into “hubs” with a lot of connections while some are made into “hermits” with relatively few connections. A ring-lattice network places an agent in a ring-type network with a given number of their closest agent neighbours.

In the standard version of the AMARC models a simple random network is used as the default that allows communication within and across the five model zones and may be conceived to represent a real network in a country such as Burkina Faso where the mobile phone has enabled cheap national-scale communication and the population is relatively mobile. However, the impact of changing the network type used in the models can be investigated in order to further understand the role of agent communication in the modelled migration decision.

Table 11 of Appendix 6 displays the numbers of agents modelled as migrating from each zone using a version of the AMARC3 model that places agents in a scale-free network with up to 50 of their peers (AMARC3_scaleFree). The five run averaged total number of migrants modelled by AMARC3_scaleFree as leaving all zones between 1970 and 1999 is 7,459, 16% more than were modelled to migrate by the standard version of AMARC3 that places agents in a random network. However, unlike the AMARC3 simulation output, the zone which contributes the greatest proportion of migrants is Bobo Dioulasso (24% of total), with Ouagadougou contributing the second highest proportion (22.88%). Sahel, the zone from which the standard version of AMARC3 modelled as contributing the greatest proportion of migrants (26.30%), is modelled as contributing 21.41% of migrants by AMARC3_scaleFree. It appears therefore that the presence of a scale free network is, over five averaged model runs, through some influence related to the creation of hubs and hermits within the model population, increasing migration away from the two more densely populated urban centres. It is likely therefore that the close proximity of agents located within the restricted geographical extent of the two cities causes more hub agents to exist in urban zones, resulting in increased sharing of migration intentions and causing overall tendencies towards migration to increase through application of the subjective norm component of the decision to migrate. By contrast, the greater geographical distribution of agents in the more rural zones may result in the presence of more hermits in these locations and a reduction in overall tendencies towards migration.

Table 12 of Appendix 6 displays the numbers of agents modelled as migrating from each zone using a version of the AMARC3 model that places agents in a ring-lattice network with up to 50 of their peers (AMARC3_ringLattice). The five run averaged total number of migrants modelled by AMARC3_ringLattice as leaving all zones between 1970 and 1999 is 5,474, 14% fewer than those modelled by the standard version of AMARC3 that places agents in a random network and 27% fewer than those modelled by AMARC3_scaleFree. Corresponding well with the standard AMARC3 modelled flows however, the largest proportional contribution to the overall AMARC3_ringLattice flow comes from Sahel (30.63% of total). The lowest proportional contribution meanwhile is modelled as being from Southwest (12.32%) with Bobo Dioulasso showing a marginal increase in proportional contribution using the ring lattice network (23.63%). It appears therefore that the use of a ring lattice network in the AMARC3 model considerably reduces the overall flow of modelled migrants without altering the proportional distribution of migrant origins across the five zones. Figure 7.42 compares the five run averaged total migrant flows modelled by the random, scale-free and ring-lattice network versions of the AMARC3 model.

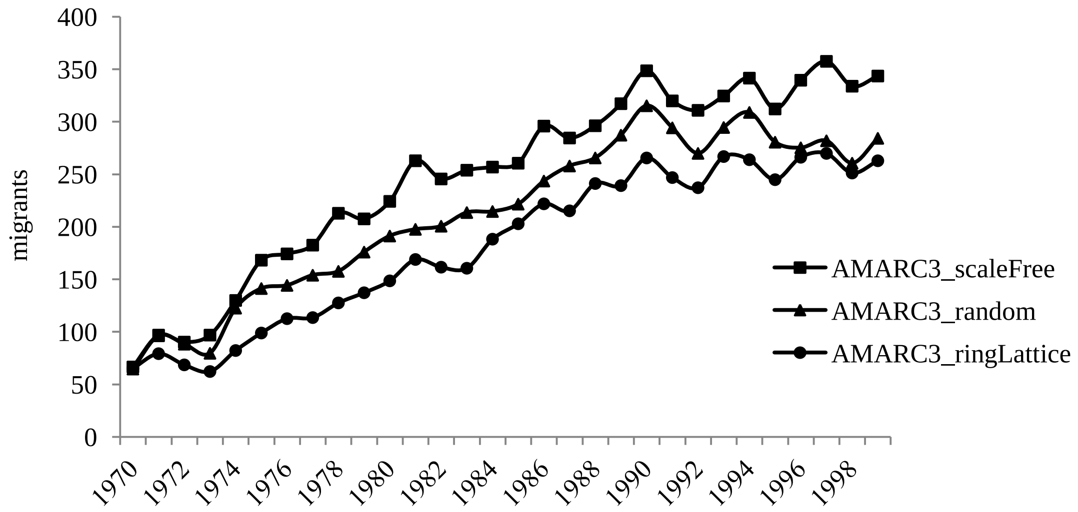

Figure 7.42: Comparison of the averaged results of five runs of the AMARC3, AMARC3_scaleFree and AMARC3_ringLattice models.

It can be clearly seen from Figure 7.42 that the scale-free network version of the AMARC3 model results in consistently higher levels of overall migration throughout the thirty year test period. By contrast, the ring-lattice network version models migration rates to be consistently lower throughout the test period. As a result, the random network used as the default option throughout the model validation and testing process results in a median level of modelled migration where agents are permitted to interact with up to 50 of their peers. It is therefore evident that the random network structure employed as the default basis for social interaction within the AMARC models provides a sound median basis. However, the fact that changing the social networks within which agents find themselves affects the migration flows simulated, suggests that the role of social interaction in the AMARC models is effective in changing the properties of modelled migration trends. The presence of a clearly altered trend in AMARC3_scaleFree modelled migration away from both Ouagadougou and Bobo Dioulasso further supports the notion that, using the cognitive basis described by this thesis, the role of social networks in the modelled migration decision is considerable. Figures 7.43 and 7.44 display direct comparisons of the migrant flows modelled as leaving Ouagadougou and Bobo Dioulasso under the three network scenarios.

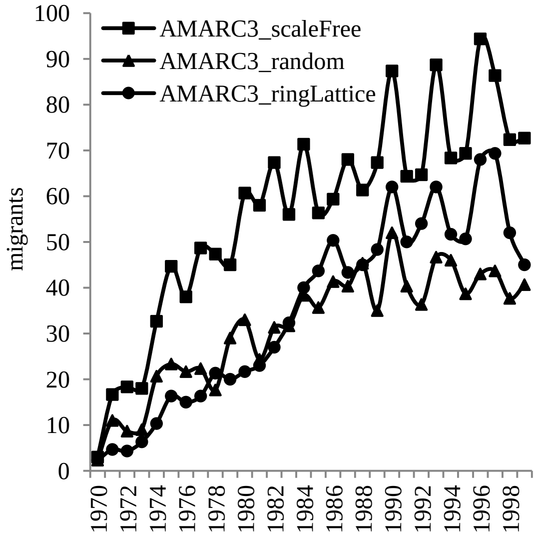

Figure 7.43: Comparison of five run averaged modelled departures from Ouagadougou by the AMARC3, AMARC3_ scaleFree and AMARC3_ringLattice models.

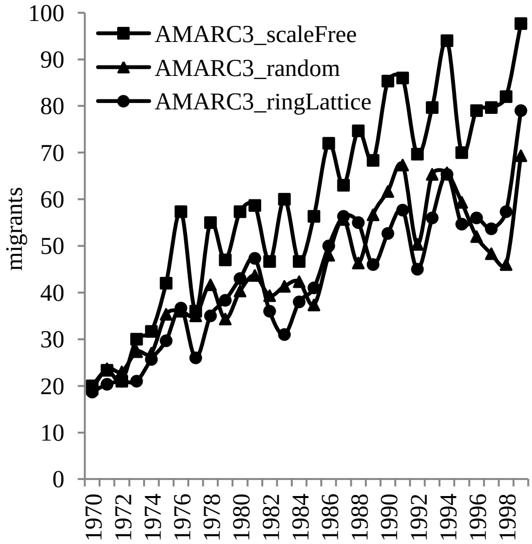

Figure 7.44: Comparison of five run averaged modelled departures from Bobo Dioulasso by the AMARC3, AMARC3_ scaleFree and AMARC3_ringLattice models.

In the case of modelled departures from both Ouagadougou (Figure 7.43) and Bobo Dioulasso (Figure 7.44), the version of AMARC3 that uses a scale-free network to govern agent-agent communication results in clearly higher rates of migration than are modelled by the random and ring-lattice network models. As previously stated, scale-free modelled migrant flows from both these urban locations represent a considerably increased proportion of the total modelled flow of migrants seen under either random or ring lattice network structures from 1971 onwards. Due to the median impact of a random modelled network upon migration flows and the fact that this research does not intend to focus specifically upon the precise role of networks upon migration decisions, such a network is used as the default throughout the remainder of this thesis. As mentioned in Chapter 5, each agent is networked with up to fifty of their peers, a value deemed appropriate through both sensitivity testing of the impact of network size and logical reasoning in terms of the number of peers an individual might be anticipated to interact with through their social network.

The results of sensitivity testing of the impact of random network size upon AMARC3 total modelled migration are displayed in Table 13 of Appendix 6. The total number of agents modelled as migrating by the AMARC3_random model increases considerably as the number of peers each agent is connected with increases. The version of the model that links each agent with a maximum of 10 peers results in a total thirty year modelled migration flow of 3,359. By contrast, when each agent is connected with a maximum of 100 agents a total thirty year modelled migration flow of 8,547 is modelled. Such an impact is to be anticipated as a result of the role of peer opinions in the subjective norm component of the decision to migrate. The more peers an agent has that favour the migration option being considered, the greater the likelihood that a high subjective norm score will be applied to that option and the greater the likelihood that it will result in the realisation of a migration behaviour. Rather than being assessed in terms of the percentage of an agent's peers that favour a particular migration option, the subjective norm component of the decision to migrate uses real values. Figure 7.45 displays a temporal comparison of the total migration flows modelled each year by the AMARC3_random model when run with the range of different network sizes.

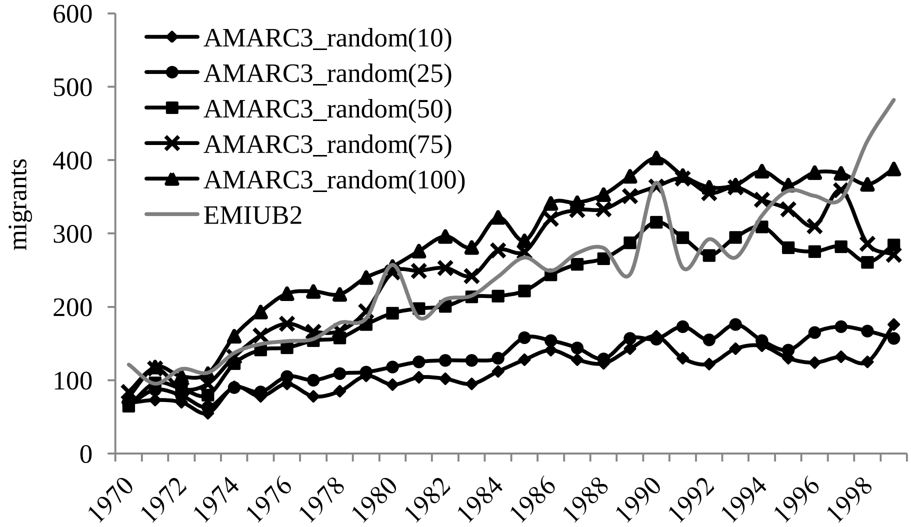

Figure 7.45: Comparison of the averaged results of five runs of the AMARC3, AMARC3_scaleFree and AMARC3_ringLattice models.

It can be clearly seen from Figure 7.45 that, throughout the thirty year test period, the more peers an agent can network with, the higher their modelled propensity towards migration. Running the AMARC3_random model with the maximum peer-count restricted to fifty results in a median level of total migration within the range of peer numbers tested and appears to correlate best with the EMIUB2 observed data, at least until the point around 1994 when previously mentioned demographic components come clearly into play and the AMARC3 and EMIUB2 migration flows diverge. Table 7.1 displays the RMSD residuals calculated between the observed EMIUB2 and AMARC3_random modelled total migration flows for the range of peer-linkages tested for both periods 1970-1999 and 1970-1994.

	AMARC3_ random(10)	AMARC3_ random(25)	AMARC3_ random(50)	AMARC3_ random(75)	AMARC3_ random(100)
RMSD 1970-1999	134	150	**59**	66	66
RMSD 1970-1994	101	116	**29**	50	69

Table 7.1: RMSD residuals calculated between EMIUB2 data and the five different network size versions of AMARC3_random for the full test period 1970-1999 and the restricted 1970-1994 period for which AMARC3 demographic processes better reflect those seen in the EMIUB2 data.

Table 7.1 shows that the version of the AMARC3_random model that links agents to a maximum of fifty of their peers generates a total migration flow that is closest to the EMIUB2 observed data. When considered over the full test period AMARC3_random(50) model outputs result in RMSD residuals of 59. When the period of analysis is restricted to the 25 years from 1970-1994 that the AMARC3 model is able to best replicate observed flows (due to the population change resulting in later years from a modelled death function that does not exist within the EMIUB2 retrospective data) RMSD residuals of 29 are calculated. The lower the RMSD residuals calculated, the better the fit of the modelled data to the observed. As a result of the considerable impact of network size upon migrant flows modelled, the random networks used in later application of the AMARC3 model are restricted to fifty. Given infinite time, a full investigation of the impact of different sizes of other network types would have been advantageous in order to sensitivity test both the size and type of network used in the AMARC models. From the results displayed in Figure 7.42 it can be suggested that a smaller scale free network may have had a similar impact to the random(50) network used as standard. Although this would be an interesting avenue of research, it is deemed beyond the scope of this thesis.

7.9 Summary

This chapter primarily addresses the influence of rainfall upon AMARC modelled migration in Burkina Faso. In order to identify the role of changes in rainfall variability the chapter starts by introducing the AMARC3 model which presents the final test version of the AMARC series.

The role of the means by which rainfall is used by the model is then addressed before modelled departures and arrivals from each zone under dry, average and wet rainfall scenarios are considered. Building upon the national- and zone-level relationships identified by this investigative approach, a further analysis of the rates of migration modelled during dry, average and wet model years is performed. Following a thorough investigation and comparison of the modelled findings, the additional roles of demographic change and social networks are considered.

For the purposes of this thesis it can be concluded from the results presented in this chapter that rainfall can be seen to have a considerable impact upon the modelled migration decisions of agents in the AMARC models. It is evident that although a direct relationship between overall modelled migration and rainfall is not clearly apparent, the underlying relationships between agents located in different zones and the rainfall conditions they experience are multiple and varied in terms of both nature and clarity. While, for example, the highest rates of departure from both Ouagadougou and Centre are modelled as occurring under dry rainfall conditions, the highest rates of departure from Bobo Dioulasso and Southwest are modelled as occurring during average rainfall years. Furthermore, wet conditions lead to the highest modelled departures from Sahel. In general terms however, it appears that the greatest total flow of migrants within and from Burkina Faso is modelled under average rainfall conditions. While wet conditions are seen to result in a small decrease in modelled flows, perhaps due to the decreased ‘need’ to migrate under more favourable conditions, below average rainfall results in a clear decrease in modelled flows. Following an investigation into the role of assets on the modelled migration decision within AMARC, it is proposed that such a decrease in modelled migrant flows under dry conditions results from the reduced perceived capacity of agents to migrate under low income conditions resulting from a rainfall deficit. Such agents are considered to be ‘trapped’ by their perceived inability to invest in migration as a rainfall coping strategy.

Demographic change is seen to play a definite role in shaping the overall flow of migrants by adjusting the size of the population from which migrants will be produced. In addition, the size and structure of the social networks used by agents in performing their migration decisions are shown to alter the migration flows modelled, particularly in the case of the influence of scale-free networks on departures from urban locations. In order to further investigate the influence of rainfall upon modelled migration within and from Burkina Faso, Chapter 8 uses different rainfall scenarios as a means to test the evolution of AMARC3 modelled migrant flows under different rainfall regimes forecast for the future.

Chapter 8

Future Scenarios: Rainfall and Demography

8.1 Introduction

The process of developing, testing and validating the ABM described by this thesis has shown the AMARC models to be capable of accurately replicating the past migration-decisions of Burkinabé people between 1970 and 1999. Furthermore, the impact of rainfall upon this modelled migration decision has been revealed to have a differing but considerable influence upon the resulting migration flows simulated as originating in each of the model zones. The previous chapter presented an investigation into the role of changes in rainfall variability in the migration decisions simulated as having occurred throughout a past period for which direct validation data was available. A certain degree of variation was found to be evident between flows of migrants modelled as departing each zone under different rainfall conditions. This variation can be attributed to both variations in the independent variable, rainfall, and the capacity of the model to capture individual circumstances. While the economic and social circumstances of an individual in one zone may lead them to favour a particular migration option, norms in another zone may lead an agent experiencing the same circumstances but in a different location to favour an alternative course of action. Such effects can be seen as a benefit of the agent-based modelling approach and its capacity to consider in agent- and structural-level factors.

Having validated the AMARC model against past migration data, this research now turns to an investigation of the role of changes in rainfall variability in affecting migration decisions simulated as occurring in the future to the year 2050. In order to perform this investigation, eight different rainfall scenario datasets are used to provide annually forecast JAS rainfall values for each of the five model zones. By comparing the migration flows modelled as occurring from each zone under the different rainfall scenarios, the role of changes in rainfall variability in affecting future migration flows within and from Burkina Faso can be considered and assessed.

As identified in Chapter 7, in addition to the external influence of rainfall, demographic components play a considerable role in shaping migration flows both observed in real-world populations and simulated by the AMARC models. In order to test the role of changes in rainfall variability on modelled migration flows in Burkina Faso to 2050, each run of the AMARC3 model starts in 1970 and runs to 1999 in the same manner as those model runs presented in previous chapters. However, from the model year 2000 onwards, alternative rainfall data, rainfall thresholds and demographic factors are used. As a result, the future influence of rainfall upon modelled migration flows in Burkina Faso is assessed alongside the influence of different levels of future demographic change.

8.2 Future Rainfall Scenarios

The future rainfall scenarios used in this chapter come from the European Commission funded ENSEMBLES project. Led by the UK Hadley Centre, the climate projections generated by the project describe in detail how the climate is expected to change under standard scenarios of future emissions. Statistically downscaled from Global Climate Models (GCMs), regional rainfall data is made available by the RT3 transient experiments for West Africa from ENSEMBLES global experiments at 50km resolution. Table 8.1 displays information relating to the eight rainfall datasets used in this chapter.

Acronym:	**Institute:**	**IPCC Scenario:**	**Driving GCM:**
MPI-M-REMO	Max-Planck-Institut für Meteorologie, Germany	A1B	ECHAM5-r3
METO-HC HadRM3	Hadley Centre, UK	A1B	HadCM3Q0
KNMI-RACMO2	Koninklijk Nederlands Metoerologisch Instituut, Netherlands	A1B	ECHAM5-r3
SMHIRCA	Sveriges Meteorologiska och Hydrologiska Institut, Sweden	A1B	HadCM3Q0
GKSS-CCLM4.8	Helmholtz-Zentrum Geesthacht, Germany	A1B	ECHAM5
ICTP-REGCM3	International Centre for Theoretical Physics, Italy	A1B	ECHAM5-r3
DMI-HIRHAM5	Danich Meteorological Institute, Denmark	A1B	ECHAM5-r3
METNOHIRHAM	Meteorologisk Institutt, Norway	A1B	HadCM3Q0

Table 8.1: Regional rainfall datasets gained from statistically downscaled global ENSEMBLES project experiments at 50km resolution. Information gained from http://ensemblesrt3.dmi.dk/extended_table.html

All eight rainfall datasets gained from the ENSEMBLES project are shown in Table 8.1 to have been developed from the A1B storyline developed from the IPCC Special Report on Emission Scenarios (SRES) (IPCC, 2000). The A1 family of scenarios describe a future world of very rapid economic growth, global population that peaks mid-century, and rapid introduction of new and more efficient technologies. The A1B scenario describes the technological change occurring in the energy sector as balanced across both fossil-intensive and non-fossil energy sources. Figure 8.1 displays the IPCC (Solomon et al., 2007) multi-model averaged and assessed ranges of global surface warming relative to 1980-1999 levels for the IPCC SRES scenarios A2, A1B and B1. As can be seen from Figure 8.1 the A1B scenario presents a median level of global surface warming when compared to the A2 and B1 storylines to the year 2100.

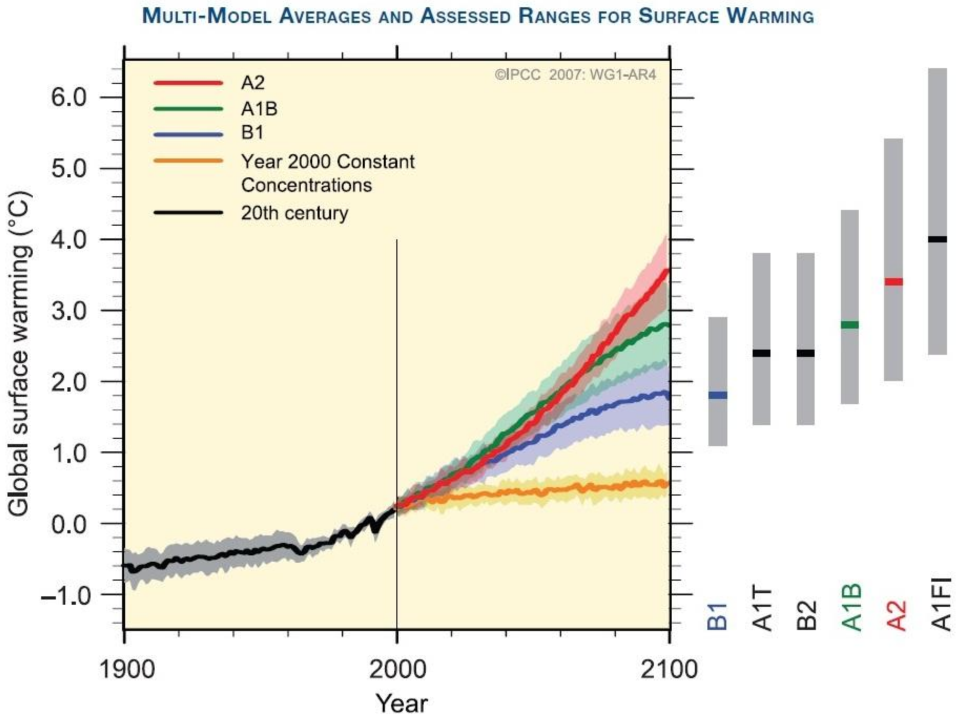

Figure 8.1: Graphical representation of the multi-model average global surface warming (relative to 1980-1999) forecast for different IPCC SRES emissions scenarios. Image taken from IPCC (2007).

Although based upon the same A1B emission scenario, each of the eight future rainfall datasets used by this research comes from a different regional climate model. While all using outputs from either the ECHAM5 or HadCM3 global climate models (GCMs) as boundary conditions for downscaling, each regional model uses a different downscaling approach to parameterising atmospheric processes. ECHAM5 is the most recent version of the ECHAM model developed by the Max Planck Institute for Meteorology by modifying global forecast models developed by the European Centre for Medium-Range Weather Forecasts to be used for climate research. HadCM3 is a coupled atmosphere-ocean GCM developed by the UK Hadley Centre by combining the atmospheric model HadAM3 and the ocean model HadOM3.

From each of the future scenario rainfall datasets listed in Table 8.1, monthly rainfall values (mm/day) for each model zone to the year 2050 were retrieved. However, in order to construct the thresholds required for use of the ENSEMBLES rainfall data in the AMARC3 model an additional historical rainfall dataset was obtained from the project, that of the Climatic Research Unit (CRU) at the University of East Anglia, UK. Available at the same spatial and temporal resolution as the future rainfall scenarios, the CRU 1970-1999 mm/day rainfall data was considered to be a more appropriate means of threshold construction than reapplication of the separate University of Delaware derived cm/month thresholds used in model development. Due to the timeframe of this research, the earlier stages of model development phase was undertaken prior to release of the ENSEMBLES project final report and data in late 2009. Figures 8.2 to 8.6 display the CRU 1970-1999 and 2000-2050 annual JAS rainfall data calculated from the scenarios gained for each model zone from the ENSEMBLES project.

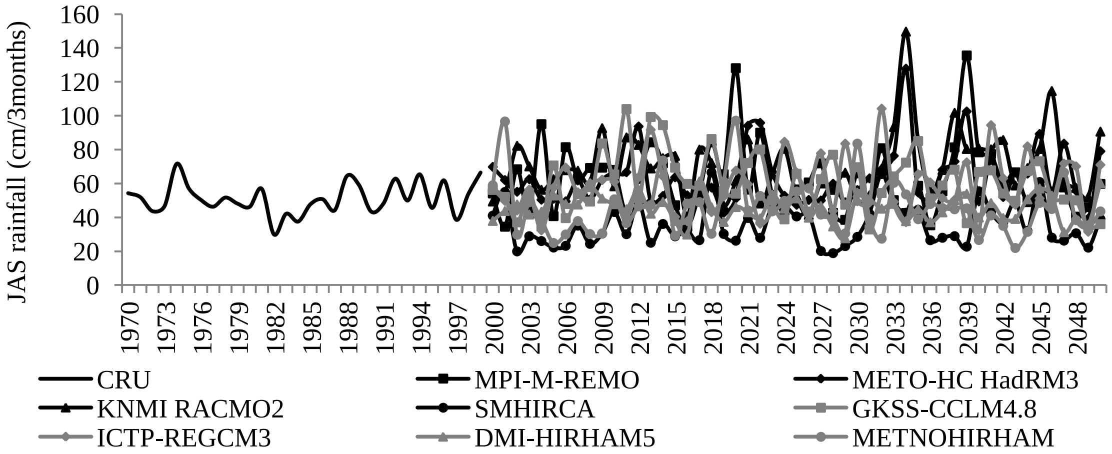

Figure 8.2: 1970-1999 CRU rainfall record and 2000-2050 ENSEMBLES scenario rainfall data for Ouagadougou.

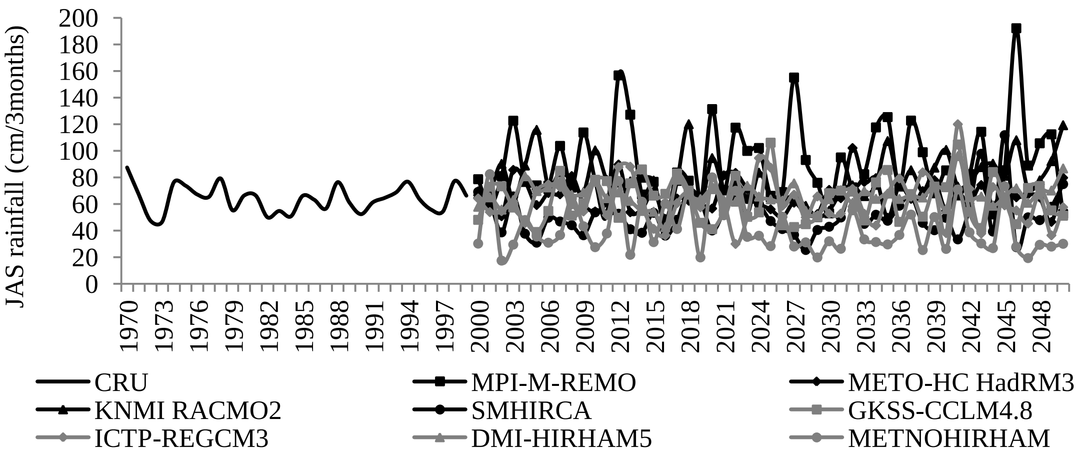

Figure 8.3: 1970-1999 CRU rainfall record and 2000-2050 ENSEMBLES scenario rainfall data for Bobo Dioulasso.

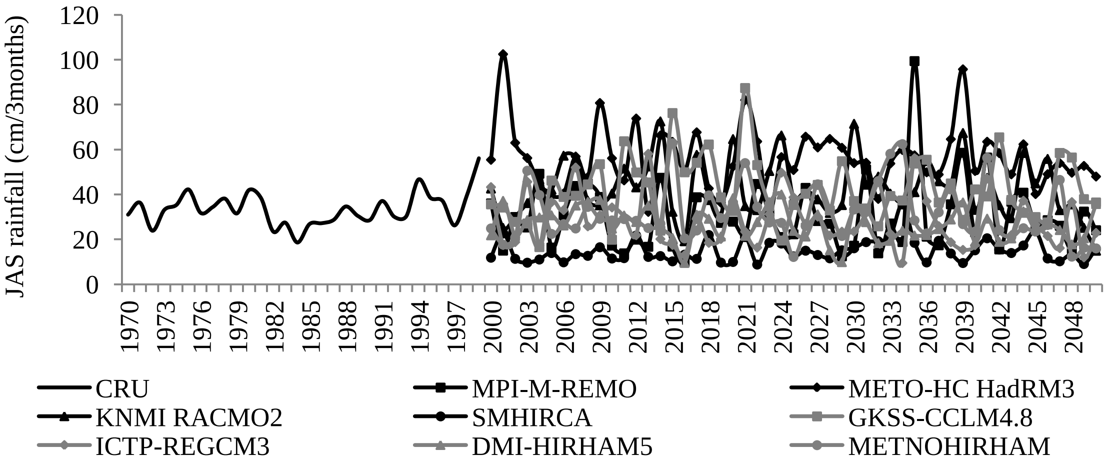

Figure 8.4: 1970-1999 CRU rainfall record and 2000-2050 ENSEMBLES scenario rainfall data for Sahel.

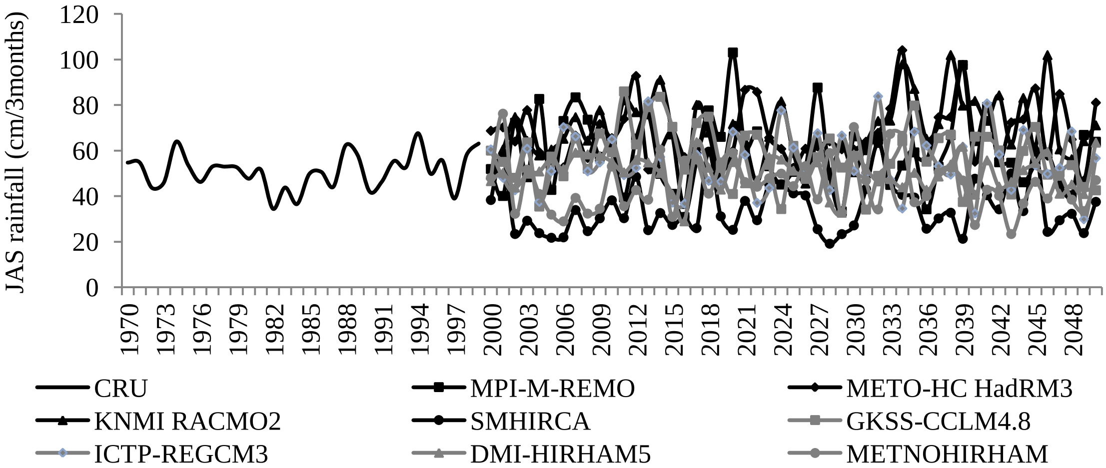

Figure 8.5: 1970-1999 CRU rainfall record and 2000-2050 ENSEMBLES scenario rainfall data for Centre.

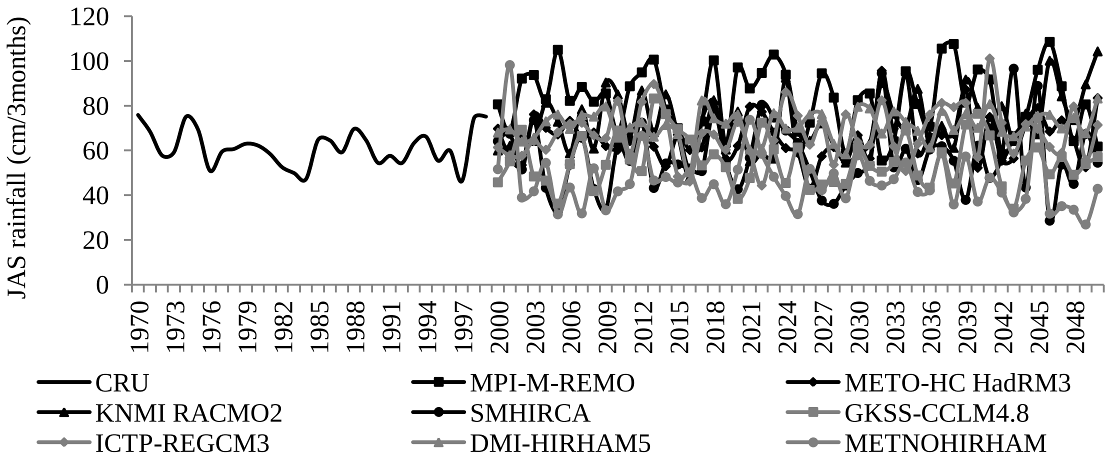

Figure 8.6: 1970-1999 CRU rainfall record and 2000-2050 ENSEMBLES scenario rainfall data for Southwest.

It can be seen from Figures 8.2 to 8.6 that the eight future rainfall scenarios model 2000-2050 JAS rainfall in each zone as varying above and below the 1970-1999 rainfall provided by CRU. In the case of all five model zones either the MPI-M-REMO, METO-HC HadRM3 or KNMI-RACMO2 datasets show the approximate highest levels of modelled rainfall. By contrast, either the SMHIRCA or METNOHIRHAM data show the lowest rainfall forecast in all five zones. Within the fifty-one year period from 2000 to 2050, each rainfall scenario shows a different pattern of anticipated change within each zone.

8.3 Future Rainfall Thresholds

Rainfall thresholds derived from the CRU 1970-1999 rainfall record are used to define each model year from 2000-2050 as dry, average or wet. Thresholds are derived from the first and third quartile values of the 1970-1999 JAS CRU rainfall record of each model zone. Each model year from 2000-2050 is therefore defined as dry, average or wet on the basis of whether the relevant JAS rainfall falls above or below the thresholds displayed in Table 8.2.

Zone:	1st Quartile – Dry/Below Average Rainfall Threshold:	3rd Quartile – Wet/Above Average Rainfall Threshold:
Ouagadougou	45.72 cm/3months	57.00 cm/3months
Bobo Dioulasso	55.55 cm/3months	68.51 cm/3months
Sahel	28.58 cm/3months	37.85 cm/3months
Centre	46.16 cm/3months	55.34 cm/3months
Southwest	56.02 cm/3months	65.86 cm/3months

Table 8.2: 2000-2050 rainfall thresholds used to determine dry, average and wet model years in each of the five zones.

Threshold values derived from the observed historical CRU data provided alongside the ENSMEBLES project scenarios present a reliable standpoint from which threshold values can be assessed. Data relating to the known environment experienced by individuals in Burkina Faso is thus used to statistically frame their modelled perception of future rainfall predictions. As with the earlier validation and testing versions of the AMARC model, definition of each year in each zone as having dry, average or wet rainfall affects the migration decisions made by agents through the behavioural attitude, subjective norm and perceived behavioural control components of their decisions to migrate.

8.4 ENSEMBLES Rainfall Classifications

In order to investigate the impact of the rainfall thresholds listed in Table 8.2 upon the differing patterns of change anticipated by each rainfall scenario across the model zones over the period 2000-2050, Figures 8.7 to 8.14 display the annual classifications of dry, average and wet rainfall identified. Figure 8.7 displays the rainfall classifications derived from the MPI-M-REMO scenario data.

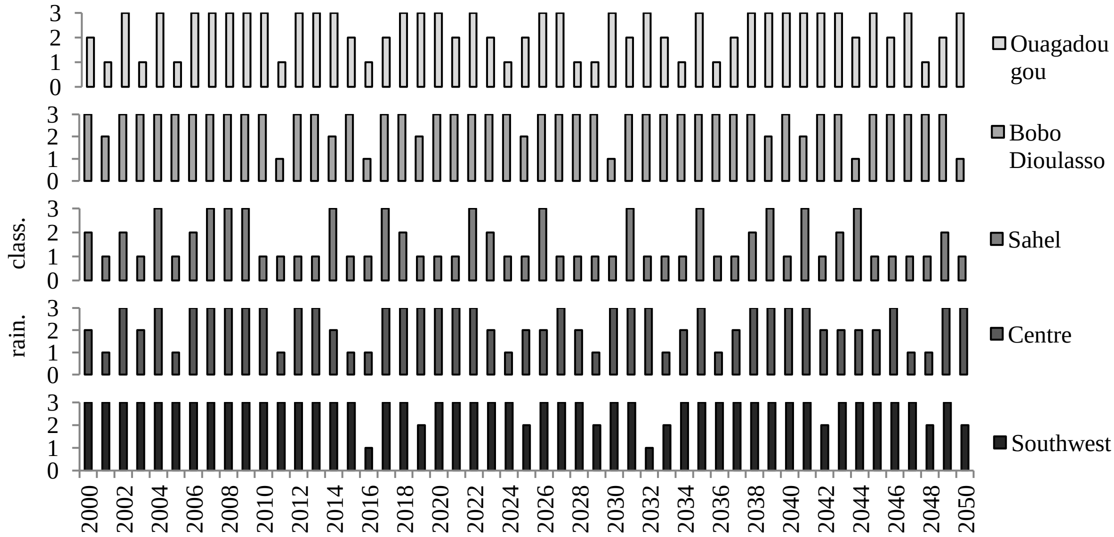

Figure 8.7: MPI-M-REMO 2000-2050 JAS rainfall classifications (1 = dry, 2 = average, 3 = wet).

When each year of the MPI-M-REMO rainfall scenario is classified as dry, average or wet using the thresholds displayed in Table 8.2 it can be seen from Figure 8.7 that different comparative trends are evident across the five zones of Burkina Faso. While much of the period 2000-2050 is classified as dry in the northernmost Sahel region a contrasting pattern is seen in the Southwest zone where the majority of years are classed as wet. Despite the trend seen across the Sahel region where the modal rainfall classification is dry, each of the four other zones, and the country as a whole, show wet modal classifications. Use of the MPI-M-REMO rainfall data therefore appears to provide a largely wet rainfall scenario across Burkina Faso with the exception of the drier Sahel zone. Figure 8.8 displays the JAS rainfall classifications derived from the METO-HC HadRM3 scenario data.

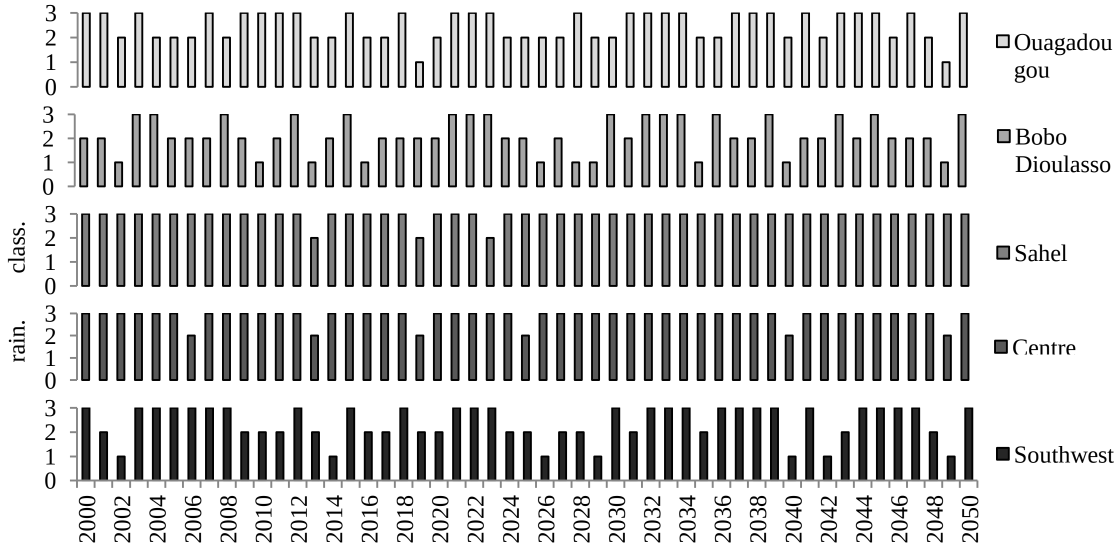

Figure 8.8: METO-HC-HadRM3 2000-2050 JAS rainfall classifications (1 = dry, 2 = average, 3 = wet).

It can be seen from Figure 8.8 that both the Sahel and Centre zones are modelled by the METO-HC HadRM3 scenario as experiencing largely wet rainfall conditions between 2000 and 2050. By contrast, Bobo Dioulasso is seen to experience a mix of dry, average and wet rainfall years. Using the modal rainfall classification values for each zone, all but Bobo Dioulasso are classed as wet between 2000 and 2050. As a result, use of the METO-HC HadRM3 rainfall data leads to a largely wet scenario across Burkina Faso. Figure 8.9 displays the JAS rainfall classifications derived from KNMI-RACMO2 scenario data.

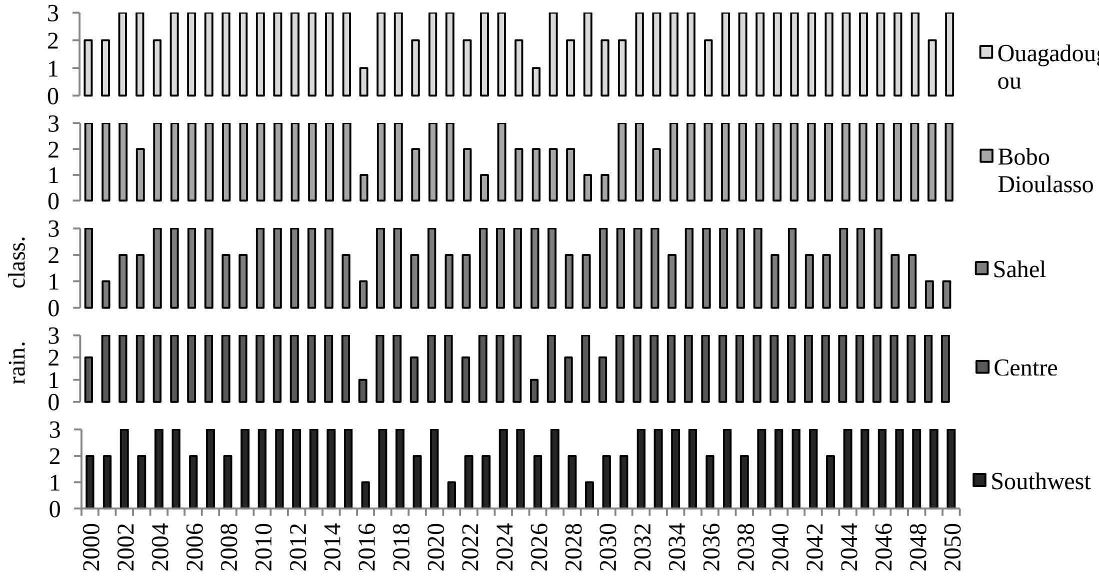

Figure 8.9: KNMI-RACMO2 2000-2050 JAS rainfall classifications (1 = dry, 2 = average, 3 = wet).

It can be seen from Figure 8.9 that the KNMI-RACMO2 data results in a high number of wet rainfall years in each of the five zones. The modal classification for each zone is wet although each of the five zones also show years of dry and average rainfall. On the basis of these classifications, the KNMI-RACMO2 rainfall data can be described as providing a wet rainfall scenario across all five zones. Figure 8.10 displays the JAS rainfall classifications derived from the SMHIRCA scenario data.

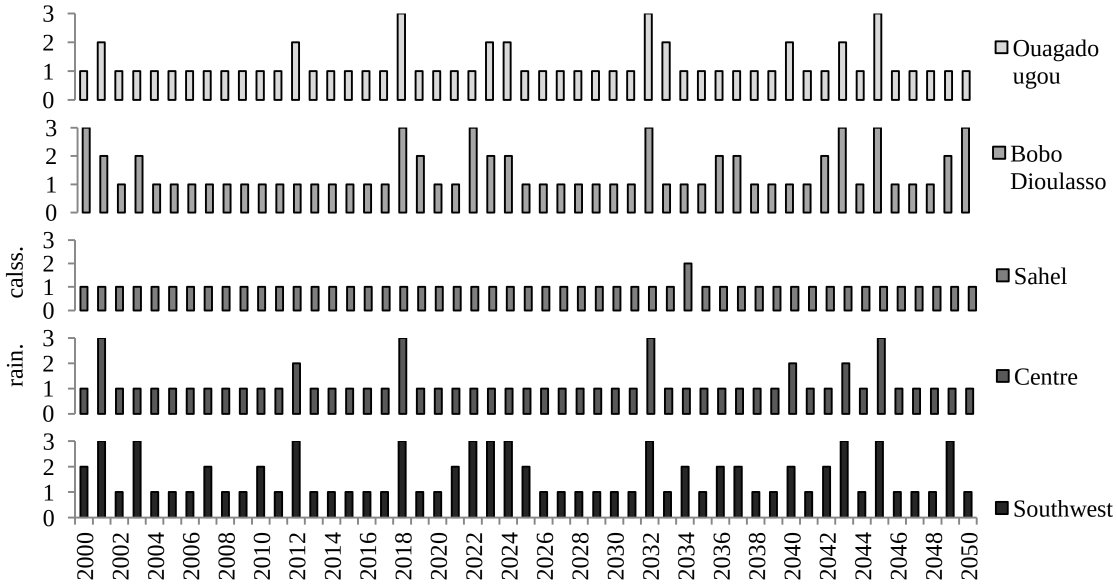

Figure 8.10: SMHIRCA 2000-2050 JAS rainfall classifications (1 = dry, 2 = average, 3 = wet).

Most visibly apparent in the case of the Sahel zone in Figure 8.10 the SMHIRCA rainfall data provides a dry rainfall scenario across all model zones using the thresholds displayed in Table 8.2. All five of the zones show a dry modal classification with the highest occurrence of non-dry years seen in Southwest. Figure 8.11 displays the JAS rainfall classifications derived from the GKSS-CCLM4.8 scenario data.

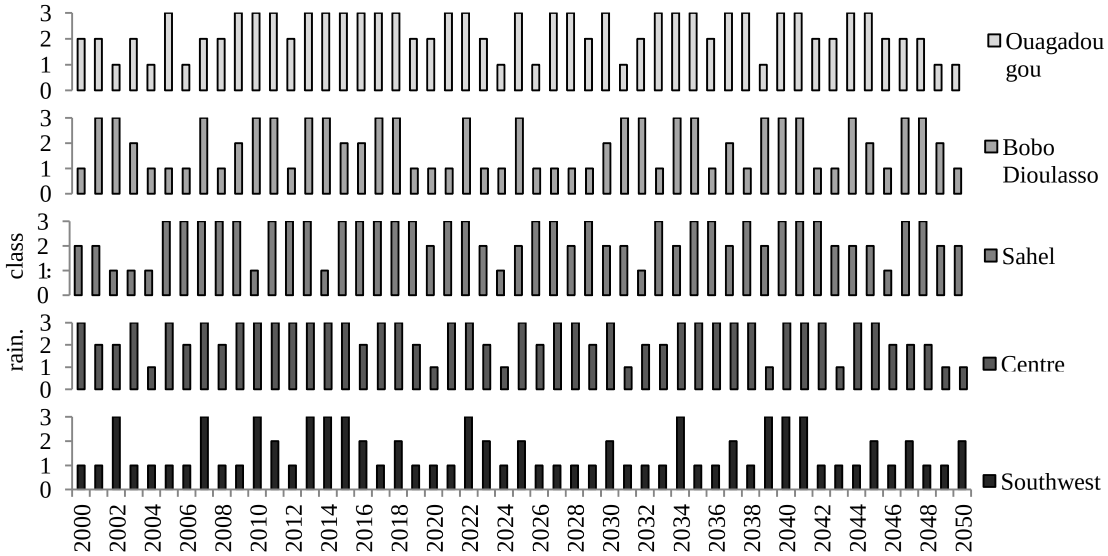

Figure 8.11: GKSS-CCLM4.8 2000-2050 JAS rainfall classifications (1 = dry, 2 = average, 3 = wet).

The GKSS-CCLM4.8 data can be seen to result in different rainfall scenarios in each model zone. While Bobo Dioulasso and Southwest are both seen to have a dry modal rainfall classification between 2000 and 2050, the three remaining zones are modelled as having a wet modal classification. As a result of the mix of dry and wet years the GKSS-CCLM4.8 rainfall scenario can be broadly described as showing an average scenario with considerable inter-annual and inter-zonal variation. Figure 8.12 displays the JAS rainfall classifications derived from ICTP-REGCM3 scenario data.

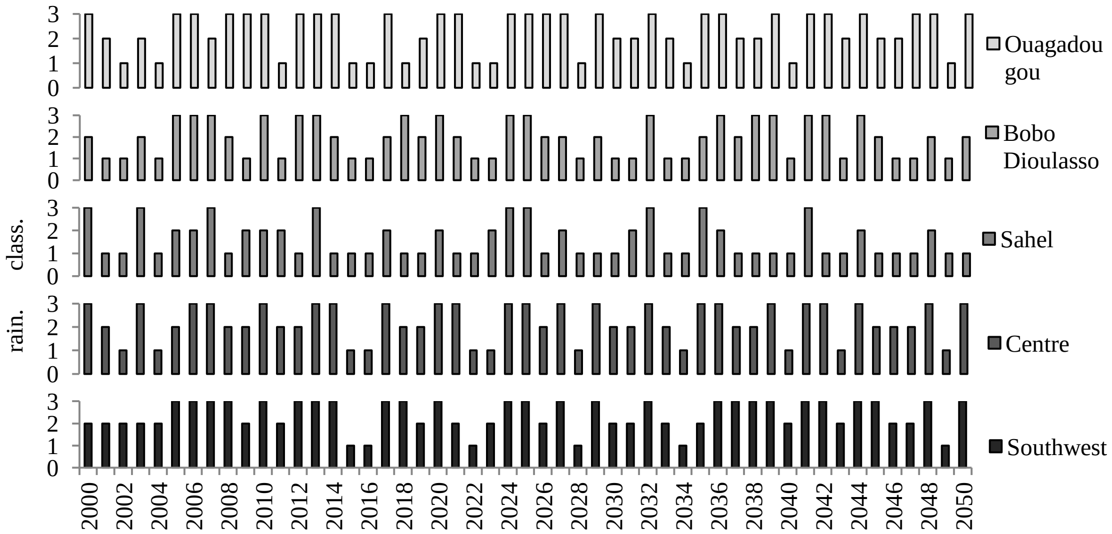

Figure 8.12: ICTP-REGCM3 2000-2050 JAS rainfall classifications (1 = dry, 2 = average, 3 = wet).

The ICTP-REGCM3 rainfall data can also be seen in Figure 8.12 to result in different scenarios in each of the zones. While Ouagadougou, Centre and Southwest are all shown to have wet modal classifications, both Bobo Dioulasso and Sahel are dry. While the modal classification for the entire country is wet, the mean classification for all years in all zones is average. As such, the ICTP-REGCM3 scenario can be considered to produce mixed but average rainfall classifications with considerable inter-annual variability. Figure 8.13 displays the JAS rainfall classifications derived from DMI-HIRHAM5 scenario data.

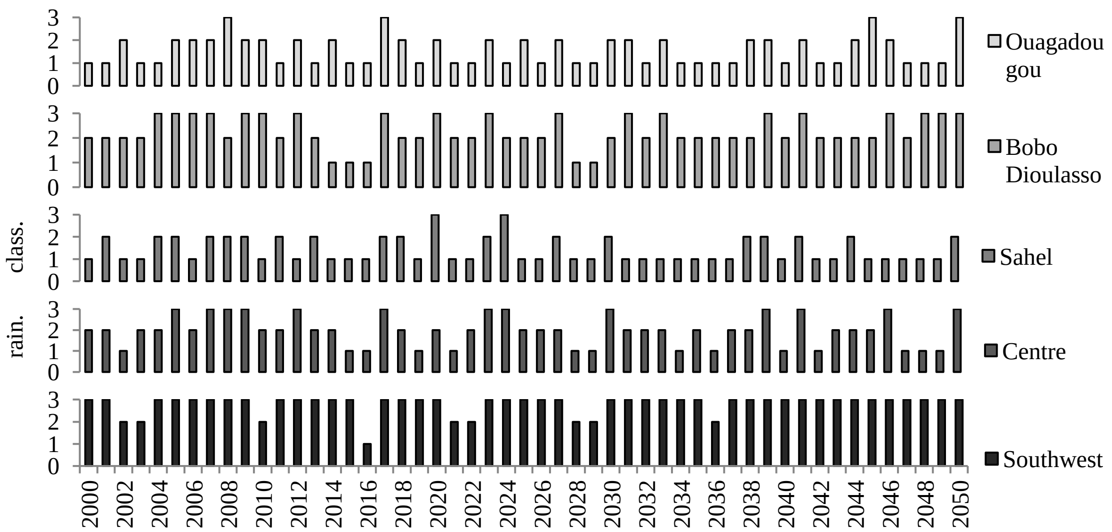

Figure 8.13: DMI-HIRHAM5 2000-2050 JAS rainfall classifications (1 = dry, 2 = average, 3 = wet).

Differences between the scenarios resulting from the DMI-HIRHAM5 rainfall data are seen to exist between zones. While both Ouagadougou and Sahel have dry modal classifications, Bobo Dioulasso and Centre are seen to have average modal classifications with Southwest classed as wet. Overall therefore the DMI-HIRHAM5 rainfall scenario can be considered to produce an average scenario across Burkina Faso that shows a high level of inter-annual variability across the defined thresholds as well as considerable inter-zonal variation. Figure 8.14 displays the JAS rainfall classifications derived from the METNOHIRHAM scenario data.

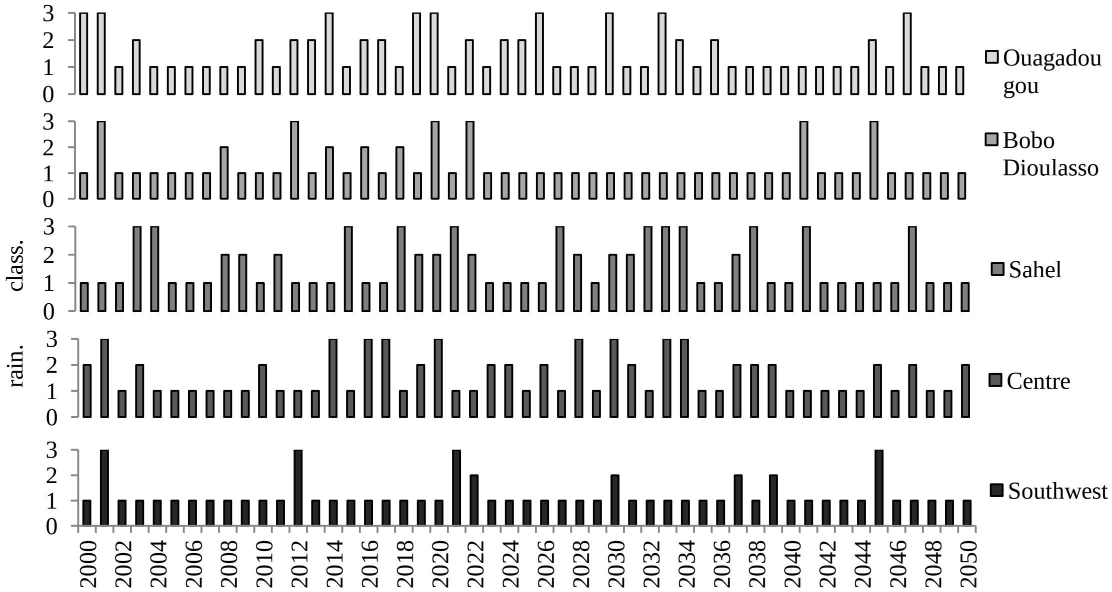

Figure 8.14: METNOHIRHAM 2000-2050 JAS rainfall classifications (1 = dry, 2 = average, 3 = wet).

It can be seen from Figure 8.14 that the modal rainfall classification resulting from the METNOHIRHAM rainfall data in each of the five zones is dry. The dry classifications are most apparent in Bobo Dioulasso and Southwest while the Sahel zone shows the most non-dry classifications. Although not as extreme as the SMHIRCA rainfall scenario the future rainfall modelled by METNOHIRHAM across Burkina Faso may also be classed as generally dry with some inter-annual variation. In addition to the eight ENSEMBLES rainfall datasets used to investigate the migration rates modelled by future rainfall scenarios in Burkina Faso, a “No Climate” scenario is also used as a means to provide a base line from which future changes in rainfall variability can be assessed. This No Climate future rainfall dataset was produced by repeating the CRU 1970-1999 rainfall record to 2050. Figure 8.15 displays the JAS rainfall classifications derived from the No Climate scenario data.

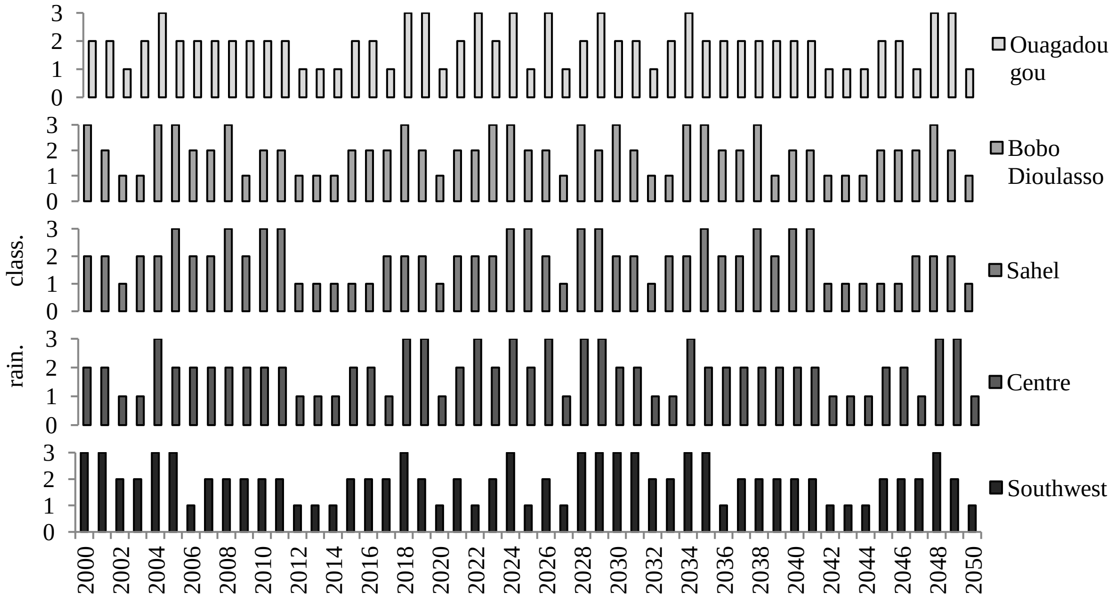

Figure 8.15: No Climate 2000-2050 JAS rainfall classifications (1 = dry, 2 = average, 3 = wet).

With the CRU rainfall data used to both calculate threshold values and construct the No Climate rainfall scenario, it is appropriate that the modal rainfall classification seen in all model zones in Figure 8.15 is average. However, although the overall classification seen from the No Climate scenario is average, numerous wet and dry classifications are also seen in each zone. In the same way as the DMI-HIRHAM5 scenario seen in Figure 8.13 the No Climate scenario can therefore be described as producing a generally average scenario with a high level of inter-annual variability across the defined thresholds. Table 8.3 displays the relative rainfall classifications identified above for each combination of regional model zone and ENSEMBLES rainfall scenario.

Rainfall Dataset:	**Ouagadougou**	**Bobo Dioulasso**	**Sahel**	**Centre**	**Southwest**
MPI-M-REMO	Ave-Wet	Wet	Ave-Dry	Ave-Wet	Wet
METO-HC HadRM3	Ave-Wet	Ave	Wet	Wet	Ave-Wet
KNMI-RACMO2	Wet	Wet	Wet	Wet	Wet
SMHIRCA	Dry	Dry	Dry	Dry	Ave-Dry
GKSS-CCLM4.8	Ave-Wet	Ave	Ave-Wet	Ave-Wet	Ave-Dry
ICTP-REGCM3	Ave-Wet	Ave	Ave-Dry	Ave	Ave-Wet
DMI-HIRHAM5	Ave-Dry	Ave-Wet	Dry	Ave	Wet
METNOHIRHAM	Ave-Dry	Dry	Ave-Dry	Ave-Dry	Dry

Table 8.3: Rainfall classification scenarios resulting from each of the ENSEMBLES rainfall datasets in each of the five zones of Burkina Faso.

When considered on the basis of the threshold values displayed in Table 8.2 each of the eight ENSEMBLES rainfall datasets reveals a different pattern of rainfall scenarios across the five zones of Burkina Faso. While the No Climate rainfall data provides an overall average scenario across the zones, it can be seen from Table 8.3 that the SMHIRCA data provides the most geographically consistently dry scenario and the KNMI-RACMO2 data provides the most consistently wet. Comparing the migration flows modelled by these scenarios will provide insight into the modelled role of changes in rainfall variability in the migration decision towards 2050.

8.5 Ensemble Model Runs

As with each version of the ABM presented by this thesis, models are run five times in order to generate five-run averaged ensemble results. Before the influence of future rainfall scenarios upon modelled migration was assessed using the AMARC3 model, the variation between ensemble runs of the same model was considered. The version of AMARC3 that uses the MPI-M-REMO future rainfall scenario was used to test the variation evident between ten model runs, assessed in terms of the difference between the total average modelled flows of migrants leaving all model zones using from one to ten ensembles. As with all other versions of the AMARC3 model, each run starts in 1970 with a total of 4,449 agents initialised across the five model zones. Furthermore, agents in each model run are networked with a maximum of fifty of their peers in a random network and use ppt.mp30 weight matrices. Figure 8.16 displays the average total migration flows modelled by up to ten runs of the AMARC3_MPI-M-REMO model for the simulation period 2000-2050.

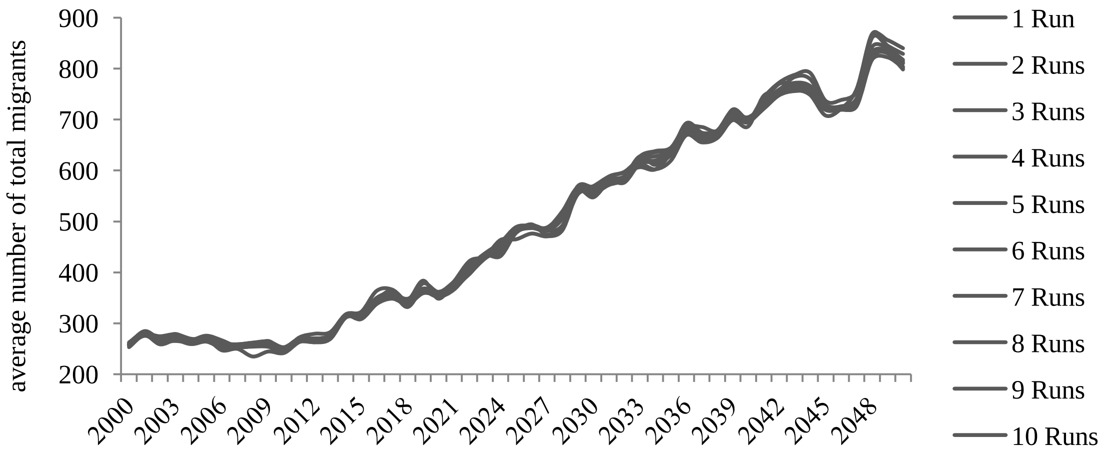

Figure 8.16: Total average annual 2000-2050 modelled migrants from between one and ten runs of the AMARC3_MPI-M-REMO model.

It can be clearly seen that the total migration flows modelled by ten runs of the AMARC3_MPI-M-REMO model are similar in terms of both scale and inter-annual variability. With a mean annual standard deviation of 7 migrants (4.5% of the maximum) between any of the one run- or ten run-averaged modelled flows, the variation between the numbers of migrants modelled under increasing numbers of ensembles is not considered to be necessary to warrant the use of any more than the five member ensembles used throughout this thesis.

8.6 Future Demographic Scenarios

In combination with the future rainfall scenarios used in this chapter, three potential future demographic scenarios are used in order to assess how different demographic components combine with the influence of rainfall upon modelled migration. Identified in Chapter 7 as having a substantial impact upon modelled migration flows, demographic change is considered alongside the different ENSEMBLES rainfall scenarios described above to permit the impact of rainfall upon modelled migration under different demographic scenarios to be considered. The three future demographic scenarios used in this chapter are taken from the UNPD (2011) data for Burkina Faso using low, medium and high variant crude birth and death rates, displayed in Tables 8.4 and 8.5 respectively.

Date:	Low Variant	Medium Variant	High Variant
2000-2005		44.9	
2005-2010		43.9	
2010-2015	40.7	42.4	44.1
2015-2020	38.3	40.7	43.0
2020-2025	35.2	38.0	40.6
2025-2030	33.1	35.6	38.0
2030-2035	31.0	33.6	36.1
2035-2040	28.9	31.8	34.6
2040-2045	26.8	30.1	33.2
2045-2050	24.8	28.3	31.6

Table 8.4: United Nations Population Division (2011) low, medium and high variant crude birth rates (per 1,000 population) for Burkina Faso.

Date:	Low Variant	Medium Variant	High Variant
2000-2005		14.2	
2005-2010		12.6	
2010-2015	11.1	11.2	11.4
2015-2020	9.9	10.1	10.3
2020-2025	8.8	9.0	9.1
2025-2030	8.0	8.1	8.1
2030-2035	7.3	7.3	7.4
2035-2040	6.8	6.8	6.8
2040-2045	6.5	6.4	6.3
2045-2050	6.3	6.1	5.9

Table 8.5: United Nations Population Division (2011) low, medium and high variant crude death rates (per 1,000 population) for Burkina Faso.

In each simulation run of the AMARC3 model the crude birth and death rate data presented in Chapter 3 are used to control the demographic evolution of the five groups of agents. Model years between 2000 and 2010 then use the UNPD medium variant crude birth and death rates. Between 2011 and 2050 low, medium or high variant birth and death rates are applied to modelled agents depending upon the demographic criteria of the simulation in question. Figure 8.17 compares the low, medium and high variant birth and death rates used in the models.

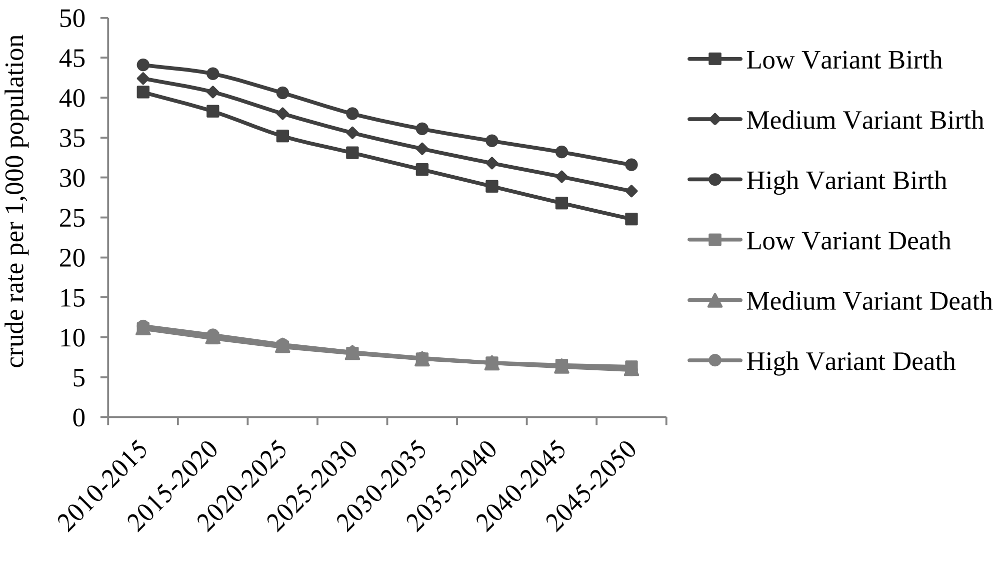

Figure 8.17: UNPD low, medium and high variant crude birth and death rates (per 1,000 population) for Burkina Faso between 2000 and 2050.

It can be seen from Figure 8.17 that, while a clear distinction is evident between the low, medium and high crude birth rates provided by the UNPD for Burkina Faso, comparatively little distinction is evident in the case of the associated death rates. Changes to birth rates in the low, medium and high variant demographic change versions of the AMARC3 models will therefore result in relatively significant changes to the modelled population with changes in crude death rate having relatively little impact. It can be anticipated therefore that the larger model population resulting from the high variant levels of demographic change will result in larger migrant flows than may result from the low and medium variant models. However, it is the nature of the changes in migrant numbers resulting from the combinations of rainfall and demographic scenarios that are key to the analysis presented in this chapter.

8.7 ENSEMBLES Rainfall Scenario Comparisons

Using the JAS rainfall thresholds identified in Table 8.2 five-run ensembles of nine versions of the AMARC3 model (using the eight ENSEMBLES rainfall scenarios and the No Climate scenario) were completed for low, medium and high variant rates of demographic change. Figure 8.18 displays the total five-run averaged migration flows modelled from all zones between 2011 and 2050 using the nine different rainfall scenarios under low variant demographic change.

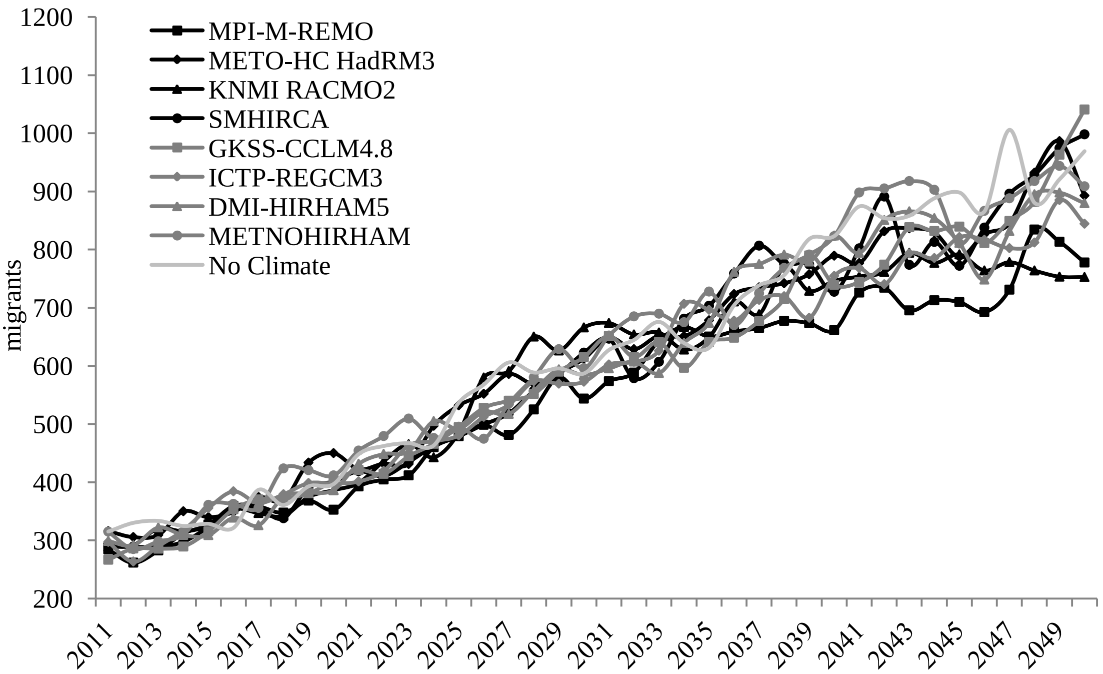

Figure 8.18: Total annual migration flows modelled by the nine rainfall scenarios using low variant UN demographic change statistics for Burkina Faso.

Only those migrant flows modelled from 2011 onwards are displayed in Figure 8.18 as the different low, medium and high population variants only apply from this model year onwards. By 2050 the highest total migration flow modelled by one of the nine rainfall versions of AMARC3 is 1,041 from the version that uses the GKSS-CCLM4.8 scenario which produces generally average rainfall across all zones with high levels of inter-annual and inter-zonal variation. By contrast, the lowest migrant flow modelled in 2050 is 753 from the version that uses the wet KNMI-RACMO2 scenario rainfall. Although this version models the lowest total migration in 2050, the lowest modelled flows between 2011 and 2050 more commonly come from the generally average-wet MPI-M-REMO version of the model. The No Climate version simulates total migration in 2050 as equaling a comparatively high 969. The difference between the maximum and minimum migration flows simulated for 2050 by the nine rainfall scenario versions of the low variant AMARC3 model therefore equals 288 or a reduction of 28% from the GKSS-CCLM4.8 maximum. Figure 8.19 displays the total migration flows modelled from all zones between 2011 and 2050 using the nine different rainfall scenarios under medium variant demographic change.

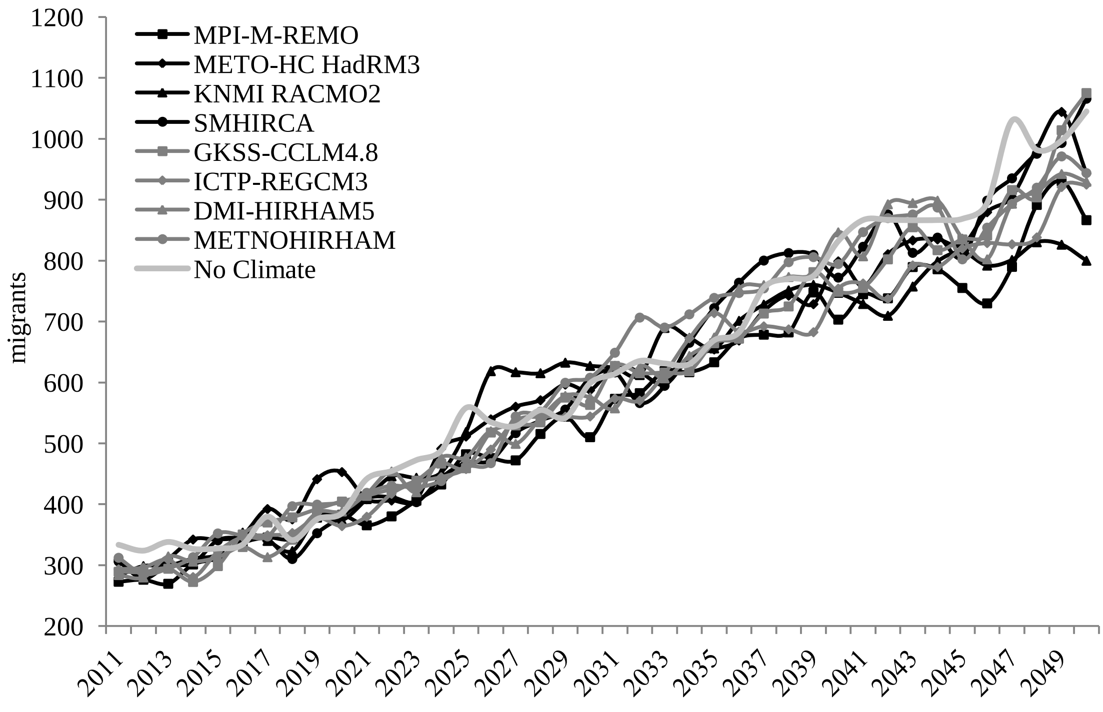

Figure 8.19: Total annual migration flows modelled by the nine rainfall scenarios using medium variant UN demographic change statistics for Burkina Faso.

Figure 8.19 shows that the total migration modelled by the medium variant demographic change statistics display a similar distribution pattern to that seen for the low population variant in

Figure 8.18. The highest total migration flow modelled for 2050 again comes from the GKSS-CCLM4.8 model run with a total of 1,075 migrants, 34 more than were modelled for the same rainfall scenario under the low variant demographic forecast. Furthermore, the lowest migrant flow in 2050 is again modelled by the KNMI-RACMO2 version of the model with a total of 800 migrants, 47 more than were modelled for the same rainfall scenario under the low variant demographic forecast and a reduction of 275 migrants or 26% from the maximum. The No Climate rainfall scenario again results in total modelled migration towards the maximum seen from any of the scenarios with a 2050 total of 1,045 migrants. Figure 8.20 displays the total migration flows modelled from all zones between 2011 and 2050 using the nine different rainfall scenarios under high variant demographic change.

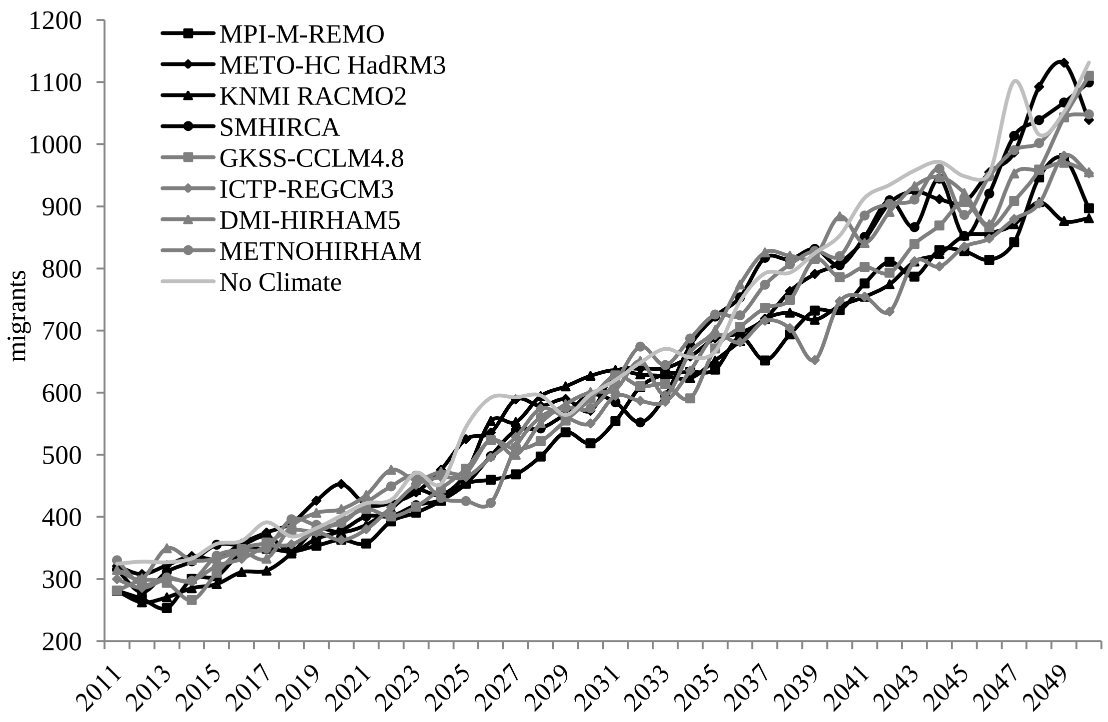

Figure 8.20: Total annual migration flows modelled by the nine rainfall scenarios using high variant UN demographic change statistics for Burkina Faso.

It can be seen from Figure 8.20 that a similar pattern of total migrant flows is again evident across the nine rainfall scenarios tested. However, the highest modelled flow under the high variant statistics is seen under the No Climate scenario with a 2050 total of 1,132 migrants, 75 more than the maximum number modelled under the medium variant demographic scenario by GKSS-CCLM4.8 (which, under the high demographic scenario results in the second highest modelled 2050 migrant flow). The lowest migrant number modelled under the high variant demographic change scenario again comes from the wet scenario provided by KNMI-RACMO2 with a 2050 total of 881 migrants, 81 more than were modelled by the medium variant scenario and representing a reduction of 251 migrants or 22% from the maximum.

Across the three UN demographic scenarios tested, the influence of each of the nine rainfall scenarios upon modelled total migration appears, on the basis of Figures 8.18 to 8.20, to remain relatively constant. In order to enable further investigation of the impact of the rainfall scenarios analysed above, Figure 8.21 displays the total numbers of migrants modelled as migrating under each combination of rainfall and demographic scenarios between 2011 and 2050.

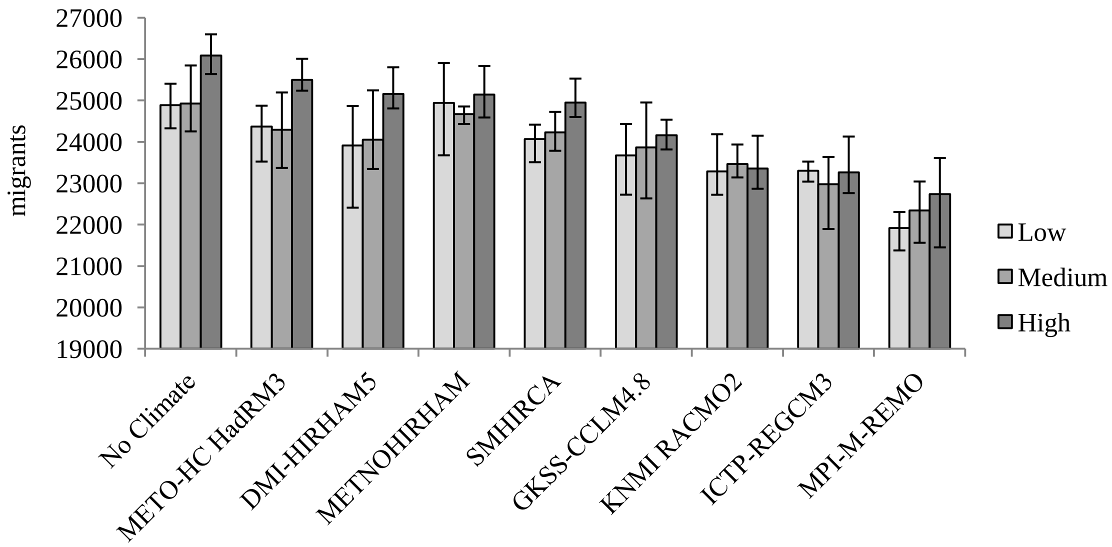

Figure 8.21: 2011-2050 forty year total migration flows modelled by the nine rainfall scenarios under low, medium and high variant UN demographic change statistics for Burkina Faso. Y-axis starts at 19,000 in order to show data at a more appropriate scale.

Figure 8.21 shows that, using total forty year modelled migration as a means of assessment, five of the nine rainfall scenarios display an incremental increase in modelled migrant numbers between low, medium and high variant demographic scenarios. The order in which the eight ENSEMBLES rainfall scenarios are presented in Figure 8.21 corresponds with the order, from high to low, in which high variant demographic scenario total migration flows present themselves. Although not followed precisely throughout the medium and low variant demographic scenario results, the general pattern/order used in Figure 8.21 is retained. Interestingly, only in the case of the low variant demographic change scenario does the No Climate rainfall scenario fail to model the highest level of total forty year migration. Using the No Climate as the base scenario that represents the degree of rainfall variability experienced in

Burkina Faso between 1970 and 1999, the numbers change in migrant flows modelled under each scenario future rainfall scenario suggest the likely impact of future changes in rainfall variability upon migration in Burkina Faso towards 2050. Figure 8.22 displays the forty year averaged percentage annual change in modelled migration flows away from the No Climate base under each of the ENSEMBLES rainfall scenarios under low, medium and high demographic change conditions.

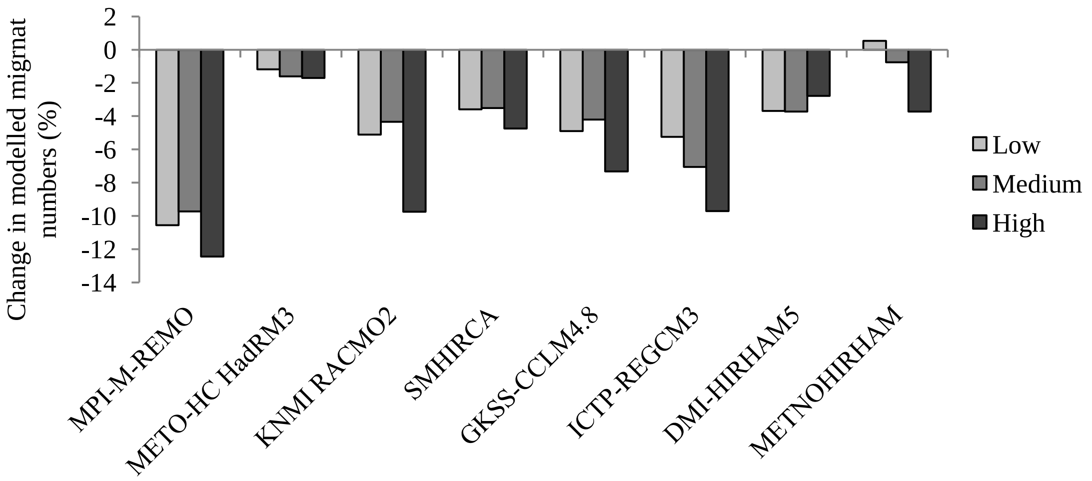

Figure 8.22: 2011-2050 forty year averaged percentage change in total migration flows modelled as occurring under each of the ENSEMBLES rainfall scenarios compared to No Climate under low, medium and high variant demographic change.

The only combination of rainfall and demographic scenarios modelled as producing a forty year net increase in migration compared to the No Climate alternative is seen in Figure 8.22 to be low variant demographic METNOHIRHAM which shows an average annual increase in modelled flows of 0.53%. All other combinations of scenarios are seen to result in a reduction in migrant numbers of between -0.75% (medium variant demographic METNOHIRHAM) and -12.45% (high variant demographic MPI-M-REMO) each year. Within the range scenario combinations tested, the mean reduction in modelled flows compared to No Climate ranges from -4.22% each year for the low variant demographic scenario to -6.53% each year for the high variant. In order to identify the nature of the lower level flows resulting in these total migration statistics and to further explore the role of future rainfall and demographic scenarios, the following section provides further analysis of the migration flows modelled under each combination of demographic and rainfall scenario.

8.8 ENSEMBLES Scenario Breakdowns

In order to permit further investigation into the role of each of the nine rainfall scenarios upon modelled migration, each individual scenario is considered in turn and the influence of low, medium and high variant demographic scenarios assessed. However, in order to do this, ten-year averages of the raw data are used in order to generate smoothed model outputs. Figures 8.22 to 8.30 display the annual ten-year averaged total modelled migration flows under the three demographic scenarios for each of the nine rainfall scenarios, presented in the order in which they are ranked in Figure 8.21. Using ten-year averages of the data where, for example, the number of migrants calculated for 2015 is the average annual number calculated from 2010-2019 data, reduces the simulation record to the model year 2046 but permits clearer observation of temporal trends in the model data.

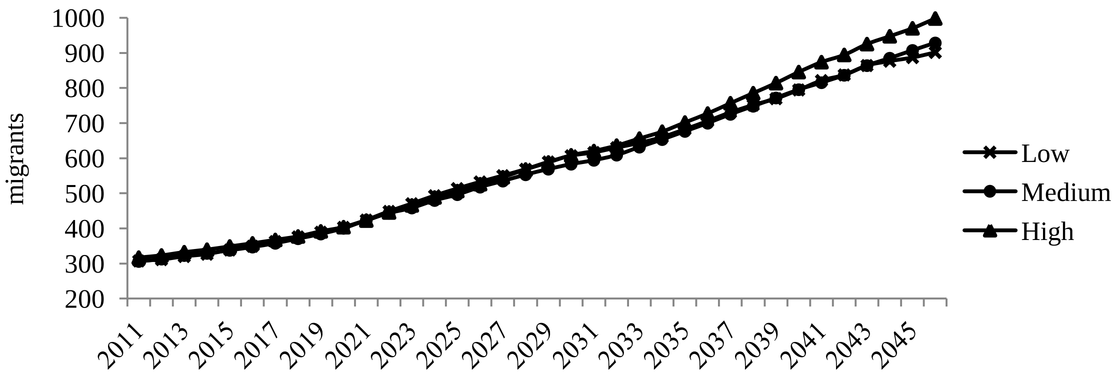

Figure 8.23: Annual ten-year average total migration flows modelled by the No Climate rainfall scenario under low, medium and high variant demographic scenarios between 2011 and 2046.

It can be seen from Figure 8.23 that, using ten-year averaged model outputs, the distinction between total migration flows modelled by low, medium and high variant demographic scenarios is clearer. For the last ten years of the simulation period for which ten-year averaged flows can be calculated (2037-2046), the total migration flow modelled by the high variant No Climate scenario is clearly greater than those modelled by both the low and medium variant alternatives. However, while this distinction is visible, no such relationship is evident between low and medium variant scenarios until 2045 when medium variant modelled migration flows are seen to be marginally higher. It is evident therefore that, using the No Climate rainfall scenario, the higher the rate of demographic change modelled, the greater the impact of the scenario rainfall upon modelled migration. By 2046, the last model year for which ten-year averaged migrant flow data is calculable, the difference between total high variant and total low variant scenario modelled migration is 97 migrants or 9.7% of the high variant scenario total. Figure 8.24 displays ten-year averaged data for the METNOHIRHAM scenario.

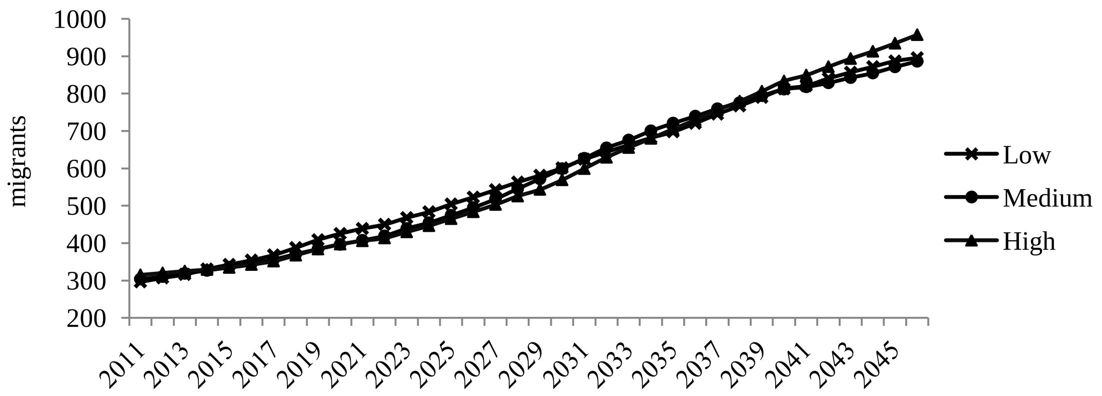

Figure 8.24: Annual ten-year average total migration flows modelled by the METNOHIRHAM rainfall scenario under low, medium and high variant demographic scenarios between 2011 and 2046.

Although not as clear as that seen in Figure 8.23, the pattern of the emerging influence of demographic change is somewhat replicated in Figure 8.24 using the METNOHIRHAM rainfall scenario and ten-year averaged model outputs. However, in Figure 8.24 the greater migration flow modelled under the high variant scenario only emerges from 2041 onwards. In further contrast, the low variant demographic scenario is seen in Figure 8.24 to result in a higher level of total modelled migration than that modelled under the medium variant scenario between 2042 and 2046. In fact, over the ten year period from 2018 to 2027, the low variant scenario is seen to produce higher levels of ten-year averaged modelled migration than are produced by either the medium or high variant versions. Between 2028 and 2032 modelled migration under the high variant scenario is lower than that modelled by both medium and low variant scenarios. By 2046 the difference between total high variant and total medium variant scenario modelled migration is 71 migrants or 7.4% of the high variant scenario total. Figure 8.25 displays ten-year averaged demographic scenario modelled migration data for the METO-HC HadRM3 rainfall scenario.

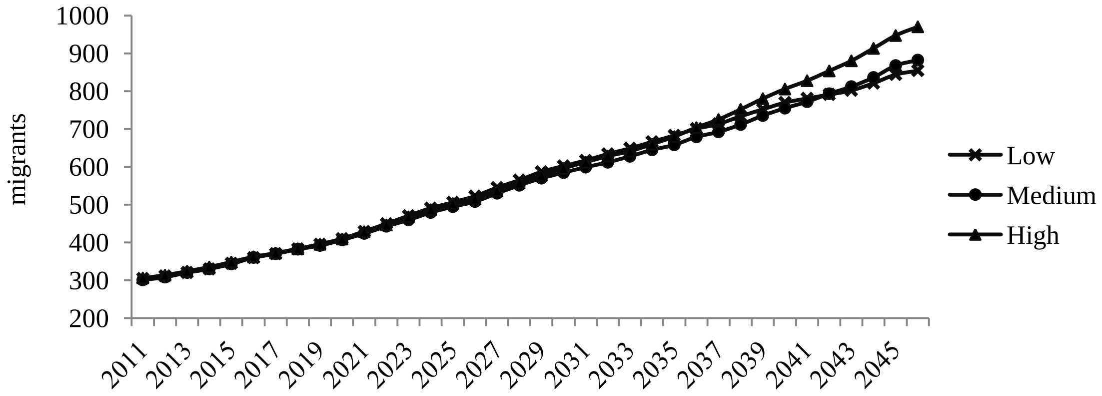

Figure 8.25: Annual ten-year average total migration flows modelled by the METO-HC-HadRM3 rainfall scenario under low, medium and high variant demographic scenarios between 2011 and 2046.

From 2039 onwards ten-year averaged migration modelled under the high variant and METO-HC-HadRM3 combination of scenarios are seen in Figure 8.25 to be clearly greater than those modelled for the low or medium demographic variant alternatives, both of which produce similarly low modelled migration. By 2046, the last model year for which ten-year averaged migrant flow data is calculable, the difference between total high variant and total low variant scenario modelled migration is 116 migrants or 12% of the high variant scenario total. Figure 8.26 displays ten-year averaged demographic scenario modelled migration data for the SMHIRCA rainfall scenario.

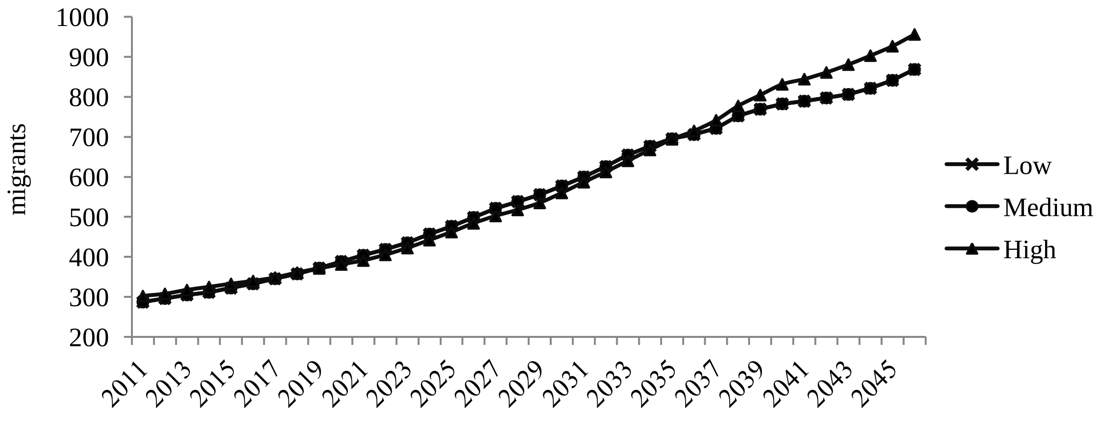

Figure 8.26: Annual ten-year average total migration flows modelled by the SMHIRCA rainfall scenario under low, medium and high variant demographic scenarios between 2011 and 2046.

Figure 8.26 shows that, using the SMHIRCA rainfall data, the high variant demographic scenario again results in a ten-year averaged modelled migration flow that, from 2039, is clearly higher than those modelled using the low and medium variant alternatives. Again, the difference between the low and medium variant ten-year averaged modelled migration flows is minimal and virtually indistinguishable at the scale shown. By 2046 the difference between total high variant and total low variant scenario modelled migration is 87 migrants or 9.1% of the high variant scenario total. Figure 8.27 displays ten-year averaged demographic scenario modelled migration data for the DMI-HIRHAM5 rainfall scenario.

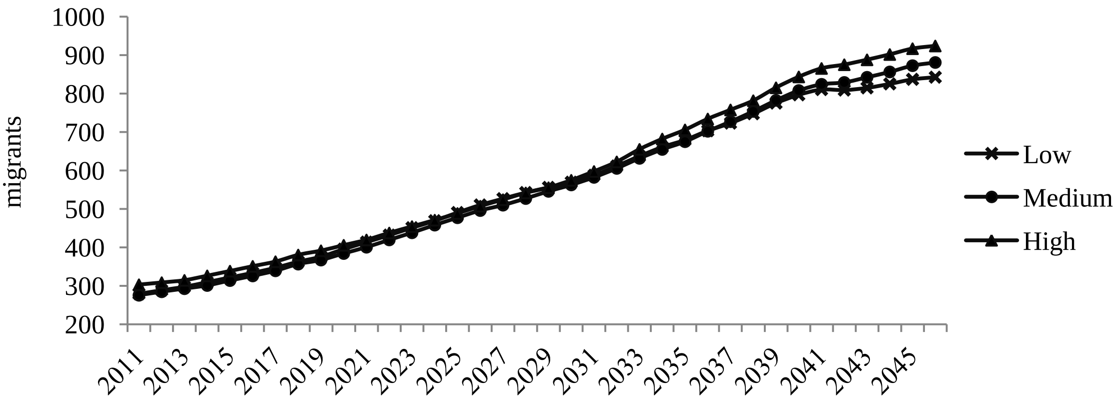

Figure 8.27: Annual ten-year average total migration flows modelled by the DMI-HIRHAM5 rainfall scenario under low, medium and high variant demographic scenarios between 2011 and 2046.

The difference between low, medium and high variant model runs using the DMI-HIRHAM5 scenario is shown in Figure 8.27 to start to emerge in the ten-year averaged total migration results from 2035 onwards when the high variant scenario starts to show clearly higher rates of modelled migration. By 2046 the low, medium and high variant model results show an even level of distribution with medium variant modelled migration falling between those modelled by the high and low variant alternatives. However, ten-year averaged medium variant modelled migration is only clearly greater than low variant from 2042 onwards. By 2046 the difference between total high variant and total low variant scenario modelled migration is 81 migrants or 8.8% of the high variant scenario total. Figure 8.28 displays ten-year averaged demographic scenario modelled migration data for the GKSS-CCLM4.8 rainfall scenario.

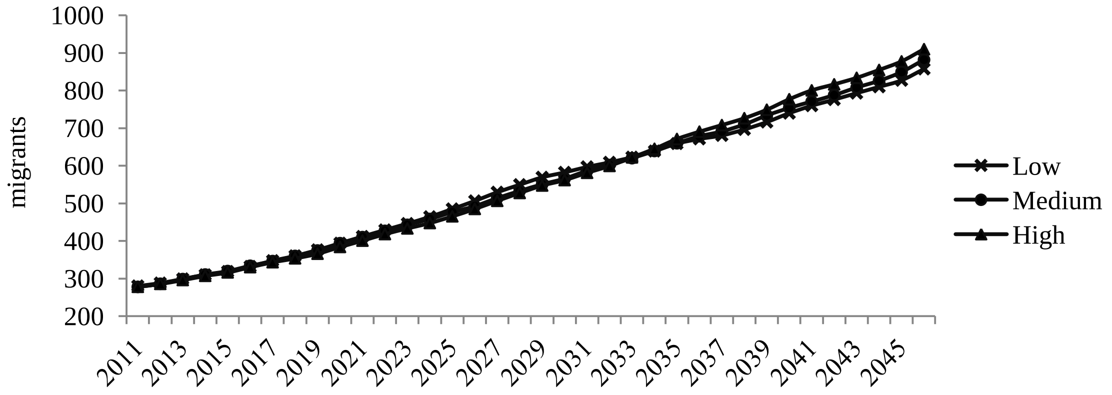

Figure 8.28: Annual ten-year average total migration flows modelled by the GKSS-CCLM4.8 rainfall scenario under low, medium and high variant demographic scenarios between 2011 and 2046.

Figure 8.28 shows that, using the GKSS-CCLM4.8 rainfall scenario, a relatively consistent relationship between the ten-year averaged modelled migration flows for low, medium and high variant demographic scenarios is evident from 2035 to the end of the model period eleven years later. By 2046 the difference between total high variant and total low variant scenario modelled migration is 53 migrants or 5.8% of the high variant scenario total. Figure 8.29 displays ten-year averaged demographic scenario modelled migration data for the ICTP-REGCM3 rainfall scenario.

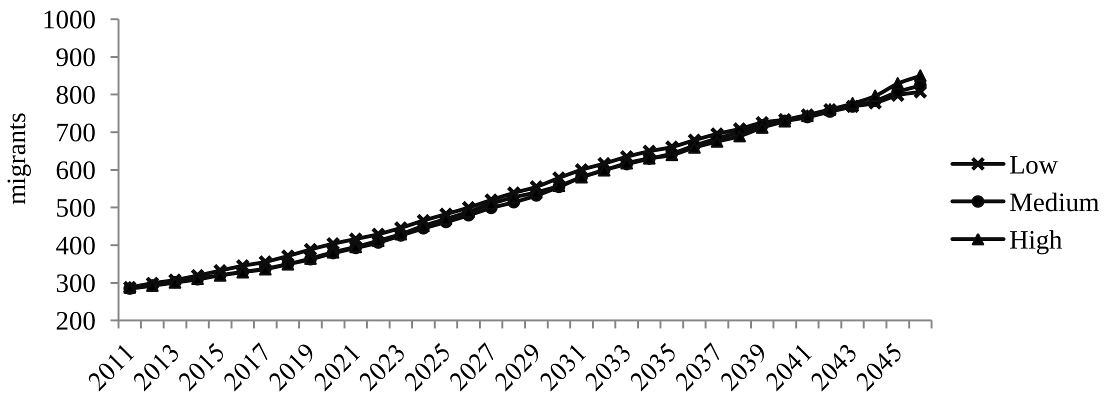

Figure 8.29: Annual ten-year average total migration flows modelled by the ICTP-REGCM3 rainfall scenario under low, medium and high variant demographic scenarios between 2011 and 2046.

It can be seen from Figure 8.29 that, using the ICTP-REGCM3 rainfall scenario, relatively little difference in ten-year averaged modelled migration flows is evident throughout the period 2011 to 2046. The anticipated hierarchy of modelled migrant flows only visibly emerges in Figure

8.29 in 2045, one year before the last data point. Between 2016 and 2035 the highest ten-year averaged migration flow is modelled by the low variant demographic scenario. By 2046 the difference between total high variant and total low variant scenario modelled migration is only 43 migrants or 5.1% of the high variant scenario total. Figure 8.30 displays ten-year averaged demographic scenario modelled migration data for the KNMI-RACMO2 rainfall scenario.

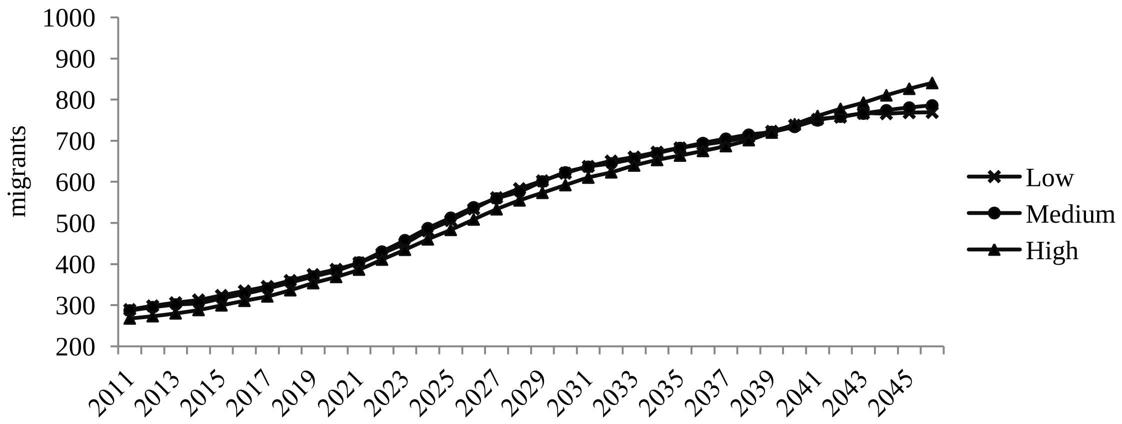

Figure 8.30: Annual ten-year average total migration flows modelled by the KNMI-RACMO2 rainfall scenario under low, medium and high variant demographic scenarios between 2011 and 2046.

Using the KNMI-RACMO2 rainfall scenario it can be seen from Figure 8.30 that, for much of the period 2011 to 2038, the high variant demographic scenario shows the lowest ten-year averaged modelled migration flow. Only from 2041 onwards does the high variant scenario show a clear increase in modelled migration beyond those modelled for the low and medium variant scenarios which show very similar ten-year averaged modelled migration flows throughout the period 2011 to 2046. By 2046 the difference between total high variant and total low variant scenario modelled migration is 72 migrants or 8.6% of the high variant scenario total. Figure 8.31 displays ten-year averaged demographic scenario modelled migration data for the MPI-M-REMO rainfall scenario.

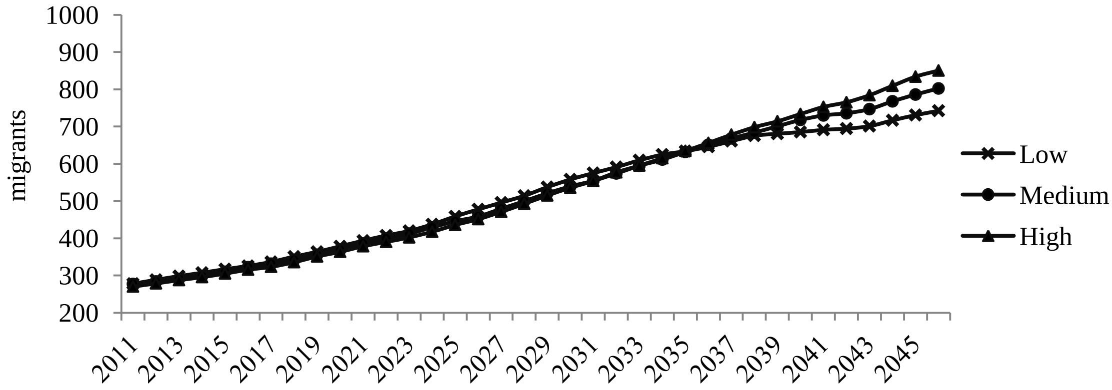

Figure 8.31: Annual ten-year average total migration flows modelled by the MPI-M-REMO rainfall scenario under low, medium and high variant demographic scenarios between 2011 and 2046.

It can be seen from Figure 8.31 that, using the MPI-M-REMO rainfall scenario, a clear distinction between the low, medium and high variant demographic versions is visible in the ten-year averaged modelled migration flows from 2040 onwards. By 2046 the difference between total high variant and total low variant scenario modelled migration is 108 migrants or 12.7% of the high variant scenario total.

By 2046 all nine rainfall scenarios tested (eight ENSEMBLES scenarios and the No Climate alternative) show the high variant demographic scenario as resulting in higher levels of ten-year averaged modelled migration than both low and medium variant alternatives. However, the duration of this higher level of modelled migration varies between rainfall scenarios. While the DMI-HIRHAM5 rainfall scenario results in a clearly higher ten-year averaged modelled migration flow for the high variant scenario from 2035 onwards, the same pattern only emerges from 2045 onwards under the ICTP-REGCM3 scenario. Furthermore, although numerous rainfall scenarios result in a clearly defined distinction between low, medium and high variant model versions, others show a far less defined order.

Ten-year averaged modelled migration flows under the No Climate and SMHIRCA scenarios show little contrast between low and medium variant results while the METNOHIRHAM scenario shows the low variant modelled migrant flow to be greater than that modelled by the medium variant scenario between 2042 and 2046. The proportional difference between high variant and low variant ten-year averaged migrant flows is seen from Figures 8.23 to 8.31 to range from 5.1% (43 migrants) of the high variant total under the ICTP-REGCM3 scenario to

12.7% (108 migrants) under the MPI-M-REMO scenario. Whatever the proportional range of the difference between low, medium and high variant demographic scenarios, it is evident from the above analysis that the impact of the different demographic parameters upon modelled migration only becomes clearly evident towards the end of the simulation period. As the different demographic scenarios only come into play from 2011 onwards it is proposed that a significant difference in modelled migration only occurs from around 2035 once the new generations of agents that result from different demographic parameters reach an active migration age.

8.9 Demographic Emergence

Analysis of the migration flows modelled under the three UN demographic scenarios in the previous section suggest that the impact of the different demographic components is only seen to emerge within approximately the last 10 years of the simulation period. In order to further investigate this phenomenon Figure 8.32 compares the ten-year averaged modelled migration flows generated by the nine rainfall scenarios. As a result of the emergence of differences between modelled flows only in the last ten years of the simulation runs, Figure 8.32 displays modelled differences between high and low demographic scenarios for the last ten years of the ten-year averaged simulation period (2037 to 2046).

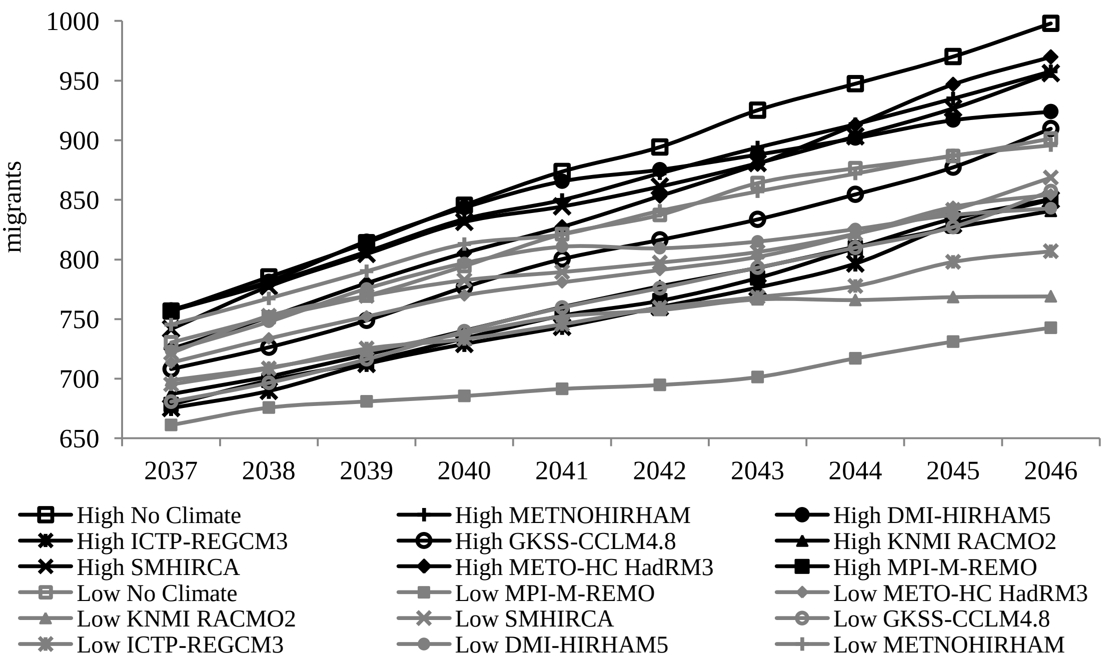

Figure 8.32: Annual ten-year averaged total migration flows modelled by the nine rainfall scenarios under low and high variant demographic scenarios between 2037 and 2046.

Figure 8.32 shows that ten-year averaged migration flows modelled by the low and high variant demographic scenarios show relatively little variation with the lowest 2046 ten-year averaged flow (Low MPI-M-REMO) being only 26% less than the highest (High No Climate). However, the high variant demographic scenario modelled migration for each rainfall scenario is seen to be consistently greater than that modelled under the low variant alternative for the same rainfall. Furthermore, high and low variant modelled migrant flows are seen to diverge throughout the period shown. In both low and high variant demographic scenarios the No Climate and METNOHIRHAM rainfall data lead to comparatively high modelled migration while the MPI-M-REMO and KNMI-RACMO2 rainfall data lead to comparatively low modelled migration flows.

Interestingly, both the rainfall scenarios that can be most clearly seen to lead to the lowest rates of modelled migration represent wetter scenarios across Burkina Faso. By contrast, the higher rates of modelled migration appear to result from either the modally average scenario created by No Climate or the generally dry conditions of METNOHIRHAM. Due to the lack of clarity with which differences between modelled migration flows can be deciphered in Figure 8.32, Figure 8.33 displays the ten-year averaged modelled migration resulting from low and high variant demographic scenarios using only the two rainfall extremes of KNMI-RACMO2 (wet) and SMHIRCA (dry) and that for No Climate (average).

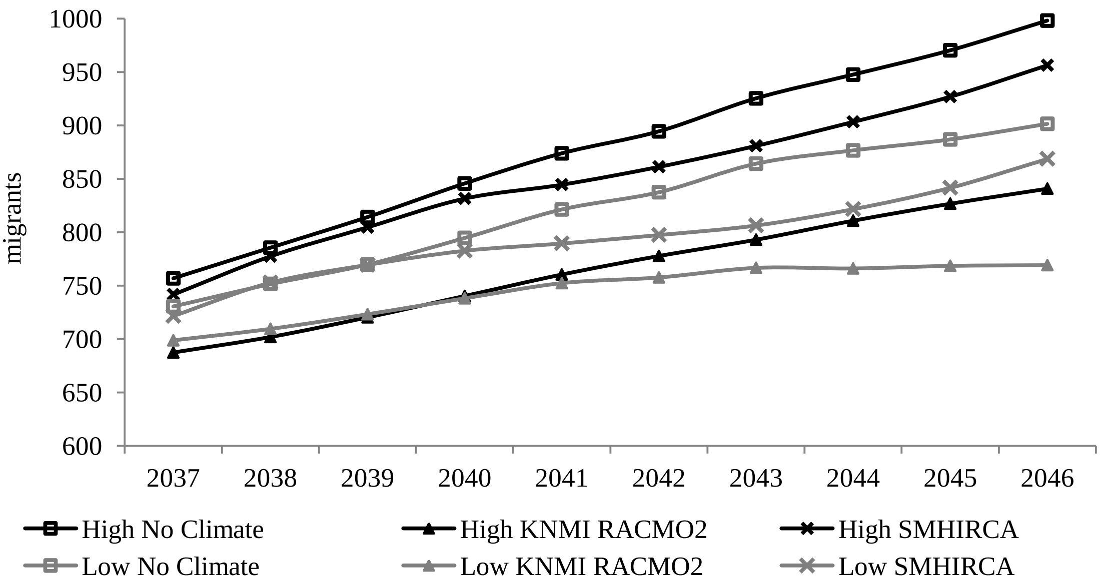

Figure 8.33: Annual ten-year averaged total migration flows modelled by the KNMI RACMO2, SMHIRCA and No Climate rainfall scenarios under low and high variant demographic scenarios between 2037 and 2046.

It can be more clearly seen from Figure 8.33 that, under both low and high variant demographic scenarios, the average rainfall scenario (No Climate) leads to the highest rate of modelled migration. While the lowest rate of modelled migration is seen to result from wet rainfall conditions (KNMI RACMO2), a dry rainfall scenario (SMHIRCA) results in a median level of modelled migration, below the average scenario but above that modelled by the wet. On the basis of Figures 8.31 and 8.32 it can be suggested that, when simulating forwards to 2050, the highest level of modelled migration is forecast to result from the overall average rainfall conditions that, in the case of No Climate, result from a modal average classification with a high level of inter-annual variation. However, a prolonged deviation away from an average scenario is seen to result in decreased modelled migration, with a greater decrease under a wet rainfall scenario.

These findings accord well with those presented in Chapter 7 where both dry and wet rainfall conditions were seen to result in reductions in total modelled migration compared to an average rainfall scenario. Such a finding can be loosely hypothesised to result from an interaction between individuals' need to migrate and their capacity to do so. A certain level of migration may occur under average rainfall conditions with individuals balancing both their need to undertake migration and their ability to do so under relatively normal conditions. A consistent reduction in rainfall away from this norm may reduce some peoples' capacity to invest in migration despite their increased desire to do so. By contrast, a consistent increase in rainfall may encourage many people to not migrate as, although they have the capacity to invest in migration, they may not have the need with conditions at their home location providing sufficient income. Although the hypothesised interaction between the need to migrate and the capacity to do so under changes in rainfall variability accord to some extent with previous findings relating to trapped populations (Black et al., 2011a), no direct support for this finding was identified from the focus group interviews conducted in Burkina Faso. In order to further understand the differences between modelled migrant flows Table 8.6 displays the different ten-year averaged total numbers of migrants and their proportional differences resulting from each combination of dry, average or wet rainfall scenario and low, medium or high demographic scenario.

Rainfall Dataset:	Low Variant	Medium Variant	High Variant
No Climate (Average)	901 (**100**%) (*94.25%*)	928 (**100**%) (*97.07%*)	998 (**100**%) (*100%*)
SMHIRCA (Dry)	869 (**96.37**%) (*87.07%*)	902 (**97.21**%) (*90.38%*)	956 (**95.81**%) (*100%*)
KNMI RACMO2 (Wet)	769 (**85.32**%) (*91.44%*)	786 (**84.66**%) (*93.46%*)	841 (**84.24**%) (*100%*)

Table 8.6: Comparison of 2046 ten-year averaged total migration flows modelled from three demographic scenarios and average, dry and wet rainfall scenarios. Actual migrant numbers shown along with proportion of maximum migration modelled under each demographic scenario (**x**%) and proportion of rainfall scenario maximum (*y*%), displayed in *italics*.

By 2046, ten-year averaged modelled migration flows under low, medium or high variant demographic scenarios show a hierarchy where the average rainfall scenario results in the highest modelled migration flow and the wet scenario results in the lowest. On the basis of the information displayed in Table 8.6 it can be seen by comparing the values shown in *italics* that, under the low variant demographic scenario, use of the wet scenario rainfall data (KNMI RACMO2) results in a modelled migrant flow that is 91.44% of that modelled by the No Climate scenario, a decrease of 8.66% and the smallest proportional change between rainfall scenarios. By contrast, the greatest difference between average and wet scenario modelled migration occurs under the high variant demographic scenario where the migrant flow modelled under the wet scenario is 15.76% less than is modelled under the average scenario. In order to present the data displayed in Table 8.6 in a graphical format Figure 8.34 displays the proportional difference between dry, average and wet scenario modelled 2046 ten-year averaged migration under low, medium and high variant levels of demographic change.

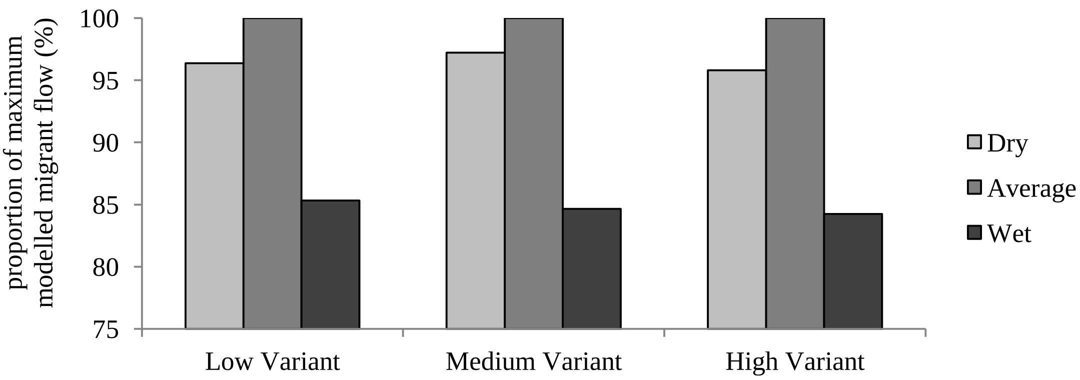

Figure 8.34: Proportional representation of the difference between 2046 ten-year averaged modelled migration under low, medium and high variant demographic scenarios using dry, average and wet rainfall conditions.

While the proportional difference between migrant flows modelled under average and wet scenarios is seen from Table 8.6 and Figure 8.34 to decrease with increasing demographic change, the relationship seen between average and dry modelled flows is not so consistent. The proportional difference between dry and average modelled flows is still seen to be lowest under the high demographic change scenario. However, the difference is seen to be greatest under the medium variant demographic scenario rather than the low. As such, the pattern of decreasing proportional change in modelled flows under increasing demographic change is not entirely replicated.

Earlier analysis has suggested the emergence of greater changes in modelled migrant flux under different rainfall scenarios with greater demographic change. Figure 8.34 shows that the greatest percentage change away from the No Climate modelled migrant flow occurs for both dry and wet scenarios under high variant demographic change. However, although a slight linear increase in difference can be seen from low to high variant scenarios using the wet rainfall scenario, the same cannot be said for the dry. Although a relatively clear and constant relationship between the migration flows modelled under an average and consistently dry or wet rainfall scenario have been identified, it is important to consider the migrant flows modelled by the rainfall scenarios listed in Table 8.3 that did not provide such consistent rainfall. In order to further explore the potential for the emergence of the increasing influence of changes in rainfall upon modelled migration with increased demographic change, Figure 8.35 displays the change in modelled migrant numbers resulting from the eight ENSEMBLES scenarios when compared to the No Climate standard under low, medium and high variant demographic conditions. The dry and wet scenarios of SMHIRCA and KNMI-RACMO2, respectively, are indicated.

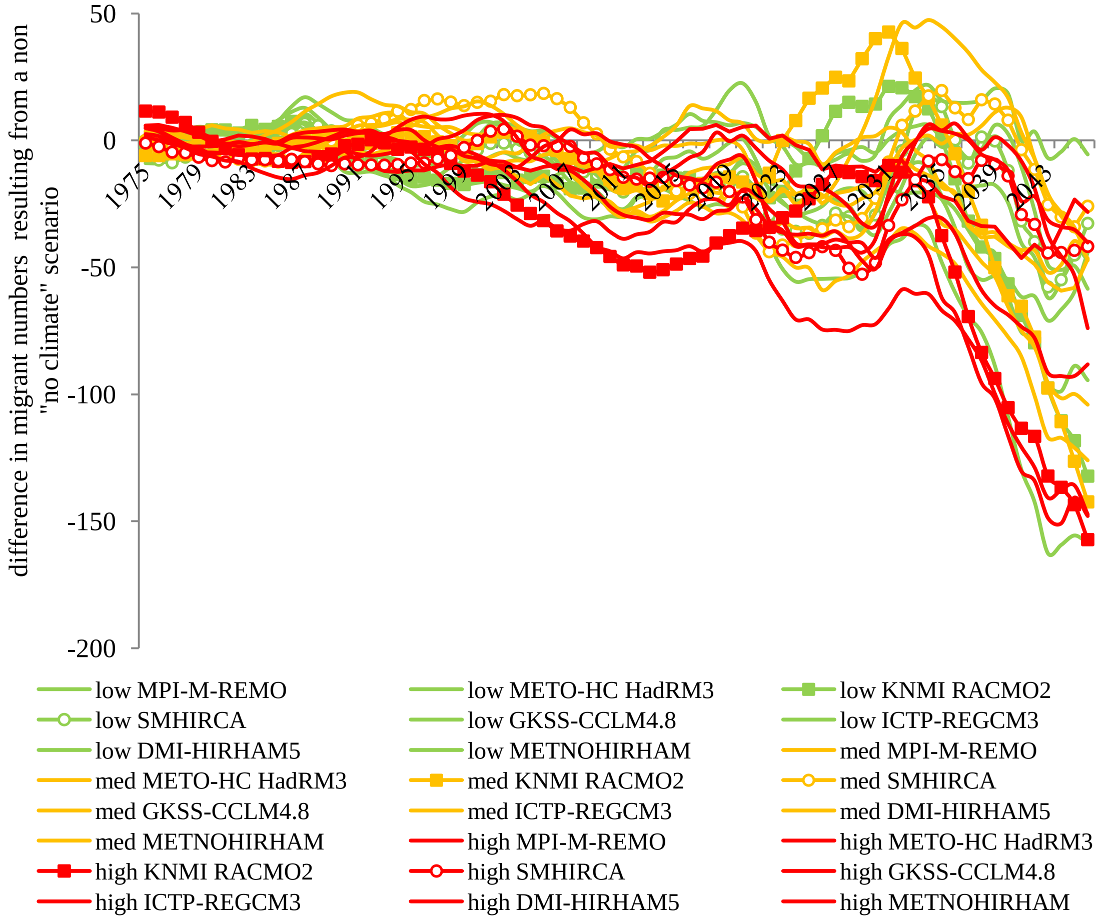

Figure 8.35: 10 year averaged differences between No Climate and ENSEMBLES rainfall scenarios for low, medium and high variant demographic scenarios.

The different combinations of demographic and rainfall scenarios can be seen in Figure 8.35 as displaying a general pattern of increased difference to the No Climate run with increased demographic change. Generally speaking, the low variant demographic scenario (green) model data show less deviation away from zero than the medium (orange) which, in turn, show less deviation than the high (red). Despite this general trend, exceptions are evident in the data. It can be seen for example that the high demographic scenario model outputs show generally the greatest negative change compared with their No Climate model run but at no point show the greatest positive change. The single greatest negative change modelled by the end of the simulation period is also seen from the low variant demographic scenario version of the MPI-M-REMO model. Although a pattern can be seen to emerge in Figure 8.35 from a direct comparison of the different migration flows modelled under the three demographic scenarios, comparing actual numbers of modelled migrants could be anticipated to inherently show greater differences between rainfall scenarios due to the greater numbers of migrants modelled under high demographic change scenarios. As a result, Figure 8.36 displays the proportional change in modelled migrant numbers resulting from the eight ENSEMBLES scenarios when compared to the No Climate standard under low, medium and high variant demographic conditions. The proportional difference is calculated as the actual number of migrants in a year divided by the relevant model population that year.

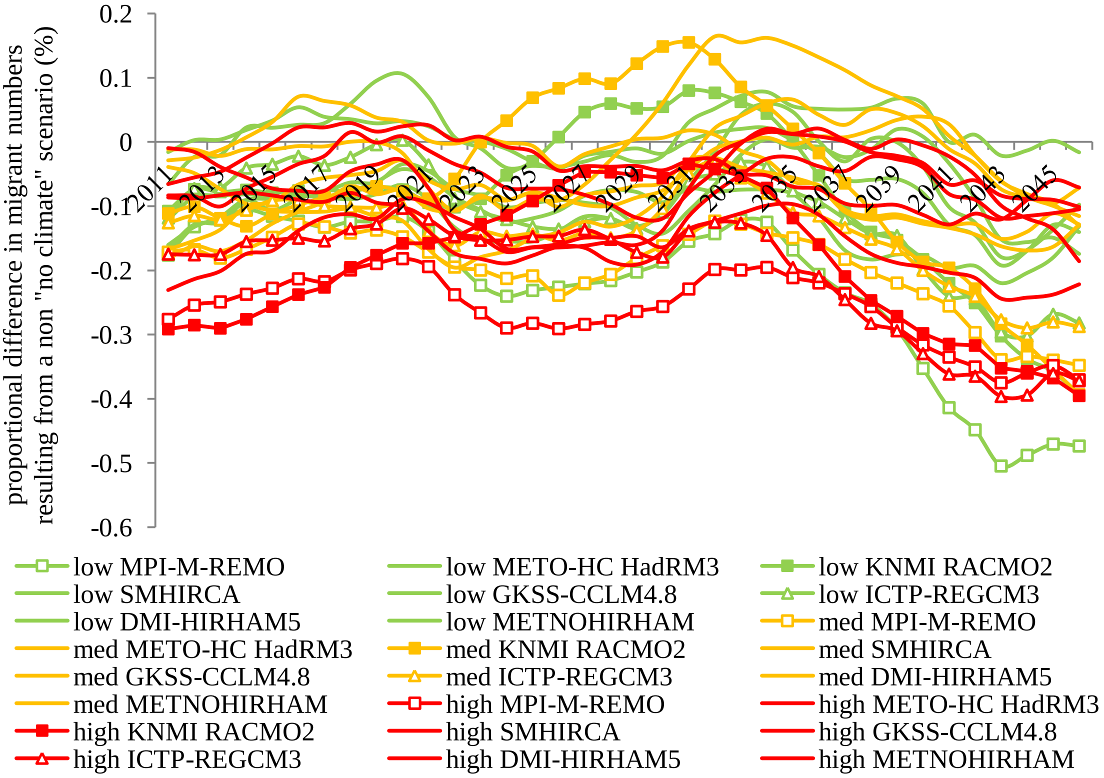

Figure 8.36: 10 year averaged proportional differences between No Climate and ENSEMBLES rainfall scenarios low, medium and high variant demographic scenarios.

It can be seen from Figure 8.36 that the general trend of emerging differences between the No Climate and ENSEMBLES rainfall scenario model runs is reduced when considered proportionally over the period 2011 to 2046. Like Figure 8.35, the greater differences shown under the high demographic scenario only appear to apply to negative change, or reductions in migrant numbers when compared to the No Climate model. Furthermore, the anomalously high level of change seen under the MPI-M-REMO low demographic scenario is accentuated by the proportional approach. Despite this, the general pattern of increasing difference under higher demographic change remains evident with the greatest consistent difference between No Climate and the majority of rainfall scenarios occurring with the larger modelled populations of agents occurring under high demographic change. Within the last 10 years of the simulation period displayed in Figure 8.36, previously identified to be the period during which differences between low, medium and high variant demographic scenarios emerge in the modelled migration flows, the clearly greater degree negative change of three high variant scenarios (ICTP-REGCM3, MPI-M-REMO and KNMI-RACMO2) can be seen. The medium variant differences for these three scenarios can then be seen to be marginally smaller negative changes while two of the three low variant changes can be seen to follow this ranking and are smaller than both medium and high. The exception to this is the greatest negative change observed towards the end of the simulation period, that for the low variant MPI-M-REMO scenario.

Increased demographic change (higher increases in population size) can therefore be seen from Figure 8.35 to broadly result in greater actual differences between migrant flows simulated by the AMARC model in a number of cases. However, this relationship is not entirely consistent across the rainfall scenarios and appears not to apply to the few increases in model flows over those seen from the No Climate scenario. Although the pattern of increased difference with increased demographic change is not as clear when considered as a proportional difference (Figure 8.36), the general trend of the relationship appears to remain. As such, the ABM presented by this thesis appears to simulate a slight and inconsistent increase in the influence of rainfall upon modelled migration with increased demographic change.

8.10 Modelled Migrant Origins

It has been identified that, across the demographic scenarios, average rainfall is seen to result in consistently high rates of total modelled migration with dry, and more notably wet scenarios, resulting in reduced flows. This is in direct contrast to the findings of a superficial analysis of the sum probability of all agent classes migrating under dry, average and wet conditions undertaken in Chapter 5. As seen in Figure 5.12, wet conditions were anticipated, on the basis of such superficial consideration of the propensity of agent classes to migrate, to result in the greatest flow of migrants. However, as a result of the agent-based modelling approach adopted here, the highest number of future migrants are simulated as occurring under average rainfall conditions with the wet future scenario showing a considerable decrease in modelled migrant numbers. In order to further investigate the nature of the modelled flows that make up the overall trend seen the following section explores the origins of migrants modelled by each of the nine rainfall scenarios under conditions of high variant demographic change. Figure 8.37 displays the ten-year averaged numbers of migrants modelled as leaving Ouagadougou under each of the nine rainfall scenarios between 2011 and 2046.

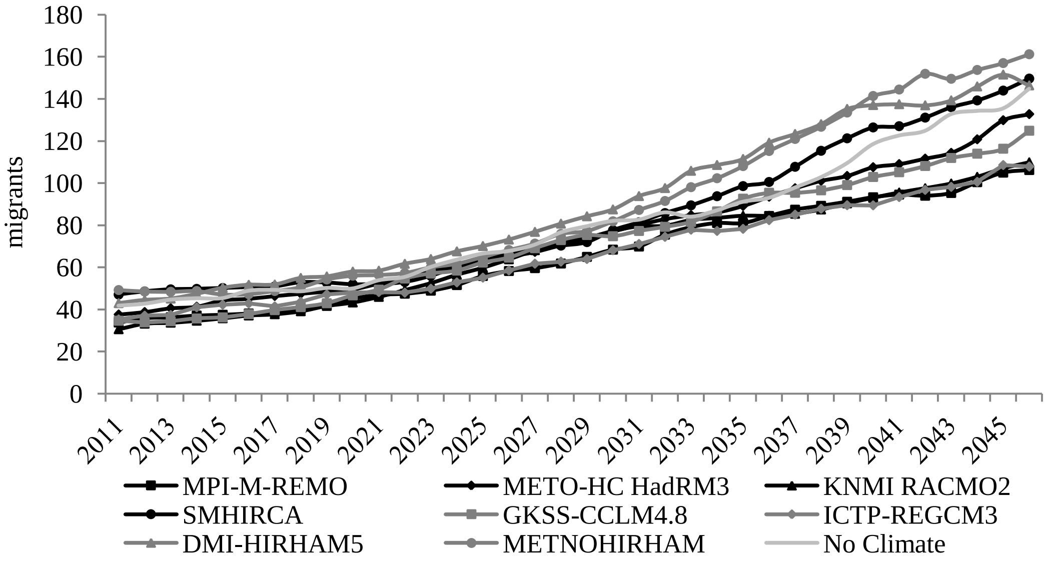

Figure 8.37: Ten-year averaged numbers of migrants modelled as leaving Ouagadougou under the nine rainfall scenarios between 2011 and 2046.

It can be seen from Figure 8.37 that, towards the end of the 35 year period from 2011 to 2046, three rainfall scenarios (SMHIRCA, DMI-HIRHAM5 and METNOHIRHAM) produce clearly higher modelled departures from Ouagadougou. Two further scenarios (METO-HC-HadRM3 and GKSS-CCLM4.8) show an intermediate level of modelled migration similar to that of No Climate while the remaining three (MPI-M-REMO, KNMI-RACMO2 and ICTP-REGCM3) show a comparably low level of migration from the zone. Each of the three scenarios that result in the greatest modelled flow of migrants from Ouagadougou show dry or average-dry conditions in the zone towards 2046. Interestingly however, it is the average-dry conditions of METNOHIRHAM and DMI-HIRHAM5 that result in greater modelled migration than those modelled under the more consistently dry conditions of SMHIRCA.

The two rainfall scenarios that result in intermediate levels of modelled migration meanwhile show average-wet rainfall conditions in Ouagadougou with a comparable level of migration modelled by the inherently average No Climate scenario. The three scenarios that result in lower levels of modelled migration from Ouagadougou show average-wet or wet conditions within the zone. As such, it appears that the highest levels of modelled out-migration from Ouagadougou occur as a result of average-dry or dry rainfall conditions while the lowest levels result from average-wet or wet conditions. This fits with the general trend of greater total migration flows being simulated under dry conditions compared to wet but shows a notable difference with more consistently average rainfall scenarios showing an intermediate level of modelled out-migration.

Furthermore, the results presented in Figure 8.37 are in direct contrast to the outcome that would be anticipated from a direct interpretation of the sum probability of any individual migrating from Ouagadougou under dry, average and wet rainfall conditions. As seen in Figure 5.11, a simplistic statistical analysis would anticipate the greatest level of migration to occur under wet conditions which are seen to result in the lowest level of modelled migration from the zone. Figure 8.38 displays the ten-year averaged numbers of migrants modelled as leaving Bobo Dioulasso under each of the nine rainfall scenarios.

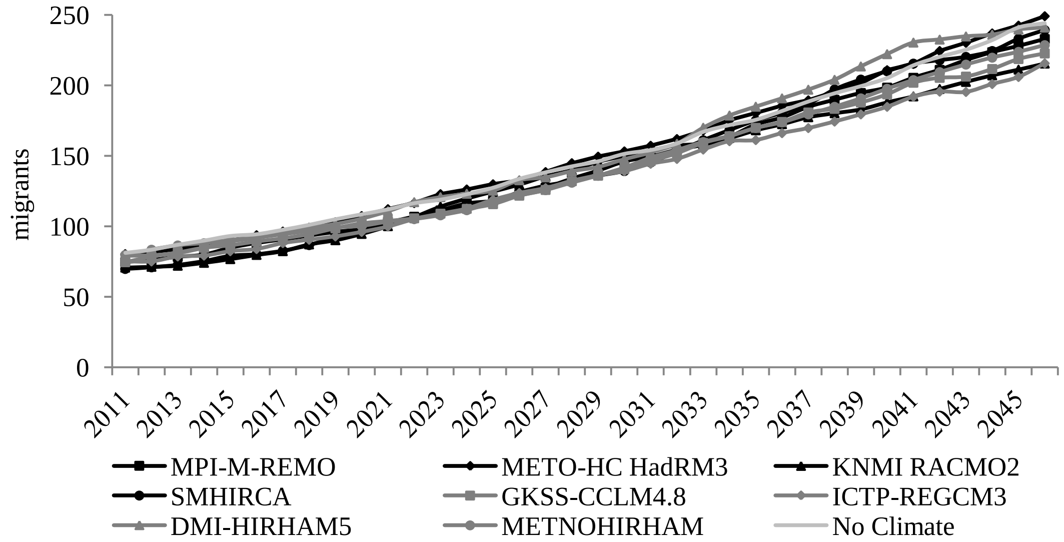

Figure 8.38: Ten-year averaged numbers of migrants modelled as leaving Bobo Dioulasso under the nine rainfall scenarios between 2011 and 2046.

While the minimum modelled 2046 migration from Ouagadougou in Figure 8.37 is 66% of the maximum, the equivalent value for Bobo Dioulasso seen in Figure 8.38 is 87%, making the minimum modelled flow only 13% less than the maximum. This smaller range of modelled migration statistics suggests a more marginal impact of the different rainfall scenarios upon modelled migration in Bobo Dioulasso. As a result, the clear difference evident in migration flows modelled from Ouagadougou is not visible within the data for Bobo Dioulasso. The two rainfall scenarios that result in the greatest modelled flow of migrants from the zone (DMI-HIRHAM5 and METO-HC HadRM3) show average or average-wet rainfall conditions in Bobo Dioulasso. However, the two rainfall scenarios that result in the lowest modelled flow of migrants from the zone (KNMI-RACMO2 and ICTP-REGCM3) also show average or wet conditions in Bobo Dioulasso. Both of the rainfall scenarios that predict dry conditions across Bobo Dioulasso (SMHIRCA and METNOHIRHAM) are seen in Figure 8.38 to result in mid-range modelled departures from the zone. As a result, no difference between modelled migration from Bobo Dioulasso is clearly apparent as different combinations of average conditions in the zone appear to result in both maximum and minimum levels of modelled migration. Despite the mixed nature of modelled migration from Bobo Dioulasso, these findings show some level of agreement with those that would be anticipated from a superficial analysis of the sum probability of all classes of agent migrating under different rainfall conditions. Such analysis, presented in Figure 5.11 suggested that the highest level of migration would be seen under average rainfall, with a marked reduction in migration occurring under dry conditions. Figure 8.39 displays the ten-year averaged numbers of migrants modelled as leaving Sahel under each of the nine rainfall scenarios.

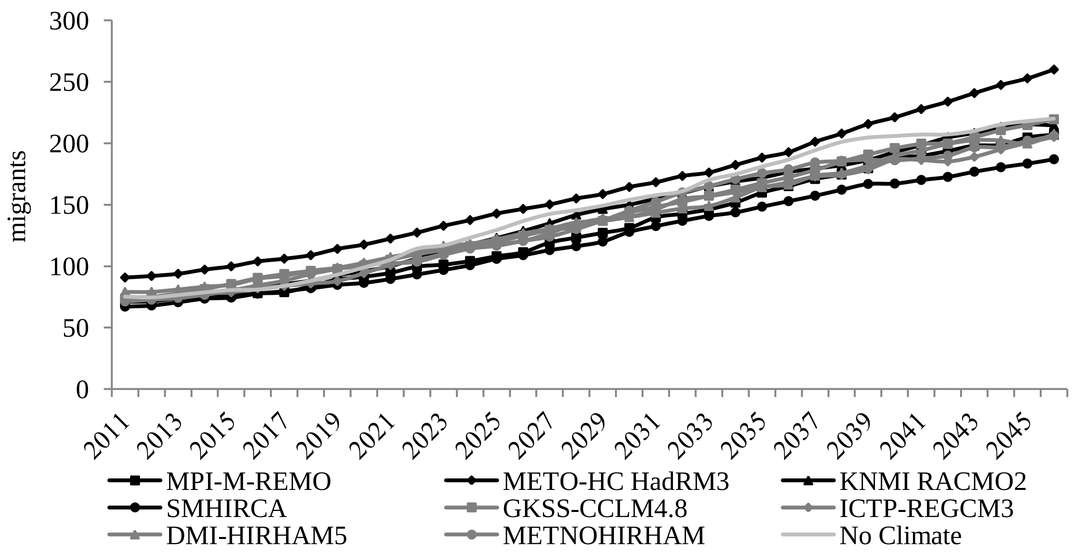

Figure 8.39: Ten-year averaged numbers of migrants modelled as leaving Sahel under the nine rainfall scenarios between 2011 and 2046.

With the minimum number of ten-year averaged migrants modelled as leaving Sahel being 72% of the maximum, a range close to that seen in Ouagadougou is evident. This suggests the presence of a clearer relationship between rainfall and modelled migration from the zone than that seen for Bobo Dioulasso. It can be seen from Figure 8.39 that a considerably greater level of modelled migration from Sahel results from the METO-HC HadRM3 rainfall scenario that predicts wet conditions for the zone. By contrast, a considerably lower level of modelled migration is simulated to result from the SMHIRCA scenario that predicts dry conditions for the Sahel. The remaining scenarios, including No Climate, result in levels of modelled migration that fall between these two distinct extremes. Interestingly, although most of these scenarios predict some combination of average rainfall conditions, two scenarios that are classed as having either wet (KNMI-RACMO2) or dry (DMI-HIRHAM5) conditions also fall within the mid range of modelled departures from Sahel. In general however, it appears that wet conditions result in increased modelled migration from Sahel, dry conditions result in decreased modelled migration, while average conditions result in intermediate modelled flows. Such a finding is in contrast to those anticipated from a superficial level of sum probability analysis. As seen in Figure 5.11 such statistical representation of migration probabilities from Sahel suggest a minimal distinction in migration resulting from rainfall with average conditions generating the greatest anticipated departures from Sahel. Figure 8.40 displays the ten-year averaged numbers of migrants modelled as leaving Centre under each of the nine rainfall scenarios.

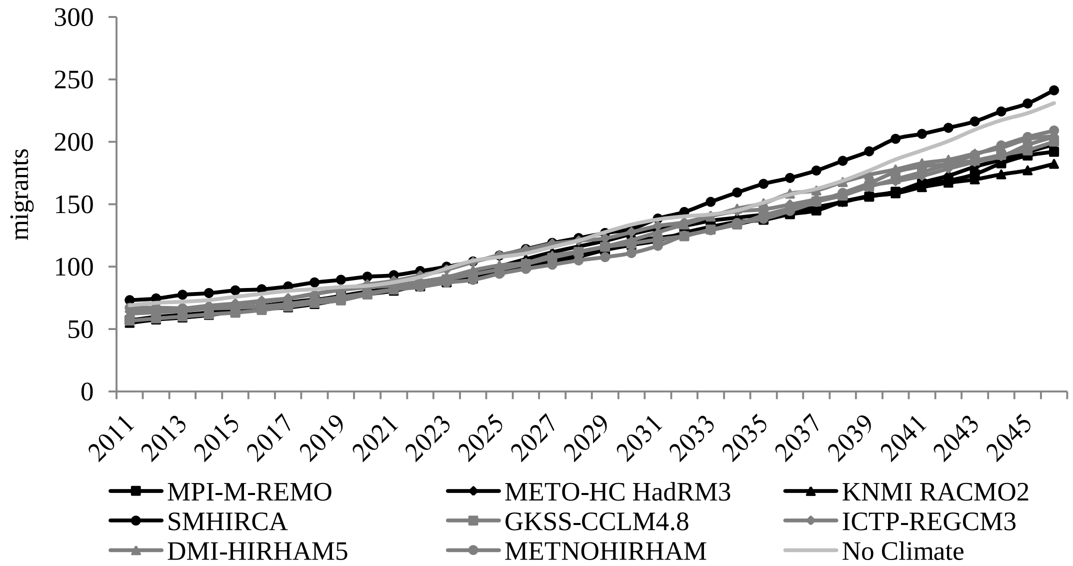

Figure 8.40: Ten-year averaged numbers of migrants modelled as leaving Centre under the nine rainfall scenarios between 2011 and 2046.

With the lowest 2046 modelled migration from Centre being 76% of the highest, some relationship between modelled migration and rainfall scenario is anticipated. It can be clearly seen from Figure 8.40 that the SMHIRCA rainfall scenario results in higher levels of modelled migration from Centre than all other scenarios throughout the majority of the period 2011 to 2046. The dry rainfall conditions forecast for the Centre zone by the scenario appear therefore to result in increased modelled migrant flows. The next highest modelled flow is seen to result from the modally average No Climate scenario. The rainfall scenario under which the lowest rate of migration from Centre is modelled is the wet KNMI-RACMO2 scenario. One other scenario (METO-HC HadRM3) forecasts wet conditions for Centre and shows a relatively low level of modelled migration. No scenario other than SMHIRCA forecasts a dry scenario for Centre. It appears therefore that dry conditions result in the highest level of modelled migration from Centre with average conditions resulting in mid-level migrant flows and wet conditions reducing modelled flows further. This again contrasts with the sum probability analysis presented in Figure 5.11 where dry conditions are, as a result of superficial analysis, anticipated to result in the lowest level of migration with the highest probability of departure seen under wet conditions. Figure 8.41 displays the ten-year averaged numbers of migrants modelled as leaving Southwest under each of the nine rainfall scenarios.

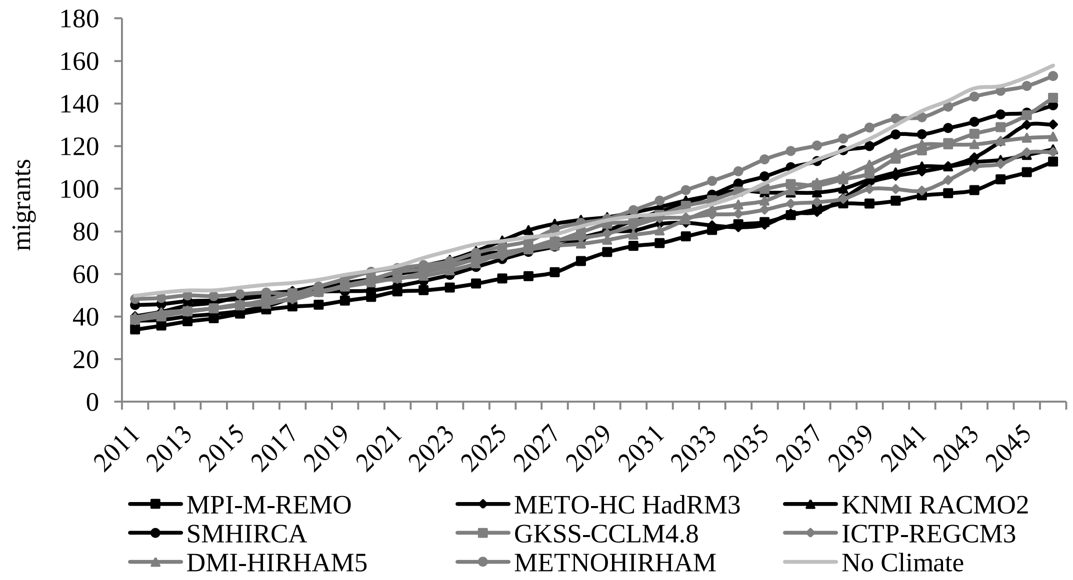

Figure 8.41: Ten-year averaged numbers of migrants modelled as leaving Southwest under the nine rainfall scenarios between 2011 and 2046.

It can be seen from Figure 8.41 that by 2046 the highest ten-year averaged modelled migration flow from Southwest results from the average conditions of the No Climate scenario. The second highest level of migration is modelled as occurring under the dry conditions resulting from the METNOHIRHAM scenario. With the minimum 2046 ten-year averaged migration flow being 71% of the maximum (No Climate), some relationship between rainfall and migration appears evident. The lowest modelled flow of migrants from Southwest is seen to correspond with the wet conditions generated by the MPI-M-REMO scenario. The only other rainfall scenario that predicts wet conditions across the Southwest, KNMI-RACMO2, shows a comparably low level of modelled migration. It appears therefore that dry conditions in the Southwest zone can be described as causing increased migrant flows from that location with wet conditions resulting in reduced departures. Average conditions meanwhile can be seen to result in modelled migrant flows between these two relative extremes. Such a finding corresponds well with that which would be anticipated from the analysis of the sum of all agent classes migrating under dry, average and wet rainfall conditions. As seen in Figure 5.11, such analysis suggests a corresponding relationship of increased migration under dry conditions with reduced departures under wet conditions.

The above analysis reveals that different rainfall conditions appear to result in different levels of modelled migrant departures from each of the five zones. While drier rainfall conditions result in increased migrant departures from Ouagadougou, Centre and Southwest the same conditions are seen to correspond with decreased migration from Sahel. Conversely, wetter conditions are seen to increase modelled migration from Sahel but correspond with decreased migration from Ouagadougou, Centre and Southwest. The clear difference in relationships between rainfall and migration seen in Sahel compared to Ouagadougou, Centre and Southwest, suggests the existence of the unique situation of Sahel. Focus group interview respondents in Sahel appeared to both identify differently with their home location and clearly faced harsher environmental conditions induced by the low annual rainfall. One explanation for the reduction in modelled departures from Sahel under dry conditions, compared to the increase modelled in other zones, may be the relative poverty evident in Sahel (as identified in Figure 5.2 by the large percentage of the population of Sahel having zero livestock assets) causing individuals to be more easily "trapped" by deteriorating environmental conditions and their desire to migrate being outweighed by their reduced capacity to do so.

Unlike the other zones, no clear relationship appears evident between rainfall conditions and modelled migration from Bobo Dioulasso despite the zone experiencing largely the same rainfall trends as the surrounding Southwest zone. Interestingly, only in the case of Southwest does the AMARC model simulate a similar relationship between departing migrants and rainfall as that anticipated from the superficial sum probability analysis performed in Chapter 5. The relative trends between rainfall trends and modelled migrant departures from each model zone are summarised in Table 8.7 in terms of the impact of drier and wetter conditions on the flow of migrants modelled under average rainfall.

Rainfall:	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest
Drier	Increase	Average	Decrease	Increase	Increase
Wetter	Decrease	Average	Increase	Decrease	Decrease

Table 8.7: Relative change in modelled migration from each zone away from the level seen under average rainfall conditions.

The modelled departures of migrants from each model zone are seen to show varied responses to the range of rainfall scenarios tested. It appears that the overall trend of greatest modelled migration under average rainfall conditions is not directly replicated in any one zone, except perhaps Bobo Dioulasso where little variation between scenarios was modelled. As a result of the zone-level trends seen it could be anticipated that the greatest rate of total modelled migration might occur under dry conditions as a result of the apparent increase in modelled migration from Ouagadougou, Centre and Southwest seen under such conditions. However, the fact that the greatest number of migrants are generally seen to originate in Sahel where modelled migration decreases considerably under dry conditions suggests a more complex interaction between zone- and total-level flows. Furthermore, average rainfall conditions are seen to result in consistently average to high modelled flows across the five zones. It is suggested that the greater total modelled flows seen under average conditions in earlier analysis can be attributed to the consistent nature of average rainfall modelled migration compared with the relative extremes witnessed under dry and wet scenarios.

8.11 Modelled Migrant Destinations

Further insight into the impact of rainfall upon modelled migrant flows can be gleaned from analysis of the destinations of migrants once they leave their zones of origin. Figure 8.42 displays the ten-year averaged numbers of migrants modelled as arriving in Ouagadougou between 2011 and 2046.

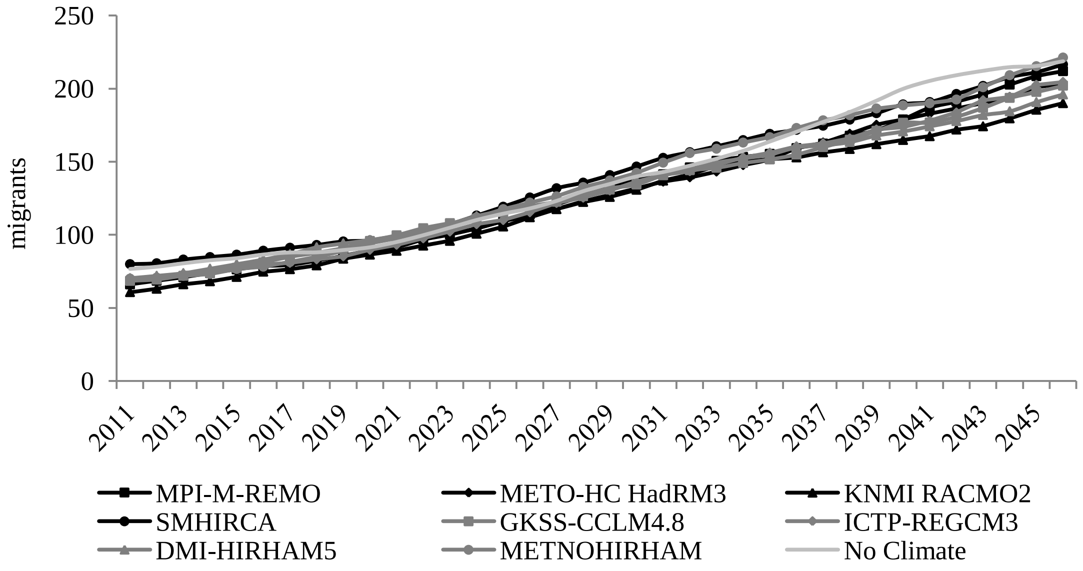

Figure 8.42: Ten-year averaged numbers of migrants modelled as arriving in Ouagadougou under the nine rainfall scenarios between 2011 and 2046.

It can be seen from Figure 8.42 that the range of migrant numbers modelled as arriving in Ouagadougou shows little variation between rainfall scenarios over the period 2011 to 2046. The minimum 2046 modelled migrant arrival rate is 86% of the maximum resulting in a variation of only 14%. Towards the end of the simulation period the No Climate rainfall scenario is seen to produce high numbers of arrivals in the zone. However, the most consistently high modelled arrivals are seen to result from the consistently dry SMHIRCA scenario. By contrast, low arrivals to Ouagadougou are modelled as occurring under the wet KNMI-RACMO2 scenario between 2011 and 2046. Despite these clear differences between dry and wet scenarios, the extent of the variation in total-flow terms is relatively small. Figure 8.43 displays the ten-year averaged numbers of migrants modelled as arriving in Bobo Dioulasso between 2011 and 2046.

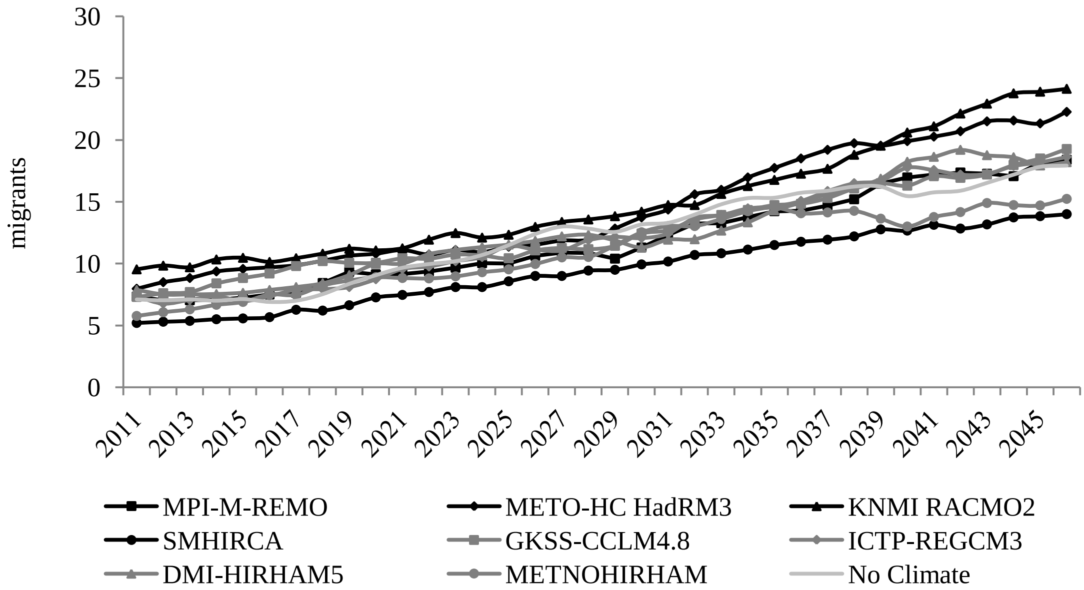

Figure 8.43: Ten-year averaged numbers of migrants modelled as arriving in Bobo Dioulasso under the nine rainfall scenarios between 2011 and 2046.

In direct contrast to the arrivals modelled for Ouagadougou, it can be seen from Figure 8.43 that the wet rainfall scenario (KNMI-RACMO2) results in consistently higher modelled arrivals in Bobo Dioulasso. Furthermore, the dry rainfall scenario (SMHIRCA) is seen to result in consistently lower modelled arrivals to the zone. The modally average No Climate scenario meanwhile results in a median level of modelled arrivals. Although a clear distinction between dry, average and wet scenario modelled arrivals to Bobo Dioulasso can be seen, the actual numbers of migrants relocating to this destination zone are relatively small. While the difference between the ten-year averaged maximum and minimum modelled flows in 2046 is only 10 migrants, this represents a proportional reduction of 42%. Figure 8.44 displays the ten-year averaged numbers of migrants modelled as arriving in Sahel between 2011 and 2046.

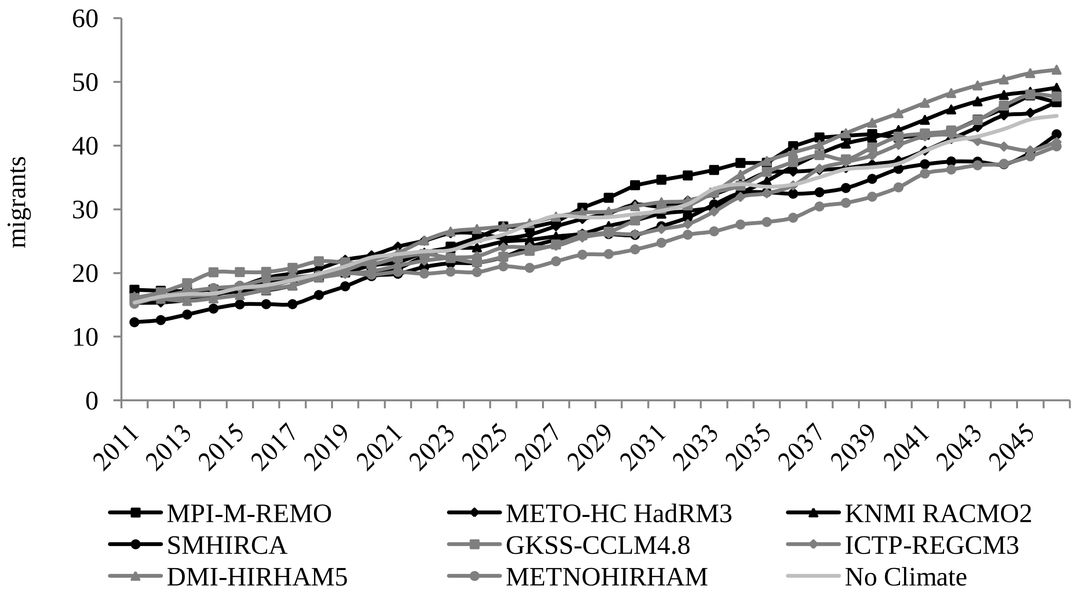

Figure 8.44: Ten-year averaged numbers of migrants modelled as arriving in Sahel under the nine rainfall scenarios between 2011 and 2046.

With a proportional difference of 23% and an actual difference between the 2046 modelled maximum and minimum of 12 migrants, arrivals in Sahel are seen to be less varied than those of Bobo Dioulasso but, with double the number of arriving migrants, may be deemed potentially more significant. It can be seen from Figure 8.44 that, towards the end of the simulation period, the DMI-HIRHAM5 rainfall scenario results in the largest number of modelled arrivals to Sahel. Resulting in average-dry conditions in Ouagadougou, average-wet conditions in Bobo Dioulasso, dry conditions in Sahel, average conditions in Centre and wet in Southwest, the DMI-HIRHAM5 rainfall scenario has been generally classed as giving an average rainfall scenario with considerable inter-annual and inter-zonal variability. Contrastingly low modelled arrivals to Sahel result from the METNOHIRHAM scenario that produces an average-dry scenario across Burkina Faso. In agreement with the low modelled arrival rate modelled under this average-dry scenario, the more extreme dry conditions of the SMHIRCA scenario result in similarly low arrivals, particularly towards the end of the simulation period. Conversely, the wet conditions resulting from the KNMI-RACMO2 scenario result in the second highest level of modelled arrivals to Sahel with the average conditions of the No Climate scenario again resulting in a median level of Sahel arrivals. Figure 8.45 displays the ten-year averaged numbers of migrants modelled as arriving in Centre between 2011 and 2046.

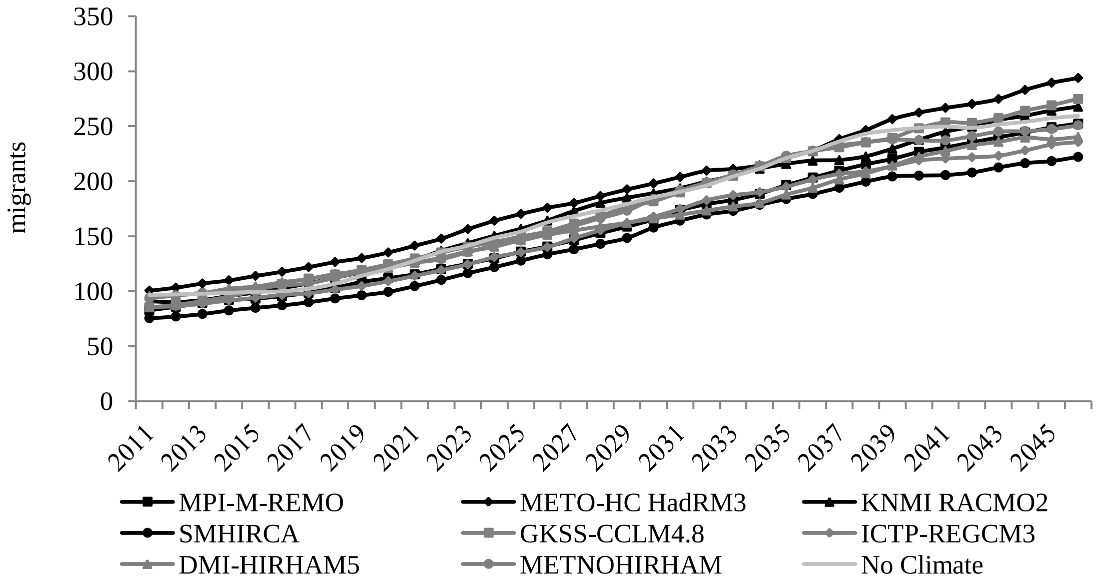

Figure 8.45: Ten-year averaged numbers of migrants modelled as arriving in Centre under the nine rainfall scenarios between 2011 and 2046.

With almost three hundred ten-year averaged migrants being modelled as arriving in Centre by some scenarios by 2046, the numbers of migrants simulated as arriving in this zone are considerably higher than those arriving in both Bobo Dioulasso and Sahel. Furthermore, the proportional difference between maximum and minimum 2046 averaged model flows of 24% suggests some relationship to rainfall. While the greatest modelled arrivals to Centre are seen in Figure 8.45 to result from the average-wet conditions of the METO-HC HadRM3 scenario, the lowest modelled arrivals to the zone are seen to consistently result from the dry conditions of the SMHIRCA scenario. The average conditions of the No Climate scenario are seen to result in moderately high levels of modelled arrivals to Centre, just below those modelled for the wet KNMI-RACMO2 scenario. Figure 8.52 displays the ten-year averaged numbers of migrants modelled as arriving in Southwest between 2011 and 2046.

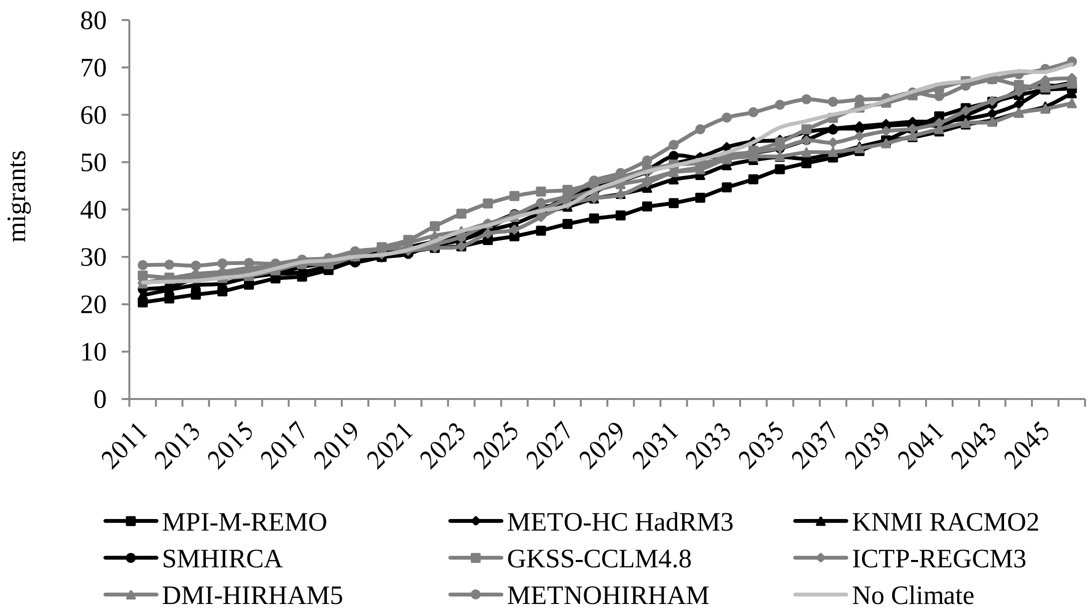

Figure 8.46: Ten-year averaged numbers of migrants modelled as arriving in Southwest under the nine rainfall scenarios between 2011 and 2046.

Towards the end of the simulation period displayed in Figure 8.46 the highest level of modelled arrivals to Southwest can be seen to result from the average, average-dry or average-wet rainfall conditions of the No Climate, METNOHIRHAM or GKSS-CCLM4.8 scenarios. Lower arrivals to Southwest are modelled to result from the mixed average rainfall conditions of the MPI-M-REMO and DMI-HIRHAM5 scenarios. Meanwhile, the more extreme dry and wet conditions produced by the SMHIRCA and KNMI-RACMO2 scenarios are seen in Figure 8.46 to result in median levels of modelled arrivals to Southwest. However, with relatively few migrants modelled to be arriving in Southwest under any rainfall scenario and only a 12% proportional difference between maximum and minimum modelled flows only a relatively small variation in modelled arrivals to Southwest suggests a minimal relationship with rainfall. Figure 8.47 displays the ten-year averaged numbers of migrants modelled as arriving in International between 2011 and 2046.

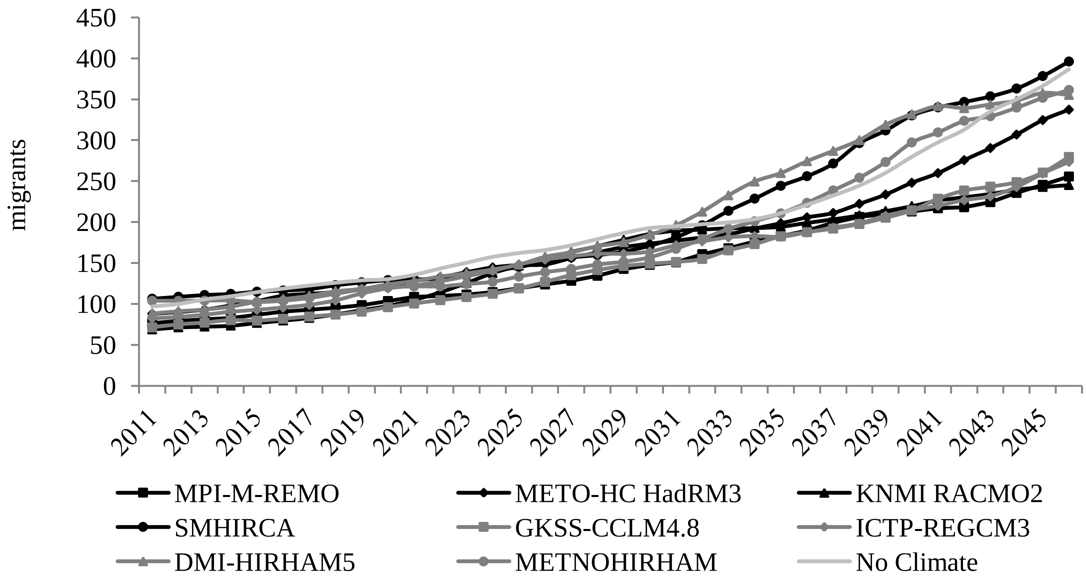

Figure 8.47: Ten-year averaged numbers of migrants modelled as arriving in International under the nine rainfall scenarios between 2011 and 2046.

With almost four hundred migrants being modelled as arriving in International under some scenarios by 2046, modelled flows to the zone that represents all destinations outside Burkina Faso are larger than any of the internal modelled migrations. Furthermore, the difference between ten-year averaged maximum and minimum 2046 modelled arrivals is 151 migrants or 38% indicating a strong influence of rainfall upon modelled migration to International. It can be seen from Figure 8.47 that the most consistently high modelled arrivals to International coincide with either the widespread dry conditions of the SMHIRCA scenario or the average conditions with inter-annual and inter-zonal variation seen to result from the DMI-HIRHAM5 scenario. High levels of modelled arrivals to International also result from the average-dry or average-wet conditions of the METNOHIRHAM or METO-HC HadRM3 scenarios and the modally average conditions of the No Climate scenario. Lower levels of modelled arrivals to International can be seen in Figure 8.47 to result from the remaining rainfall scenarios, including the consistently wet conditions of the KNMI-RACMO2 scenario. It loosely appears therefore that, while drier conditions across Burkina Faso may be identified as resulting in increased migration to international destinations, wetter conditions may be seen to result in reduced flows to such locations. As a result of a superficial analysis of the sum probability of all agent classes migrating conducted in Chapter 5, it would have been anticipated from Figure 5.13 that the greatest level of international migration would be modelled under average rainfall with dry and wet conditions both resulting in decreased flows. Although this pattern is retained to a certain extent with a reduction in flows being modelled under wet conditions, the increased flows modelled under dry conditions are at odds with the findings of the superficial analysis.

The method of rainfall assessment used in this section of analysis is inherently more vague in terms of rainfall classification as a result of the need to class a particular rainfall scenario in terms of its impact across Burkina Faso rather than in a succinct model zone. However, the impacts of the general trends in rainfall that result from each rainfall scenario have been shown to result in some interesting relationships between rainfall characteristics and migrant destinations. Drier rainfall conditions across Burkina Faso have been seen to result in increased modelled migration to both the urban centre of Ouagadougou and International destinations but decreased modelled flows to Sahel, Centre and, to a lesser extent as a result of the small sample, Bobo Dioulasso. By contrast, wetter rainfall conditions across Burkina Faso are seen to result in decreased modelled migration to Ouagadougou and International destinations but increased flows to Sahel, Centre and Bobo Dioulasso. No clear distinction between wet and dry scenarios was discernible in the case of modelled arrivals to Southwest. Table 8.8 displays the influence of drier and wetter country-wide rainfall trends upon modelled migrant arrivals to each of the six destination zones within the AMARC model relative to the migration flows simulated under average rainfall conditions.

Rainfall:	**Ouagadougou**	**Bobo Dioulasso**	**Sahel**	**Centre**	**Southwest**	**International**
Drier	Increase	Decrease	Decrease	Decrease	Average	Increase
Wetter	Decrease	Increase	Increase	Increase	Average	Decrease

Table 8.8: Relative change in modelled migration to each zone away from the level seen under average rainfall conditions.

The relationship between decreased rainfall and increased modelled migration to both Ouagadougou and International is interesting when considered in the context of previous studies by Henry et al. (2004a) and Barrios et al. (2006). As mentioned in Chapter 2, Henry et al. propose that overall both men and women were more likely to migrate to urban and international destinations if recent rainfall had been favourable. In contrast to Henry et al.'s findings on rural-urban migration, Barrios et al. propose that declining rainfall in sub-Saharan Africa has led to increased urbanisation in the region. The migration flows modelled using AMARC3 show some contradiction with the findings of Henry et al, aligning more with those of Barrios et al. despite the data used in the multi-level event-history analysis performed by Henry et al. being the same as that used to inform the ABM presented by this research.

As identified earlier in this chapter, changes in rainfall variability away from those modelled under the No Climate scenario were seen to result in a change in total modelled migration of between (-) 12.45% and (+) 0.53% with an average reduction of (-) 6.53% for the high variant demographic scenario. However, data on the numbers of total migrants (moving both internally and internationally) originating in Burkina Faso are not available. Net migration data that records the numbers of migrants arriving in and departing from Burkina Faso as international migrants (whether regional or intercontinental migrants) is however more readily available. As such, Figure 8.48 displays the 2011 to 2050 forty year averaged percentage annual change in international departures modelled under each of the ENSEMBLES rainfall scenarios compared with that seen for the No Climate scenario under high variant demographic change.

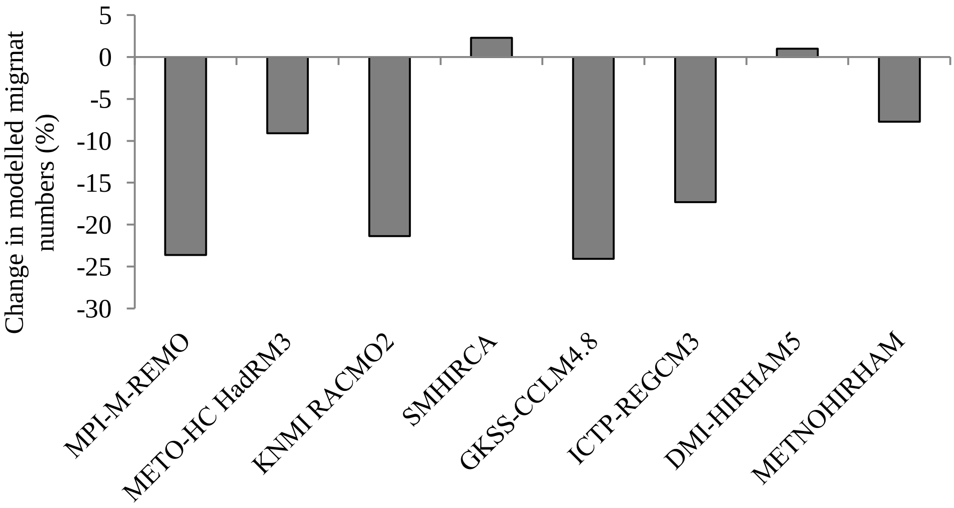

Figure 8.48: 2011-2050 forty year averaged percentage change in international departures modelled as occurring under each of the ENSEMBLES rainfall scenarios compared to No Climate under high variant demographic change.

Displaying a greater range in annual percentage change between scenarios than that seen in Figure 8.22 for total migration, modelled flows of international migrants are seen in Figure 8.48 to range from result in forty year averaged annual changes of between 2.27% and -24.08% when compared to the No Climate base scenario. The mean impact of all eight ENSMEBLES scenarios that represent any change in rainfall variability away from No Climate results in a forecast annual reduction in international migration from Burkina Faso of -12.49%. The International Organization for Migration (IOM, 2011) reported a net migration rate of -0.7 migrants per 1,000 population for the period 2010-2015 and a 2010 population of 16.3 million. From the IOM data the 2010 net migration from Burkina Faso can be estimated to have been approximately -11,410. If the forty year averaged average impact of the eight future rainfall scenarios were applied to this figure, it would suggest possible reduction in migration of 1,425 individuals remaining in Burkina Faso rather than migrating abroad.

This crude attempt to apply an average annual rate of change in migration flows modelled for an uncertain future gives an idea of the extent to which the predicted scale of change in migration flows resulting from changes in rainfall variability towards 2050 might affect recent international migration from Burkina Faso. The level of quantification of migration influenced by environmental change permitted by the modelling approach used by this thesis is deemed adequate to provide insight into the potential influence of changes in rainfall variability on future flows of migrants which are themselves uncertain. However, to classify a particular proportion of future migrants as environmental migrants would require daring assumptions as to the specific motives behind people’s migratory behaviour and the precise way in which changes in rainfall are manifest through typical socio-economic drivers of migration. Furthermore, classifying such environmental migrants as voluntary/proactive as opposed to forced/displaced would require further assumptions considered inappropriate in this context. As a result of the interest of international migration to both the policy arena and this research, the following section investigates in greater detail the international migration simulated by AMARC3 under dry, average and wet rainfall scenarios.

8.12 International Migration

The migration of individuals across international boundaries worldwide receives more attention from policymakers and the media than migration across the more conspicuous internal boundaries that divide a nation. As a result of this attention, the value of a model such as AMARC may be greater to policy-makers when used to consider the interplay of international migration and future rainfall change. In Chapter 6 the migration of individuals to international destinations was identified as the most accurately replicated flow of modelled migrants by the AMARC2 model when compared to the EMIUB2 data. In the previous section the consistently highest modelled arrivals to International were seen to result from the dry SMHIRCA rainfall scenario. Four other rainfall scenarios, including No Climate, were seen to result in an intermediate level of International arrivals. The remaining scenarios, including the wet KNMI-RACMO2 scenario, resulted in clearly lower levels of modelled migration to International. In order to better understand the dynamics of these international migrant flows, Figure 8.49 displays a breakdown of the ten-year averaged origins of those migrants modelled under the dry SMHIRCA scenario between 2011 and 2046.

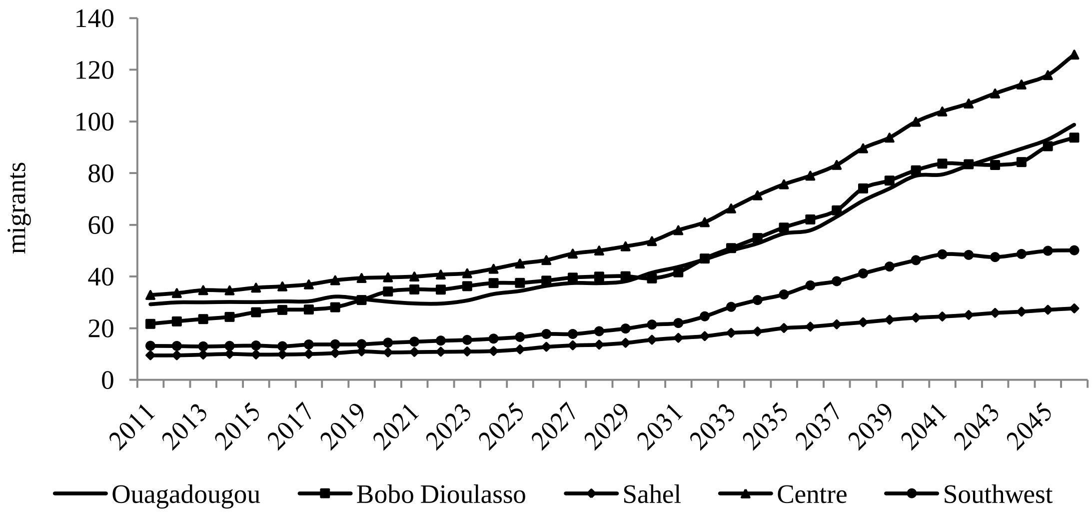

Figure 8.49: Ten-year averaged numbers of migrants modelled as originating in each model zone and arriving in International each year between 2011 and 2046 under the SMHIRCA rainfall scenario.

It is clear from Figure 8.49 that the largest number of individuals modelled as migrating to international destinations under the SMHIRCA rainfall scenario originated in Centre. With very similar ten-year averaged departures, the two urban zones, Ouagadougou and Bobo Dioulasso, are seen to produce the next highest number of international migrants. With considerably fewer migrants originating in Southwest and even fewer in Sahel, the three zones of Centre, Ouagadougou and Bobo Dioulasso can be considered to be the major contributors of international migrants under dry rainfall conditions. For a direct contrast, Figure 8.50 displays a breakdown of the ten-year averaged origins of those migrants modelled under the wet KNMI-RACMO2 scenario between 2011 and 2046. In order to enable a more direct comparison, the y-axis of Figures 8.48 and 8.49 are kept the same despite the different scales of the total flows to International that they represent.

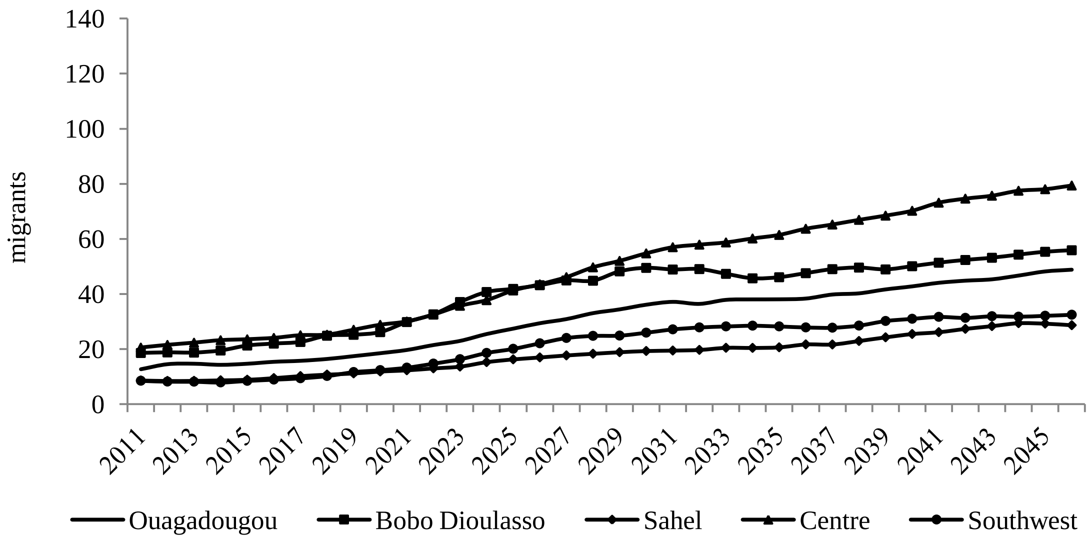

Figure 8.50: Ten-year averaged numbers of migrants modelled as originating in each model zone and arriving in International each year between 2011 and 2046 under the KNMI-RACMO2 rainfall scenario.

Under the wet KNMI-RACMO2 scenario the highest number of International migrants are again seen in Figure 8.50 to be modelled as originating from Centre. However, the scale of the departure from Centre is clearly lower than that modelled under the dry SMHIRCA scenario. Results from the wet scenario also again show relatively high modelled migration from Bobo Dioulasso and, to a lesser extent, Ouagadougou. In the case of modelled flows to international destinations from Ouagadougou, Bobo Dioulasso, Centre and Southwest, those modelled under the wet scenario are consistently lower than those modelled under the dry equivalent suggesting that modelled international migration is considerably lower from Burkina Faso under wet rainfall conditions. The exception to this rule is seen in the case of Sahel. Under the dry scenario the ten-year averaged modelled migration from Sahel to International peaks at twenty-eight migrants in 2046. The equivalent peak under the wet scenario is also seen to occur in 2046 with twenty-nine migrants. As a result, despite modelled migration from all other zones showing a considerable decrease under wet conditions when compared to dry, the flow from Sahel is seen to remain virtually static, therefore representing a relative increase. In order to provide a point of intermediate comparison, Figure 8.51 displays a breakdown of the ten-year averaged origins of those migrants modelled under the average No Climate scenario between 2011 and 2046.

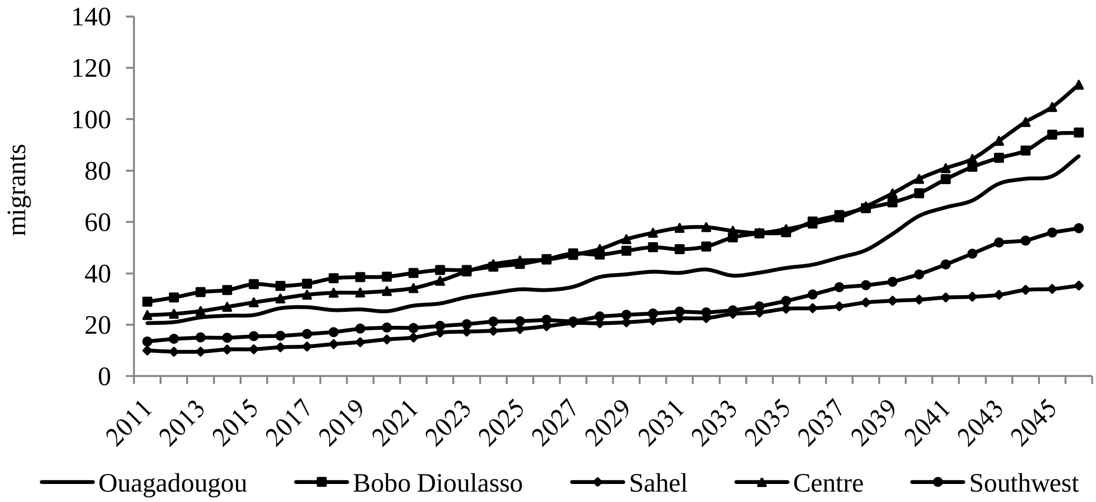

Figure 8.51: Ten-year averaged numbers of migrants modelled as originating in each model zone and arriving in International each year between 2011 and 2046 under the No Climate rainfall scenario.

While it can be seen from Figure 8.51 that, under the No Climate rainfall scenario, the largest number of ten-year averaged international migrants are modelled to originate in Centre by the end of the simulation period, the distinct nature of this flow throughout the simulation period is not as marked as those seen in Figures 8.48 and 8.49. Throughout much of the period from 2011 to 2046 the numbers of migrants modelled as migrating to International are almost as high as those originating in Centre. Although modelled flows from Southwest to International appear to be similar under the No Climate scenario to those seen under SMHIRCA, the modelled flow of migrants from Sahel to International under No Climate is greater than those modelled for either SMHIRCA or KNMI-RACMO2. To enable further understanding of the nature of the changes of modelled international migrant flows, Figures 8.51 to 8.55 display the ten-year averaged numbers of migrants modelled as leaving each zone for international destinations under the dry, average and wet scenarios over the last ten years of the simulation period.

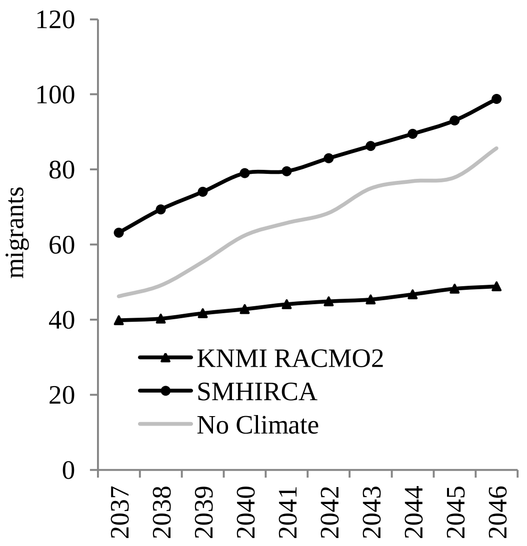

Figure 8.52: Ten-year averaged international departures from Ouagadougou under dry, average and wet rainfall conditions between 2037 and 2046.

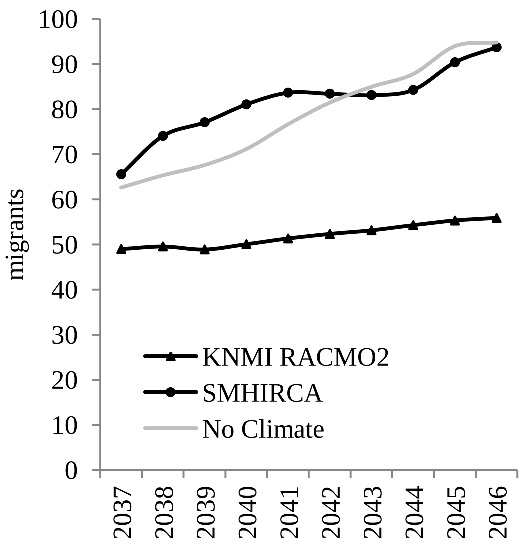

Figure 8.53: Ten-year averaged international departures from Bobo Dioulasso under dry, average and wet rainfall conditions between 2037 and 2046.

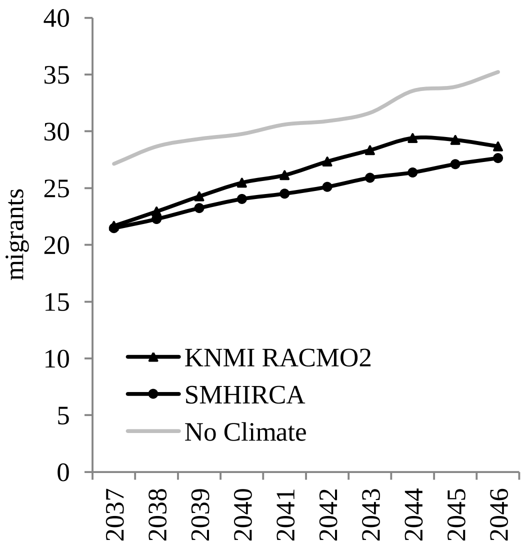

Figure 8.54: Ten-year averaged international departures from Sahel under dry, average and wet rainfall conditions between 2037 and 2046.

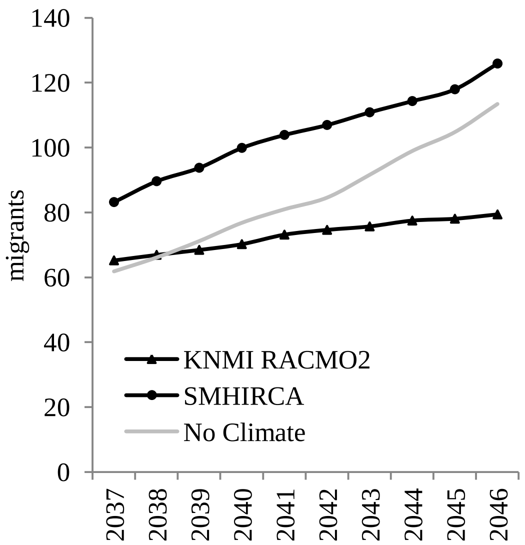

Figure 8.55: Ten-year averaged international departures from Centre under dry, average and wet rainfall conditions between 2037 and 2046.

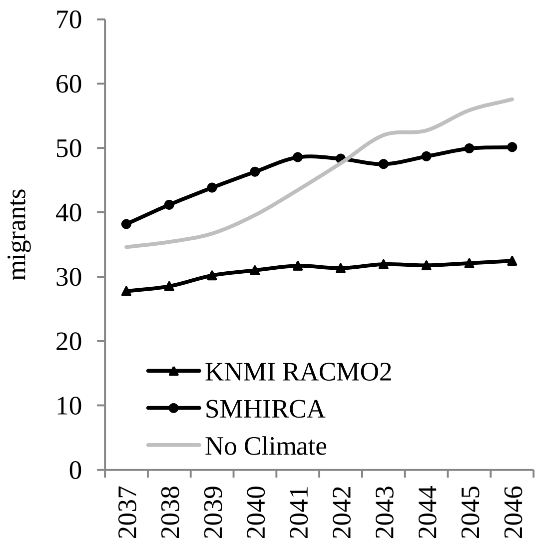

Figure 8.56: Ten-year averaged international departures from Southwest under dry, average and wet rainfall conditions between 2037 and 2046.

It can be seen from Figures 8.51 to 8.55 that international departures from the five model zones appear to have different relationships with rainfall. Departures from both Ouagadougou and Centre to International are seen to be greatest under the dry conditions of SMHIRCA, lowest under the wet conditions of KNMI-RACMO2 and intermediate under the average conditions of No Climate. This pattern is replicated to some extent in international migration from both Bobo Dioulasso and Southwest where wet conditions still result in the lowest modelled departures but no consistent difference is evident between modelled flows under dry and average conditions. Only in the case of international departures from Sahel does the wet scenario result in a modelled flow greater than that seen under dry conditions. In this instance the international departures modelled under average conditions are greater than those modelled under both wet and dry conditions. However, the significance of this finding compared to those of other zones may be argued to be reduced due to the smaller numbers of individuals modelled as migrating from Sahel under any scenario. Table 8.9 summarises the influence of drier and wetter conditions upon the modelled tendencies of individuals migrating to international destinations relative to the level of migration seen under average rainfall.

Rainfall:	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest
Drier	Increase	Average	Decrease	Increase	Average
Wetter	Decrease	Decrease	Decrease	Decrease	Decrease

Table 8.9: Relative change in modelled migration to International from each zone away from the level seen under average rainfall conditions.

A relatively clear and consistent hierarchy of international migrant origins is evident in Figures 8.48, 8.49 and 8.50 with the largest actual number of migrants to International seen to originate in Centre with Bobo Dioulasso as the second most common origin, Ouagadougou as third, Southwest as fourth and Sahel as the least common origin zone. In their analysis of the impact of rainfall upon the first out-migration from the village, Henry et al. (2004a) found that individuals living in wetter regions were far more likely to leave their home location for an international destination than those living in a drier area. In order to explore how the findings of the AMARC model correspond with the statement made by Henry et al, Figure 8.57 displays the proportion of the original population of each of the rural zones that the No Climate flows of modelled migrants represent.

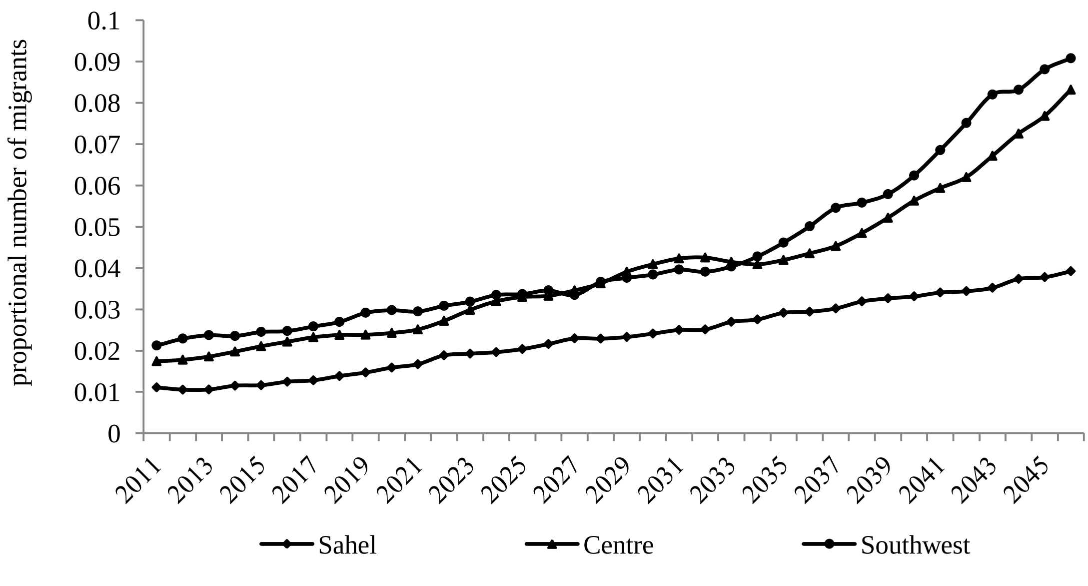

Figure 8.57: Ten-year averaged proportional numbers of migrants (number of migrants/original zone population) modelled as originating in each model zone and arriving in International each year between 2011 and 2046 under the No Climate rainfall scenario.

It can be seen from Figure 8.57 that, in accordance with Henry et al.'s (2004a) findings, agents originating in the wettest zone, Southwest, have the greatest tendency towards international migration. Furthermore, the north-south rainfall gradient seen in Burkina Faso is replicated in the modelled flows of migrants to International with the lowest tendency to migrate seen in the dry Sahel and a medium-high tendency seen in the intermediately wet Centre.

8.13 Summary

This chapter has used the validated and tested AMARC models to investigate the role of future rainfall in the modelled migration decision of Burkinabé people. Eight rainfall scenarios produced by the ENSEMBLES project have provided rainfall data that, alongside a No Climate rainfall scenario which provides a base scenario by repeating 1970-1999 recorded rainfall, have been used as the basis for future rainfall analysis. The process of investigating the influence of future rainfall scenarios upon modelled migration has been undertaken in parallel with consideration of the interacting influence of different future scenarios of demographic change. Low, medium and high variant demographic scenarios developed by the UNPD provided the core demographic components used in the analysis. A fourth scenario projecting zero change was also used.

In accordance with the findings presented in Chapter 7, no clear and consistent relationship between rainfall and modelled migration is evident across all scales of analysis. However, a broad relationship between rainfall and total modelled migration can be seen where, simulating forwards to 2050, the highest level of modelled migration is forecast to result from a combination of average rainfall conditions such as those seen under the No Climate base scenario. A consistent deviation away from an average rainfall scenario results in decreased modelled migration, with a greater decrease seen under a wet rainfall scenario. In total migration terms the forty year averaged average influence of a future rainfall scenario other than No Climate is a -6.53% change in modelled migration towards 2050 under a high variant demographic scenario. When considered in terms of international migration alone, this figure increases to a -12.49% change thus potentially considerably affecting forecast net migration.

Interestingly, the pattern of decreasing migration with changes in rainfall variability away from the No Climate base contrasts with the pattern of modelled migration that may have been anticipated on the basis of the superficial assessment of the sum probability of all agent classes migrating under different rainfall conditions conducted in Chapter 5 but agree with the initial findings presented in Chapter 7. While the actual differences between the flows of migrants modelled by different rainfall scenarios were seen to increase with increased demographic change, the proportional differences between the flows were not as clear. As a result of the delayed impact of different demographic scenarios upon modelled migration, caused by agents having to reach maturity before they start actively migrating, clear differences between ten-year averaged model flows were only revealed from c.2037 onwards.

Through a more detailed analysis of the origins of modelled migrants, further detail on the relationship between future rainfall and modelled migration was achieved. While drier rainfall conditions were seen to result in increased migrant departures from Ouagadougou, Centre and Southwest the same conditions corresponded with decreased migration from Sahel. Conversely, wetter conditions were seen to increase modelled migration from Sahel but correspond with decreased migration from Ouagadougou, Centre and Southwest. No clear relationship appears evident between rainfall conditions and modelled migration from Bobo Dioulasso despite the zone experiencing largely the same rainfall trends as the surrounding Southwest zone. Furthermore, only modelled migration from Southwest was seen to loosely correspond with that which may have been assumed from the simplistic sum probability analysis conducted in Chapter 5.

Results from analysis of the destinations of migrants under different future rainfall scenarios revealed that drier conditions across Burkina Faso were seen to result in increased modelled migration to both the urban centre of Ouagadougou and International destinations but decreased modelled flows to Sahel, Centre and Bobo Dioulasso. By contrast, wetter rainfall conditions across Burkina Faso were seen to result in decreased modelled migration to Ouagadougou and International destinations but increased flows to Sahel, Centre and Bobo Dioulasso. No clear distinction between dry and wet scenarios was discernible in the case of modelled arrivals to Southwest. Furthermore, modelled arrivals to both Ouagadougou and Southwest showed little relative variation between rainfall scenarios while arrivals in International were seen to be highly influenced by changes in future rainfall. As a result of the methodology used by this research Chapter 9 presents the conclusions drawn.

Chapter 9

Conclusions and Recommendations

9.1 Introduction

The Agent Migration Adaptation to Rainfall Change (AMARC) agent-based model (ABM) developed by this thesis is intended to develop upon the progress already made by attempts to understand migration influenced by environmental change and, in particular, to quantify any non-linear dynamics of the phenomenon. Although previous research in the field is seen to have largely used top-down generalised approaches to quantifying environmental migration, some studies have also used statistical methods to derive links between climate proxies and migration on national or smaller scales. By developing upon such statistical approaches and incorporating notions of human cognition and decision-making in the context of a computational simulation this research attempts to further contribute to our understanding of environmental migration. Rather than focussing solely upon the overarching statistical trends that have been previously considered to capture the migration dynamics of a group, this research therefore adopts a more individual-centric approach that permits dynamic and unique interactions between agents and their environment in the undertaking of migration decisions. In the same way that climate models have evolved from early attempts which focussed upon regression-based trends to more recent versions which consider the underlying processes that have led to large-scale patterns, it is proposed that our ability to investigate the impact of manifestations of never before seen changes in climate upon human migration can be comparably improved through greater understanding of the processes that lead to overarching trends. The agent-based modelling approach described by this thesis is intended to provide such improved understanding, at least in the context of Burkina Faso.

The AMARC ABM has been developed using a cognitive perspective gained from the MARC conceptual model presented in Chapter 3. As such, the resulting model can be described as a cognitive model developed from the Theory of Planned Behaviour and intended to represent the migration decision-making process undertaken by Burkinabé agents affected by rainfall variability. However, with the aim of building upon previous statistical approaches used in the field to date, each unique component of the modelled migration decision is parameterised through statistical analysis performed on the EMIUB database. As the rules of interaction used within the model are parameterised using retrospective migration data, the AMARC model can additionally be described as having been constructed using an empirical basis.

By using an empirical foundation for the development of each component of agent decision-making incorporated into the ABM, the value of this research is not considered to be gained from the quantification of environmental migration alone. Additional value is proposed to be gained from the patterns of migration modelled as occurring in each zone as a result of different rainfall conditions. By developing the ABM using five sets of agents in discrete zones across Burkina Faso, the influence of changes in rainfall upon different communities in different locations could be assessed and provide insight into the complex and multifaceted nature of the migration decisions that cause some individuals to migrate and others to stay in the face of broadly similar external changes. The remainder of this chapter presents the conclusions drawn through development, testing and analysis of the AMARC model and proposes recommendations for future development.

9.2 Model Development

Numerous approaches exist that are suited to the development of the rules that govern modelled interactions in an ABM. While this research used an empirical approach to generate the rules that inform each component of the modelled migration decision, a logical alternative would have been to develop such rules through a process of bottom-up reasoning using findings from the focus group interviews conducted in Burkina Faso, relevant literature on migration and logic alone. However, due to the potential policy implications of findings made in the arena of environmental migration, it was considered that, although rules of interaction defined in the model could be developed from theory and field testing, the process of parameterising these rules should be quantitatively, rather than qualitatively, assessed. Furthermore, due to the availability of a vast amount of retrospective migration data from the EMIUB, it was considered that greater detail could be gained through analysis of this resource than could be collected in many months of fieldwork. Issues with the continuity and completeness of the dataset and its lack of specific intention to be used in the field of ABM were encountered. However, due to the scarcity of such comprehensive migration data the EMIUB was considered too valuable an asset not to use. By using an empirical basis for rule parameterisation it was further considered that the ABM would present a logical next-step in the methodological approach used to assess the environmental migration. Rather than opting to employ an entirely different approach to those statistical methods previously seen in articles aiming to identify relationships between climate proxies and migration, this research combines a novel cognitive perspective with an empirical basis.

As a result of the statistical approach of rule parameterisation, the period of fieldwork undertaken in Burkina Faso represented a period of in-situ validation of the variables identified from existing theory as most appropriate for later statistical analysis. During this period, thirty focus group interviews were undertaken across the five zones into which Burkina Faso is divided within the ABM. Although the information gained from these interviews could have been used to generate rules of agent behaviour in response to complex stimuli, such rules would have been generated from the vocalised behaviour of a significantly smaller sample population than could be captured from the EMIUB data. Furthermore, the tendencies towards migration cited within the focus groups could be argued to not accurately portray true migration decision-making as, in many situations, the intentions vocalised by individuals may not have matched the reality of their actual behaviour. The decision to base as much of the rule development upon empirical analysis was therefore considered to promote the integrity and value of the final model.

The core model component to which the greatest empirical contribution was made was the behavioural attitude value returned by each agent towards each migration option available to them. The pertinent variables of age, gender, marital status, origin location and rainfall were identified as contributing to this behavioural attitude from statements made by focus group interview respondents across Burkina Faso. Using a multivariate binary logit model, each of these variables, excluding rainfall, were identified to be significant ($p < 0.05$) statistical determinants of migration behaviour within the EMIUB data. Although not a significant determinant of migration using the multivariate binary logit model ($p < 0.38$), rainfall was found to be less significant when considered alone ($p < 0.98$). The increased significance of rainfall as a determinant of migration when considered alongside additional components such as age, gender and marital status, combined with Henry et al.’s (2004a) clear evidence of a statistically defined link between rainfall and migration in Burkina Faso at different scales of analysis suggests that the impact of rainfall upon migration is manifest through other primary determinants (age, gender, marital status and origin location) and their interplay in the multiple and connected drivers of migration. Empirical analysis of the EMIUB data provided weight matrices of behavioural attitude values that represented the probability of an individual with given characteristics of age, gender, marital status and origin location migrating to a given destination under known rainfall conditions.

Gained from the University of Delaware Air Temperature and Precipitation Record, 1970-1999 rainfall data for Burkina Faso came in the form of a monthly global gridded high resolution (0.5 degree latitude x 0.5 degree longitude) record. Monthly rainfall data was then used to calculate annual July August September (JAS) rainfall for the period. Quartiles of these JAS rainfall values were used to gain numerical representations of dry, average and wet rainfall conditions in each of the five model zones. Using these threshold classifications, the probability of an individual within the EMIUB data with given characteristics migrating to an alternative location in years with a known rainfall classification (ppt) could be established. As well as using the entire 1970-1999 ($mp30$) EMIUB data period, the shorter 1990-1999 ($mp10$) period was also used to generate alternative probability values that could be used as an additional test of model validity. Furthermore, the classification of each year as dry, average and wet was also undertaken using the sum of the current and two previous year's JAS rainfall ($ppt3$) for purposes of additional validation and testing.

In their paper investigating the role of rainfall upon out-migration in the context of Burkina Faso, Henry et al. (2004b) found that the definition of environmental conditions used in their analysis, whether considered in terms of land degradation or rainfall, affected the proportion of people migrating. Intended to study changes in climate variability, manifest through changes in rainfall variability, the ABM presented by this thesis focuses on the impact of the occurrence of episodic fluctuations in rainfall through its classification of each year as dry, average or wet. As such, the longer term slow-acting process of land degradation resulting from changes in mean climate conditions is not explicitly considered. However, the division of Burkina Faso into five model zones within three distinct rainfall regions permits consideration of the different responses of individuals to environmental changes such as temporal fluctuations in rainfall in separate agroclimatic zones. Furthermore, the use of a range of future rainfall scenarios in the model allows the accumulation of repeated dry, wet or average rainfall years to potentially occur and result in a more sustained impact of rainfall conditions if they move from an episodic occurrence to more of an agro-climatic norm.

Demographic change within the ABM was constructed using simplistic birth, death and marriage functions that affected each modelled agent. Although more complex fertility functions related to age and gender could potentially be incorporated into the model that permitted more age-specific functions related to the birth, marriage and death of agents, such a step was not taken by this research. As the primary aim of the ABM was to investigate the role of changes in rainfall variability upon modelled migration decisions, the more simplistic means of modelling demographic change was applied so that migration flows modelled by simulations could be more readily interpreted without the added complexity of additional demographic change. Furthermore, reliable and detailed data upon the age-related fertility of Burkinabé communities was not readily available. As such, UNPD (2011) data was used to provide statistical birth and death rates that were applied to all agents in the model. In the examination of future changes in demography towards 2050, birth and death rate functions used in the ABM were updated to reflect those forecast by the low, medium and high variant forecasts produced by UNPD.

9.3 Model Validation

In developing the AMARC model for use as a tool to investigate the role of changes in rainfall variability upon modelled migration the process of validating and testing the ABM was central to enabling valuable output when the model was later applied to running future scenarios. By making each agent initialised into the ABM at startup in 1970 reflect the real attributes of each individual surveyed by the EMIUB in 2000 and recorded as being alive in 1970, a highly stringent form of model validation was enabled. As a result the 1970-1999 migration modelled by modelled agents could be compared with those of the real EMIUB observed individuals they represent. At the most rigorous level of model validation, where a direct comparison between modelled and observed population movements was undertaken, the AMARC1 model was found to show a good level of agreement with the EMIUB1 data. Showing a 0.975 level of significance over the thirty years of comparison at both the national and zonal levels of analysis the AMARC1 model could be said to show a strong correlation with the observed record. However, although the shape of the relationship between observed and modelled flows of migrants was retained to the end of the simulation period, the actual numbers of migrants observed and modelled were seen to diverge with time.

By including the additional demographic parameter of agent birth and comparing the resulting modelled migration with the total flow of migrants recorded by the EMIUB (including those born after 1970), the scale of the relationship between observed and modelled flows was significantly improved. The correlation between EMIUB2 observed (dataset that includes individuals born after 1970) and AMARC2 (model version that permits agent birth) modelled flows was seen to increase to well above the 0.995 significance level at both national and zonal levels of analysis. However, root mean squared deviation statistics showed that, although the general scale and shape of migrant flows was accurately portrayed by the AMARC2 model, the year to year variation in flows was less valid with a total flow RMSD of 12.7% and the worst RMSD seen in departures from any one zone of 26.1%. Although the major contributors to the high RMSD scores are proposed to be the clear peaks in migration recorded as occurring in 1980 and 1990, and which may be attributable to some feature of the socio-economic climate at those times, no clear evidence of such events is available. At this relatively broad level of analysis however, the AMARC2 model was considered to appropriately portray the migration decisions of individuals in Burkina Faso, particularly as the migration decision modelled within the ABM was not intended to fully replicate the multiple and interacting socio-economic dimensions of the migration decision but aimed to elucidate the role of changes in rainfall variability upon that decision.

By considering the destinations of modelled and observed migrants throughout the 1970-1999 validation period, further investigation into the ability of the ABM to replicate the migration decision was permitted. It was found that across all five of the origin zones the destinations of the observed and modelled flows of migrants were seen to be similarly proportionally distributed. Although in most cases the modelled flow of migrants was seen to be marginally less than those observed, the accuracy with which the AMARC2 model replicated the proportional distribution of migrants across the potential destinations further supported previous evidence of the ability of the model to replicate the migration decision being undertaken by EMIUB respondents. Another way of permitting further validation of the AMARC2 model was enabled through a comparison of the observed and modelled arrivals of migrants in each zone. The relative proportional distribution of the observed migrants across destinations was seen to be relatively accurately replicated by the modelled flow despite both under- and over-estimation of the migrants seen to arrive in the some destinations.

Through the process of model validation described above it is evident that, not only did the AMARC2 model replicate the general trend and, to a lesser extent, annual variation in migration seen from the EMIUB2 migration record, it also replicated the origins and destinations of modelled migrants. A final means of validation was provided through an investigation into the characteristics of modelled migrants and their relation to those of their observed counterparts. Evidence that the migrants modelled by AMARC2 were seen to be effectively distributed across the agent classes in proportions approximately relative to those anticipated through the sum probability of such agents migrating offered further evidence of the ability of the model to replicate the observed nature of migrant flows in Burkina Faso. Finally, a comparison of the impact of the different approaches to calculating behavioural attitude probability values revealed that, although analysis of 1990-1999 EMIUB data ($mp10$) still produced a highly significant correlation of 0.94, the higher RMSD score of 71 (22.1%) suggested a less close fit with the EMIUB data.

9.4 The Modelled Impact of Changes in Rainfall Variability

Following a thorough process of validation, the AMARC model was thus deemed to provide a reliable representation of the impact of changes in rainfall variability on migration decision-making undertaken by Burkinabé people. The next step in this research was therefore to undertake an investigation into how different rainfall conditions throughout the 1970-1999 validation period were seen to affect modelled migration flows. The final version of the AMARC model used to investigate the role of changes in rainfall variability upon migration was AMARC3, a model that used exactly the same basis as both AMARC1 and AMARC2 but included the final demographic component of agent death. By incorporating death into the ABM, the modelled migration flows were seen to correlate better with the observed data until approximately 1994 when the agent death occurring within the model resulted in a significantly different model population size and the AMARC3 total modelled migrant flow diverged away from those of both AMARC2 and the EMIUB data.

By comparing the impact of episodic rainfall fluctuations in terms of their occurrence over one year (ppt) or three years ($ppt3$), contrasts between the two modelling strategies could be identified. Although the differences between the two modelled flows of migrants were seen to be relatively minor, their occurrence in each zone, particularly in the case of departures from Bobo Dioulasso, highlighted the impact that a relatively small change can have upon the modelled outcome of an ABM. As a result of the separate ppt and $ppt3$ approaches tested, the rainfall conditions of each year of a model run may be differently classified. As a result of such classifications, different behavioural attitude probability values would be retrieved by agents therefore affecting their tendencies towards migration. Furthermore, historical changes in the migration patterns of a community affect later migration decisions made by members of that community and their networked peers in a cascade of influence. In order to retain consistency throughout the remainder of the analysis performed on the AMARC3 model, the $ppt.mp30$ (rainfall classified on the basis of that year alone and using the full thirty years of data) version of the model was used as the default option.

In order to test the influence of changes in rainfall variability upon the modelled migration decision, the first step taken by this research was to run the AMARC3 model from 1970-1999 under artificially dry, average and wet rainfall scenarios and compare the migrant flows modelled with those seen under the standard rainfall scenario. It was found that, over the thirty year period from 1970 to 1999, the average rainfall scenario (where every year was classed as average) resulted in consistently higher modelled migration than either the dry or wet alternatives. Furthermore, throughout the majority of the test period, the dry scenario resulted in lower modelled migration than that seen under the wet scenario. Despite these trends in total migration, the flows of modelled migrants from each zone that made up the total showed distinct relationships with rainfall. While dry rainfall conditions resulted in increased modelled migration from Ouagadougou, the same conditions were seen to result in a significant reduction in migrant numbers from Sahel and, to a lesser extent, Centre. Meanwhile, average rainfall conditions in Bobo Dioulasso and, to a lesser extent Southwest, resulted in increased modelled migration from these zones.

According to the first means of analysing the influence of rainfall on migration within and from Burkina Faso, it appeared that any deviation away from average rainfall conditions could be said to result in a decrease in modelled migration, with a greater reduction in modelled migration seen as a result of dry conditions. By analysing the arrivals modelled as occurring under each of the three artificial rainfall scenarios the influence of rainfall upon modelled migration could be further explored. It was found that, while migration flows to internal destinations did not appear to correspond consistently with any particular rainfall pattern; arrivals to International (the model zone that represents all destinations outside Burkina Faso) were more clearly linked to rainfall. Once again, average rainfall conditions were seen to result in the highest rate of modelled arrivals in International with any deviation away from average conditions resulting in a decreased flow.

Throughout the analysis of modelled departures and arrivals resulting from the artificial rainfall scenarios, patterns of modelled migration flows resulting from dry, average and wet rainfall conditions were, in some instances, inconsistent throughout the 1970-1999 test period. As a result a second means of analysis was undertaken. By analysing the rate of migration modelled from each zone during individual years classed as dry, average or wet on the basis of the Delaware rainfall data for each zone, the impact of real changes in rainfall variability upon modelled migration could be investigated. It was found that the highest modelled rate of migration under any rainfall classification was seen from Sahel with wet years resulting in the highest rate of modelled migration. Furthermore, the lowest rate of departure under all three rainfall classifications was consistently seen to occur in Centre. Only modelled departures from Bobo Dioulasso and, to a lesser extent, Southwest mirrored the pattern of highest departures under average conditions seen for total migration in the artificial scenario analysis. However, when modelled departures from all zones were considered together, average rainfall conditions were again seen to result in the greatest rate of departure. Although wet years were seen to result in a moderate decrease in modelled migration, dry years showed only a marginal decrease compared to average years.

It is evident therefore that, in using an historical period of known rainfall and known migration to explore the role of changes in rainfall variability upon the modelled decision, some agreement is evident between the two investigative approaches used. While the approach of using longer term classification of the entire simulation period as dry, average or wet resulted in relatively clear relationships between rainfall and modelled migration, the relationships seen as a result of the more analytical shorter term approach were less clear. It appears therefore that an extended period of one rainfall classification (dry, average or wet) accentuates the modelled relationship between rainfall variability and migration by permitting a particular migration trend to recur throughout the population of modelled agents as a result of the use of one ‘type’ of behavioural attitude value (linked only to dry, average or wet conditions) in consecutive migration decisions of agents. From the results of the two approaches to investigating the role of changes in rainfall variability in the migration decision, it was hypothesised that the AMARC3 model appeared sensitive to rainfall both in terms of the occurrence of certain rainfall conditions and the duration of such an occurrence. However, as a result of the often contrasting relationships identified between rainfall and migration for each origin and destination location, the precise impact of rainfall upon total national-scale migration was deemed to be sensitive to internal changes at the zone level. As a result of the combination of zone-level flows however, average rainfall conditions were seen to result in the highest rate of modelled migration while both dry and wet conditions were seen to cause some level of reduction in total modelled flow.

In addition to investigating the influence of rainfall upon modelled migration within and from Burkina Faso over the validation period 1970-1999, this research used the AMARC3 model to simulate how different rainfall scenarios towards 2050 impacted upon modelled migration flows within this timeframe. The eight future rainfall scenarios used by this research came from the European Commission funded ENSEMBLES project and ranged from a consistently dry scenario (SMHIRCA) to a consistently wet scenario (KNMI-RACMO2) for the whole of Burkina Faso through a variety mixed average conditions across zones. An additional ‘No Climate’ base scenario was also used that replicated the Climate Research Unit’s 1970-1999 observed rainfall to 2050. Analysis of the dry, average and wet annual classifications calculated on the basis of quartile thresholds showed that each of the nine future rainfall scenarios revealed a different pattern of rainfall classifications across the five zones of Burkina Faso. By incorporating the use of four demographic scenarios (UNPD low, medium and high variant scenarios plus an artificial ‘zero change’ scenario) into the analysis of future migrant flows modelled under each of the rainfall scenarios, the interacting impact of rainfall and demography on modelled migration was investigated. Using total forty-year modelled migration as a means of assessment, five of the nine rainfall scenarios were seen to display an incremental increase in modelled migrant numbers from low to high variant demographic scenarios.

From the forty year analysis of demographic and rainfall scenarios undertaken, some indication could be gained of the possible future impact of changes in rainfall variability to 2050. By comparing the total migration modelled as occurring under each of the ENSEMBLES rainfall scenarios with that modelled under the No Climate base scenario for each UNDP demographic scenario the relative influence of forecast changes in rainfall variability could be simply calculated. The forty year averaged average annual difference between migration modelled under each ENSEMBLES scenario and the No Climate base were thus used to suggest the likely change in future migration. The forty year averaged differences ranged from a 0.53% change (low variant demographic METNOHIRHAM) to a -12.45% (high variant demographic MPI-M-REMO) change in modelled flows each year. When modelled flows of international migrants under each of the ENSEMBLES scenarios were treated to the same process of analysis the forty year averaged percentage change in migrant flows was calculated as ranging from 2.27% to -24.08% under the high variant demographic scenario. The range of changes in international flows was calculated to provide an average annual percentage change of -12.49% under conditions other than those of the No Climate base. When applied to the 2010 net migration for Burkina Faso calculated from IOM (2011) data this average annual change was seen to represent a reduction of 1,425 departing migrants that year. Although this figure was able to hint at the potential influence of future changes in rainfall variability upon migration from Burkina

Faso, it was noted that such a figure could not be deemed to represent environmental migrants, nor could such a number be reliably achieved without undertaking daring assumptions as to the precise motives of such migrants. Furthermore, it was suggested that in no way could such a finding be used to estimate what proportion of said migrants were relocating as a proactive adaptation strategy or as an involuntary last resort.

Although no precise figure of the scale of migration influenced by environmental change can be realistically gleaned from the AMARC3 model, the insight provided into the relative scale of flows modelled under different combinations of rainfall and demographic scenarios are highly beneficial. By analysing the influence of the low, medium and high variant demographic scenarios on modelled migration under each of the rainfall scenarios it was evident that demographic change had a greater influence upon modelled flows under some rainfall scenarios. By the end of the simulation period, all nine rainfall scenarios showed greater modelled migration under the high variant demographic scenario. However, while the distinction between low, medium and high variant modelled flows was most clearly evident in the case of the MPI-M-REMO scenario, where the low variant modelled flow was 12.7% less than that modelled under the high variant by the end of the simulation period, the equivalent proportional difference under the ICTP-REGCM3 scenario was just 5.1%.

Despite the apparent variety in the comparative nature of migration flows modelled under low, medium and high variant demographic scenarios and each of the nine different rainfall scenarios, a more consistent relationship between the flows modelled under the dry (SMHIRCA), average (No Climate) and wet (KNMI-RACMO2) rainfall scenarios was found. Using these three rainfall scenarios and all four demographic scenarios, a relatively consistent relationship between modelled migration, rainfall and demography was established. It was found that the average rainfall scenario resulted in the greatest level of modelled migration under each demographic scenario with dry and, to a greater extent, wet scenarios resulting in decreased modelled migration across all demographic scenarios. When these overall migration flows were broken down into their respective origins it was found that different rainfall conditions appeared to result in different levels of modelled migrant departures from each of the five zones. While drier rainfall conditions resulted in increased migrant departures from Ouagadougou, Centre and Southwest, the same conditions were seen to correspond with decreased migration from Sahel. Conversely, wetter conditions were seen to increase modelled migration from Sahel but correspond with decreased migration from Ouagadougou, Centre and Southwest. No clear relationship was evident between rainfall conditions and modelled migration from Bobo Dioulasso despite the zone experiencing largely the same rainfall trends as the surrounding Southwest zone. Interestingly, only in the case of Southwest did the AMARC3 model simulate a similar relationship between departing migrants and rainfall as that anticipated from the superficial sum probability analysis of the statistical tendencies of a population towards migration.

When the modelled destinations of migrants under each of the nine rainfall scenarios were considered it was found that the impacts of the changes in rainfall variability resulting from each scenario were shown to result in some interesting relationships between rainfall characteristics and migrant destinations. Drier rainfall conditions across Burkina Faso were seen to result in increased modelled migration to both the urban centre of Ouagadougou and International destinations but decreased modelled flows to Sahel, Centre and, less significantly, Bobo Dioulasso. By contrast, wetter rainfall conditions across Burkina Faso were seen to result in decreased modelled migration to Ouagadougou and International destinations but increased flows to Sahel, Centre and, less significantly, Bobo Dioulasso. No clear distinction between wet and dry scenarios was discernible in the case of modelled arrivals to Southwest.

From the scenario-based analysis of migration flows modelled between 1970 and 1999 and towards 2050, it is evident that the influence of rainfall upon modelled migration is complex and varied. As outlined in Chapter 2, Henry et al. (2004a, 2004b) used multi-level event history analysis and descriptive analysis to make some notable findings with regard to the tendencies of Burkinabé people towards migration under certain agro-climatic and rainfall conditions. Henry et al. (2004a) found that individuals living in wetter areas were far more likely to leave their village for international destinations than those in drier areas. Using the Southwest zone as an example of a wetter location and the Sahel as an example of a drier one, it was found that similarly low actual flows of migrants were modelled as leaving both zones for international destinations towards 2050. However, when considered as a proportion of the original population of each zone, in the context of the rural households examined by Henry et al, it could be seen that the results of the AMARC3 ABM replicate the findings of the authors in showing that agents originating in the wet Southwest zone had a considerably higher tendency towards international migration than those originating in the drier Sahel.

Despite apparent agreement between the findings of Henry et al. (2004a) and this research in relation to tendencies towards international migration, some significant contrasts between the two studies can be seen. Henry et al. (2004a) also found that the odds of males migrating were 60% higher if rainfall conditions were unfavourable than if they were “normal”. Although the precise number of males modelled as migrating under dry, average and wet rainfall conditions has not been specifically identified within this research, the general tendency identified through simulations using the AMARC models reveal that favourable/wet conditions result in an overall reduction in modelled migration compared to those seen under normal, or average, conditions. The only exception to this rule was seen in the case of Sahel where modelled migration out of the zone was seen to be greatest under wet conditions but only marginally lower when normal/average.

A final finding of Henry et al. (2004a) was that overall both men and women were more likely to migrate to urban and international destinations if recent rainfall conditions had been favourable. However, analysis of the AMARC3 modelled destinations of migrants under dry, average and wet rainfall scenarios to 2050 found that drier rainfall conditions resulted in increased migration to both the urban centre of Ouagadougou and international destinations. Although directly contradicting the findings of Henry et al, such a tendency towards urban and international migration destinations partially reflects the findings of Barrios et al. (2006) who found that declining rainfall in sub-Saharan African countries was directly linked with increased urbanisation in the region.

9.5 Emergent Properties

Often sought in the analysis of the outputs of a complex system such as that developed within an ABM, emergent properties are generally considered to be an indicator of the successful implementation of agency within a model. Such emergent outcomes would not be anticipated from an analysis of the sum of the parts input into a model but are unexpected outcomes that come about as a result of agent behaviour. The first potential item of emergence sought from this research was investigated in relation to changes in modelled migration under changing demographic scenarios. Although increased actual migration as a result of increased demographic change (larger population size) might be expected to occur within a model such as that presented here, a proportional increase in migrant numbers (migration rate) would not be anticipated. By analysing both the real and proportional flows of migrants modelled under each demographic scenario it was found that increased demographic change implemented in the AMARC3 model was resulting in a clearly increased influence upon modelled migration when considered in real terms. When considered in proportional terms (number of migrants divided by population size) the pattern of increasing migration with increased demographic change was replicated, albeit not as clearly or consistently. It can therefore be tentatively concluded from the demographic scenarios used in the ABM that the influence of rainfall upon modelled migration increases with increased demographic change, an unanticipated and emergent outcome.

9.6 Implications

Despite the quantitative nature of this research, the value that can be gained from model outcomes is considered to be derived not only from a quantitative assessment of the numbers of migrants modelled to relocate under different scenarios of future changes in rainfall variability but also from the nature of the multiple and complex relationships identified between rainfall and migration. The variety of migration responses to rainfall change in each zone show that each combination of origin and destination location has a unique relationship with rainfall leading to no clear and all-encompassing trend between rainfall and migration in the context of Burkina Faso. Although a trend between total migration and rainfall has been identified, the migration flows that make up this overall trend are often contradictory. Even at the next level of analysis - total migration from each zone - wetter conditions are modelled to result in increased departures from Sahel but decreased departures from the neighbouring zone, Centre. Furthermore, within these zone-level flows, the different destinations chosen by migrants are likely to show similarly contrasting relationships with rainfall. As such, despite appearing consistent throughout this research, the overall trend between rainfall and migration is proposed to be one which is highly susceptible to a significant change in sign as a result of a relatively minor way in which agents respond to rainfall changes in their location.

The apparent sensitivity of the relationship between migration and rainfall at the level of analysis used by this research suggests that attempts to quantify such a complex and multifaceted process as environmental migration on a global scale are somewhat futile. However, if demand from policymakers exists for such numbers, the use of a dynamic and complexity-enabling system such as agent-based modelling to simulate the multiple micro-level motives and interactions that lead to macro-level migration flows seems more appropriate than previous trend-based econometric approaches. Furthermore, the agent-based modelling approach can provide a platform from which the impact of changing circumstances upon modelled migration can be performed.

In terms of international migration from Burkina Faso, the results of the ABM presented here propose that any future change in rainfall variability away from normal conditions are likely to lead to a reduction in the migrant departures. As such it can be assumed that more people would, under the scenarios of future change tested, either migrate within Burkina Faso or, more likely, remain in-situ. It is proposed that such behaviour results from such factors as the inability of communities to invest in migration during drier conditions (leading to reduced migration) or the relative abundance of employment at home under wetter conditions (leading to slight reductions in migration). In the case of decreased migration under drier conditions, such a root cause would present a significant challenge for policymakers and those organisations providing support for communities adapting to future changes in climate.

Although this research only goes so far as to contribute information on the different and complex relationships between rainfall and migration in Burkina Faso, the agent-based methodology presents a valuable resource for further development. On the proviso that ample data be available, and on the basis that an appropriate degree of abstraction can be determined, agent-based modelling presents a promising methodology to further explore the notion of 'environmental migrants' and reduce the element of guesswork described by the IPCC that has led to this research. With the ever-increasing computing power available to modern research, there is strong potential for greater collaboration between modellers, social scientists and climate researchers in order to better understand the impacts of climate change through social simulation. However, in order for such developments to be made in the near future and in the absence of perfect data, some degree of trade-off needs to occur between the social science desire for significant quantitative representation and the modelling response of sensitivity testing assumption-based parameters. By accepting a greater degree of sensitivity testing and exploring further possibilities beyond what An (2012) terms, 'empirical or heuristic rules' there exists great potential for further development of an agent-based modelling approach within the environmental migration field. At this stage in the evolution of agent-based models within the field, such techniques as participatory agent-based modelling may be fruitful avenues to explore in order to develop models in case study locations for which comprehensive data such as the EMIUB is not available.

9.7 Future Model Development

Throughout validation and testing of the AMARC models the importance of demography upon modelled migration was highlighted. Although the demographic change modelled as occurring within the existing AMARC models was considered sufficient to provide a constant basis from which migration could be modelled, it would be interesting to test the impact of more complex demographic functions upon modelled migration flows. In order to create a more complex demographic process, fertility and mortality functions could be constructed that changed in tandem with agent age. As such, new agents would be more likely to be born to females within the age-range of greatest actual fertility. Similarly, agents would be more likely to die as they neared the average life expectancy of Burkinabé people. Although such demographic functions may be capable of better replicating the exact population dynamics that exist within Burkina Faso, limited availability of data on age dependent fertility and mortality rates between 1970 and 2050 meant that fewer assumptions were required in the formation of the more simple method of change implemented in the AMARC models. However the inclusion of more complex demographic functions could provide further insight into the interaction effects of, for example, a population with greater longevity, upon modelled migration within the networked society of agents.

Leading on from alterations to demographic change within the ABM, further interesting work could also be undertaken in adapting the AMARC models to represent migration decisions being undertaken at the household, rather than individual, level. By arranging agents into households within which realistic paternal or maternal hierarchies were constructed, the dynamics of the group interactions that lead to household migration decision-making could be investigated. As a result, the marriage function implemented within the model could be developed to permit an actual representation of two households being joined and their networks linked. Furthermore, potentially influential household elements such as economic structure and access to land could be advantageously included. However, in order to effectively implement such changes, significant further data would be required on the cultural and contextual dynamics of household decisions made within the numerous contexts found in each of the zones in Burkina Faso.

Adding a household component to the migration decision was considered to be an unnecessary complication in the context of this research in order to avoid the migration decision becoming overburdened with complex interactions. However, the success achieved in modelling the migration decisions of individuals suggests that incorporating a household level of interaction would further enhance the ability of an ABM to replicate the true migration decisions undertaken. Adding such a household component would adjust the social context within which the migration decision was performed and result in a potentially significant impact upon the subjective norm component of the AMARC modelled decision to migrate. As well as incorporating the household component, the subjective norm component used by this research could be improved through the availability of comprehensive data on the influence of social networks upon migration decision-making. Increased location-specific data collection within this context would be of great benefit to any further research undertaken within the field. Further testing of theoretical subjective norm components could also be enabled. It may, for example, be interesting to investigate how different network scenarios affect modelled migration outcomes. One example of such an endeavour may be to test the impact of a network where agents or households seek out wealthy/well connected peers in order to benefit their own migration potential.

Another model component used in the migration decisions of each agent was the behavioural attitude of each individual towards each migration option. Derived from probability values calculated from the EMIUB data, the behavioural attitudes used by agents were based upon three components: age, gender and marital status. Although hugely increasing the data analysis and computation required in model construction and implementation, the consideration of additional, or alternative, variables upon migration probabilities could be interesting. Furthermore, consideration of migration destinations on the basis of the rainfall characteristics of both origins and destinations could enhance the ability of the AMARC models to replicate migration behaviour within Burkina Faso. However, under the current model structure, a significant increase in the number of probability values stored in each weight matrix would be required to represent the likelihood of an agent migrating under the combination of origin and potential destination rainfall conditions. Such a step would also add an additional level of complexity deemed unnecessary in this first application of the AMARC model.

Although again adding to the degree of complexity involved in the model, another advantageous addition to the AMARC models may more explicit consideration of the duration of impact of the independent variable, rainfall. By testing the influence of one and three year rainfall on modelled migration, such a factor was explored to some degree by this research. However, greater understanding of the duration of rainfall events that affect an individual’s migration decision-making would be advantageous. Similarly, greater understanding of the impact of an individual’s own history upon their chosen adaptation strategy would be useful.

The migration decision used in the AMARC models permits migration once a year at the end of each wet season with all migrants modelled as returning to their location of origin before the start of the next. While this synchronous approach was useful in preventing unnecessary complexity in this version of the ABM, further development of the model to incorporate migration at different points in the calendar year and different durations of stay is likely to permit greater accuracy in the modelled outcomes. On this basis, the time steps in future models could be asynchronous with events triggering other events on a continuous rather than discrete basis. As such, the ABM presented by this thesis provides a solid basis from which further developments in model complexity can be undertaken. Such developments should however be approached from a perspective that acknowledges the notions of simplicity of model design commonly promoted within the literature and the need to balance complexity with uncertainty.

Each modelled agent's perception of whether or not they had the ability to undertake migration behaviour was considered on the basis of their assets. The only reliable data available to this research was the year 2000 livestock assets of the EMIUB respondents. As such, a behavioural control function was created that used livestock assets as the primary determinant. However, the value of livestock assets in representing the perceived behavioural control of individuals living in the largely urban zones of Ouagadougou and Bobo Dioulasso could be argued to be limited. As such, future versions of the AMARC model would benefit enormously from comprehensive temporal data on assets as well as their precise role in affecting the decision-making process behind migrations of different distances and across different potential barriers. With the recent development of geographical information systems (GIS) technology into ABM software such as AnyLogic, the assets of rural populations could further be linked to such processes as land degradation through the use of remotely sensed imagery and the normalized difference vegetation index (NDVI). As a result, greater inclusion of the longer term impacts of increases in periodic droughts upon livelihoods and migration could be permitted. Through a process such as this the interaction effects of changing assets upon migration tendencies within the networked society of modelled agents could be permitted.

Additionally, the remittances sent by migrants to their household could be incorporated into a future model and the effect of these remittances on future rainfall adaptation investigated. Using the asynchronous modelling approach mentioned above to permit time to be more continuous in future models, agent assets could be advantageously used to schedule migration. If an agent were, for example, to accrue an income that exceeded a particular threshold, they could be modelled to begin undertaking a migration decision in the face of the circumstances affecting them. Similarly, if rainfall were modelled to have an impact upon income variability at a specific rate, once an agent's income were to fall below a set threshold they could again begin to consider migration. However, if remittances received from other migrants sent them back above the threshold level, they may choose not to consider migration. In a context such as this income may be simulated to lag rainfall while migration decisions may be simulated to lag income. As such, a future model may more appropriately represent the impact of rainfall upon real migration decision-making.

Numerous small changes to the AMARC models could thus be undertaken to further test the influence of existing model components upon the migration flows simulated. Although outside the scope of this research, intended to test the value of ABM to simulating environmental migration in the context of Burkina Faso, such changes could provide greater understanding of the role of interactions between model entities upon the migration flows output. Even the relatively small assumptions made by this research could have some impact upon the migration flows modelled. For example, the exclusion of migrants recorded in the EMIUB as having relocated for marriage or postings will have had an impact upon modelled migration through the behavioural attitude probabilities used in the migration decision. As a result, further investigation into the use of ABM in the field of environmental migration could incorporate these components and test their likely marginal impact upon model outcomes. In the case of all such minor judgements made in the development of the AMARC models, consistency and transparency of decisions were maintained in order to create a standardised canvas from which the primary model outcomes could be assessed.

9.8 Summary

From the above conclusions, it can be seen that the influence of rainfall upon the modelled migration decision in Burkina Faso is affected by multiple complex and interacting mechanisms. The ABM presented by this thesis has sought to create a balance between a level of complexity adequate to appropriately portray the migration decision but simple enough to test the value of the modelling strategy upon simulation outcomes. As a result of the process of model development, numerous opportunities for future changes in model structure have been identified that present clear potential for future research using agent-based models within the field. By parameterising the model using as much empirically derived data as possible, the development of the AMARC model provides a solid basis upon which future attempts to quantify the influence of changes in climate on migration can draw. Migration literature shows that the migration decisions undertaken by different individuals with different contexts and circumstances vary significantly. As a result of these inherent components of complexity and agency, agent-based modelling is considered to be an appropriate tool for producing a form of quantitative analysis that incorporates important components at both macro and micro levels. As a result, a model such as AMARC can, with the availability of appropriately comprehensive data, be reapplied to agents with different contexts and circumstances. By breaking down the migration decision into its component parts the AMARC model could, given the availability of suitable data, therefore be applied to alternative situations where the influence of changes in rainfall variability upon migration shows considerable contrast to that seen in Burkina Faso. On this basis it is proposed agent-based modelling presents a viable opportunity to further understand the complex relationship between rainfall and migration and work towards reducing the uncertainty that led the Wilbanks et al. (2007) to suggest that current estimates of environmental migrants were then, “at best, guesswork”.

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Appendices

Appendix 1:	Focus group interview briefing sheet with list of questions in English and French.
Appendix 2A:	Breakdown of Sahel focus group responses into the structure provided by the Theory of Planned Behaviour.
Appendix 2B:	Breakdown of Northern Centre focus group responses into the structure provided by the Theory of Planned Behaviour.
Appendix 2C:	Breakdown of Centre focus group responses into the structure provided by the Theory of Planned Behaviour.
Appendix 2D:	Breakdown of Southwest focus group responses into the structure provided by the Theory of Planned Behaviour.
Appendix 3A:	Binary Logit model outputs.
Appendix 3B:	Multivariate binary logit model outputs.
Appendix 4:	Complete range of *ppt.mp30* behavioural attitude probability values displayed in five weight matrices.
Appendix 5:	Tabulated observed and modelled migration flows referred to in Chapter 6.
Appendix 6:	Tabulated observed and modelled migration flows referred to in Chapter 7.

Appendix 1 - *Focus group interview briefing sheet with list of questions in English and French.*

Focus Group Questions:

Arrival:
Approach head of department and ask permission to carry out interviews in area. Ask for appropriate villages to visit and name of village head.
Approach village head and ask permission to conduct interviews. Ask for 6-7 appropriate people to speak to in order to select a broad spectrum of the society (age, ethnicity etc).

INTRODUCTION:
Translator to introduce himself. Introduce Christopher and Michael. Say where we have come from and that we are carrying out a study on migration in Burkina Faso. We have about 10 questions to ask the group and are very grateful for them taking part. Some of the questions ask about them while others ask for their opinion on how people in their community act in certain situations.

INDIVIDUAL QUESTIONS:
Demographic information…

a) age
b) sex
c) married
d) children
e) job
f) ethnicity
g) religion

1. Where were you born?
Ou êtes-vous nés?

2. If not here, why did you leave your last place and come here?
S'il n'est pas né ici, pourquoi avez-vous migré ici?

GROUP DISCUSSION QUESTIONS: Translator to emphasise change in questions.

3. Are there any reasons why people would want to leave [add location]?
Selon vous, qu'est ce qui peut amener gens à quitter ici pour migrer ailleurs ?

4. Do friends / family influence someone's decision to leave a place?
- By giving advice? Asking them to leave? Or influencing them?
Est ce que les amis / parents peuvent par leur conseils, leur influences amener quelqu'un à migrer ou à rester?

5. From a community/location like this, who is likely to be the first to make the decision to leave? Vulnerable?
- Who would these people be? Young/old? Married/single?
- And then who is likely to follow?
Dans une communauté / emplacement (lieu) comme ici, qui est susceptible de prendre la décision de quitter le premier?
- Qui peuvent être ces personnes ? jeunes/vieux ? mariés/celibataires ?
- Et qui pourrait le suivre?

6. What does someone need to be able to move?
- What do you have to have to be able to go?
- How much money?
- And how long does it take to save this?
De quoi quelque'un besoin (moyens) pour migrer?
- *Combien de temps met-on pour avoir cet argent ?*
- *Est-ce que la migration coûte chère?*

7. How does someone decide where they want to go to and how long they will stay?
- Local, regional, abroad?
Comment quelqu'un décide où il veut aller?
- *locale, regionale, autre pays ?*

8. How does the amount of rain that falls in the wet season affect someone's decision to move?
- Do you have an example of this?
- And does it affect their <u>**ability**</u> to move? From q. 6.
Comment la pluviométrie affecte la migration ?
- *Avez-vous un exemple ?*
- *Est-ce que la pluviométrie a des effets sur leur capacié à migrer ?*

AND EXPAND... When? Did you move? What about this year?

9. Does migration solve the problems?
- If so, how?
- If not, why not?
Est ce que la migration est la solution à vos problemes? Si oui, comment? Si non, pourquoi? Si toutefois vous migrez pour aller à un endroit et vous vous apercevez que ce n'est pas le bon endroit, que feriez-vous ?

10. What other options are there, apart from migration, that can improve someone's standard of living?
A part la migration, que peut / peuvent être la / les solution(s) en vue d'ameliorer les conditions de vie ?

Appendix 2A - *Breakdown of Sahel focus group responses into the structure provided by the Theory of Planned Behaviour.*

SAHEL (200-499mm average annual rainfall).
Dori (17), Kampiti (18), Debere Talata (19), Windou (20), Djemba (21).

Main push factor appears to be lack of water.
All of Burkina Faso is poor but here in the Sahel they are poorest and suffer the most.

ATTITUDE TOWARD BEHAVIOURS:

MODEL COMPONENTS:
Sex (Fulani women cannot migrate alone, apart from for marriage)
Employed/Unemployed
Newly Married/Married
Age (between 15 and 20, people only migrate to where they have family at the destination. Between 21 and 35 people migrate anywhere with no worry about family connections)
Poverty level
Previous migration success (personal or familial)
Reports given by others with experience of behaviour.

IN-SITU ADAPTATION:
Wages are very low in the area. There is an excess of labour and people have to work hard as there is always someone willing to do the job for less.
Market gardening projects encourage some people to stay. Plus building of water pumps.
People will remain at home if they possibly can.
Older people prefer to remain in-situ but will migrate if their children cannot provide enough for their family. Even old men will migrate if the rains are bad.
When there is a good wet season people do not have to migrate as much.
One wet season is not enough to grow crops for an entire year so people have to migrate.
Kampiti they have a grain store that was stocked with 10 tonnes of grain by the WFO. In times of hardship they can sell this grain cheaply to prevent people having to migrate as much.
The ideal solution in many locations is a dam.
In the north money is best invested in cattle. They are a more stable investment and make you less reliant on crops. Therefore les likely to migrate?

INTERNAL MIGRATION:
People cannot survive in the north without migration remittances.
Migration can solve many people's problems. Seen as a good solution as most who migrate do so because they have little/nothing left.
The poorest people are the most willing to undertake internal migration. Willing to take risks.
People see this as easy first step.
Success is seen as down to luck.
Anyone can set off…walking or cycling.
People are used to migrating. Even when things are fine at home, people still migrate.
i.e. To gold mine in Essakan. One can get there and back more easily and cheaply. Also the potential for a lucky break and making a fortune at a BF goldmine. Being able to walk to your destination means you will always be able to get home again.

MIGRATION WITHIN AFRICA:
People may undertake this as a second step after they have worked and saved at a migration destination within BF.
Success is envisaged in IC but on nowhere near the scale of International migration.
Can be expensive, i.e. 35,000 CFA to get to IC

Migration seen as a bad thing for local culture/populations as the community loses young men. Wages in IC are higher than in BF. However, there is the added cost of travelling to IC over the cost of travelling within BF…border crossing can be expensive (bribes etc).

<u>INTERNATIONAL MIGRATION:</u>
Seen as very successful due to the strength of foreign currencies.

<u>FIRST TO MIGRATE:</u>
Orphans first. Those with no-one to talk to at home.
Newly married people. Loan taken out by parents to pay dowry must be repaid. (man migrates alone in first instance although wife may join him at a later time)
Poorest.
18-35 year olds.
When individuals migrate it is to top up the family income. The whole family will only migrate if they have nothing left. They sell their cattle etc and leave for a new start. Whole families therefore only leave in very bad years.
Individuals will move alone fairly happily. Families will keep selling things to survive without all having to leave. Once everything is gone though they will have to leave.
Fulani people in the north have to also consider when they need to move their cows. They store grass for the dry season. If this is far too little then they will move the cattle. If they only just fall short then they will bring grass to the cattle.
Young men…15-35 migrate first. Slightly older men may follow (36-45). Older men do not migrate. They have larger families, more responsibilities and may have sons old enough to migrate for them.

SUBJECTIVE NORM:

- Parents and friends have no say. It is down to the individual. Parents cannot make child stay.
- People have self-confidence in their own migration decisions and do not listen to others.
- Parents generally want children to remain at home. If no work there, they must let them leave.
- Some parents fear to ask their children to migrate.
- If family has 3 sons of a suitable migration age, then they are likely to send 3 away to work. In June, at the start of the wet season, 2 will return home to work the land while the third will remain away and send remittances.
- Migration is difficult so people would rather their children stay home.
- Cultural pattern. Older people migrated when they were young. Now it is the turn of the younger generation.
- Head of the household often holds decision making power. Can often only relate to himself though. Older men can send their sons to migrate, as their parents sent them.
- In groups of younger people, their parents and friends can advise them on what to do but never tell them.

PERCEIVED BEHAVIOURAL CONTROL:

- Anyone can migrate.
- Some people plan migration in advance and can save money.
- Employers occasionally arrive during dry season and transport people back to IC.
- Those living in extreme poverty migrate the most as they are the ones willing to take the greatest risks.
- Migration is very expensive and requires money. People can take loans if necessary.
- Money. Poor people can have a problem.

Appendix 2B - *Breakdown of Northern Centre focus group responses into the structure provided by the Theory of Planned Behaviour.*

NORTHERN CENTRE, 500-699mm average annual rainfall 1960-1998.
Borguinde (22), Som (23), Baani (24), Djibo (25).

ATTITUDE TOWARD BEHAVIOURS:

<u>IN-SITU ADAPTATION:</u>
Life here is very difficult. People need to leave to look for money. Only in-situ work in the dry season Is cattle raising.
Root cause of migration here is money. There is not enough work.
Only option apart from migration is cattle raising.
Collection of sewage as fertiliser.
Cutting and storing grass for cattle feed during dry season.

<u>INTERNAL MIGRATION:</u>
People must migrate to supplement their income and harvest. Cannot grow enough food to last a year here.
Lack of rain means people must migrate somewhere. Migration is a good option for people.
Migration is very common. Not everyone will necessarily migrate every year though. It will depend upon their stock of food and their tendency to migrate.
Internal migration is far cheaper than going outside the country. Can go far by bike.
If someone is willing to work hard then they can go to the gold mines in Burkina Faso.
Internal migration will tend to be only seasonal and so people will return for the wet season.
Persecution in Cote has led to people favouring Bobo area. At least here you will earn something and not be persecuted. In Cote you may earn more, but there is greater risk.

<u>MIGRATION WITHIN AFRICA:</u>
People like to go to Cote as it is relatively close and there is a higher chance of success.
Most common destination is cote d'ivoire
It is expensive to reach somewhere like cote. If you have enough means though, you will go.
If looking for plantation work or increased rainfall then Cote is the place.
Distance travelled and length of contract may mean that people are more likely to stay for longer.
Civil war in Cote reduced its popularity for a while. You may get a large amount of money but you may also be persecuted. This has led to a shift in favour towards Bobo.
People who migrate to Cote often do not return for the wet season and so stay away for up to and over 1 year.

<u>INTERNATIONAL MIGRATION:</u>
Generally considered to be very fruitful but a miserable option.
Need to have links at destination.
If move illegally to the west, people will stay away for a very long time. I f legal then they may return for visits.

<u>FIRST TO MIGRATE:</u>
Young men. 17-20 usually at first departure. Married and un married alike. Even 10 if the type of work is suitable.
Men aged 18-35. Beyond 35, men do not tend to migrate unless they are very poor and have no sons to send.
Also, 20-50?
Married girls do not move. Unmarried girls only move very rarely.
Young married men migrate commonly but their wives usually remain at home.
Older men migrate only if they have no other family to send or the season is very bad.

Men over 60 will generally not migrate at all.

SUBJECTIVE NORM:

- People are most likely to follow another person's advice if they have already been successful in migration.
- Most parents do not want their child to migrate but it is necessary.
- Parents can suggest to their child that he migrates because they have greater experience.
- Parents can prevent a child from leaving as it is an agreement between father and child.
- There is only one way to choose a destination…places where other migrants have succeeded. Even if the journey to get there is difficult, people will strive to reach such a place.
- Parents can advise children.
- Friends also influence…a friend may ask another to join him on his migration to a destination.
- Children generally ask their parent's opinion on migration. Some do not and just leave if they know their parent would have advised against it.
- If parents see that their neighbours' child has migrated successfully, then they will push their child to go too.
- Globalisation has touched family life in towns. Parents do not influence their child.
- In Africa, success is not individual…people will tell their friends where they can achieve well.
- Groups of boys may all leave at once and go to the same destination.

PERCEIVED BEHAVIOURAL CONTROL:

- The further you travel, the greater the cost.
- Poorer people are the first to migrate and do so the most. Poor only migrate within Africa.
- Richer people may migrate also to get richer. Rich may go outside Africa.
- Travel costs are the greatest challenge when migrating.
- Saving is very difficult as it reduces your already stretched budget. Loans can be used.
- People will sell what they have to be able to migrate. To raise a cow worth selling for example can take 1-2 years.
- If you have enough money you will go to Cote.
- Step by step migration is cheaper and more common than going all the way at once.
- Poor rainfall means that more people will go.
- In extreme situations whole families may migrate and not return. ie 1973. If they have not enough food for three years then they will up and leave.
- Most migration occurs in years of bad rainfall.

Appendix 2C - *Breakdown of Centre focus group responses into the structure provided by the Theory of Planned Behaviour.*

CENTRE (700-899mm average annual rainfall 1960-1998.)
Ouarkoye (4), Ouarkoye (5), Pouankuy (6), Bukwye (7), Fada (26), Koare (27), Komadougou (28), Fada (29).

ATTITUDE TOWARD BEHAVIOURS:

MODEL COMPONENTS:
Employment…search for land to grow?

IN-SITU ADAPTATION:
In response to flooding, people move a shorter distance and for a shorter period of time.
People leave to look for money.
Lack of fertile land pushes people. The biggest push is not being able to produce enough.
Building a dam to provide water for market gardening in the dry season can enable people to stay in-situ
Issues of land availability with many Mossi immigrants.

INTERNAL MIGRATION:
May migrate due to shortage of land for farming.
Looking for land where they can grow more.
Migrating as a farmer with cattle is often successful.
Moving as an individual to find work in a city can often fail. Networks help.
Internal seasonal migration.
Fairly cheap.
Destinations from here are usually the cities, Ouaga and Bobo. Sometimes to gold mines.
These are good areas for rainfall. People tend to migrate in search of employment for financial means.

MIGRATION WITHIN AFRICA:
Migration from the west area is only to abroad, i.e. Cote d'Ivoire (6). If you cannot make a living here then you must go aborad.
People tend to head to Cote d'Ivoire (and some to Niger from the East)
Some migrate in search of knowledge
More expensive. Cost is comparatively greater than it used to be.

INTERNATIONAL MIGRATION:
More common (but still rare) for over 35s.

FIRST TO MIGRATE:
Young men. Affected by unemployment.
Young women when they get married.
Fulani?
Old people do not move from here, even to follow younger migrants in the worst times.
Migrants are usually young men aged 20-35.
Before the age of 20, people talk with others about migration and decide where they will go when they are 20.
Poorest people.

SUBJECTIVE NORM:

- Individual decision.

- No consideration of other influences, purely level of profit that can be achieved at destination.
- When migration concerns the whole family, everyone will follow the decision of the father.
- If your family are not supporting you and a friend tells you to go somewhere then you are likely to.
- If someone promises greater profit somewhere then you may go.
- May leave to get away from parents!
- There is no external influence from other people.
- On occasion, if a friend leaves, they may ask another to go with them.
- In Bwaba culture, asking others is rare. In Mossi culture this is more common.
- Migration can be obligatory as a means to support your family – during the dry season to top up supplies and feed family.
- A parent can provide what their child needs to stop them needing to migrate.
- When people migrate and return
- Friends can advise people to stay.
- Parents can ask children if family is organised in that way. Migration must be carefully arranged to prevent leaving the household short-handed.
- Parents normally don't ask their children to migrate as they don't want to make the decision for them.
- If a child asks their parent for permission the parent is usually supportive. If they are not then the child will most likely go anyway.

PERCEIVED BEHAVIOURAL CONTROL:

- Migrating alone can cost nothing at all. Especially if only over a short distance. Moving an entire family can be very expensive.
- Costs a lot in money and suffering.
- Those with the means can catch a bus. However, those who really need to migrate will not be able to catch a bus and so will likely not go by bus.
- Father or son may migrate to check a location to relocate family from one place to another in the future.
- Those who have to migrate are often those who cannot afford it.
- The family may send one member initially to test an area for 1 wet season. If all goes well the family may follow the next year.
- When there is enough rain there is no need to move.
- During a bad year (2004) many families wanted to move but stayed in-situ. This was because they could not afford to eat, let alone migrate.
- As most migrants from here are young people, they can sell their bicycle and leave with what they have. Even if going abroad.
- Young can travel step-by-step.
- If you don't know someone in the place you are heading it can make migration very expensive
- To achieve more expensive migration, people may work and move in steps.
- People with the courage to do so can migrate with nothing.
- People's families contribute to the cost of their migration.
- When parents try and stop migration the child may end up having to leave with just their bicycle.
- Some families who are used to migration will send someone to migrate even when they do not really need to. Every year there will be a migrant.

Appendix 2D - *Breakdown of Southwest focus group responses into the structure provided by the Theory of Planned Behaviour.*

SOUTHWEST 900 + mm average annual rainfall 1960-1998.
Tengrela (10),Karfiguela (11), Banfora (12), Lemouroudougou (13), Tangora (14).

Poverty and lack of food are the main causes of migration from here.
Shortage of jobs.

ATTITUDE TOWARD BEHAVIOURS:

MODEL COMPONENTS:
Employment

IN-SITU ADAPTATION:
Floods can cause households to relocate temporarily, or sometimes permanently.
Dams can make life in the southwest possible without migration.
Money and marriage are the two things that make people migrate from here.
There is always enough food here so even in bad years for rainfall there is no need to move as a result of rainfall.
Could change crop.
Dry season market gardening.

INTERNAL MIGRATION:
Migration from here to Ouaga is almost as far as to Cote.
This area is used as a staging post for migrants moving to Cote.
Migrating away from home is difficult and makes people uneasy.

MIGRATION WITHIN AFRICA:
Young people searching for money must extend their reach beyond Burkina Faso.
Most people who leave here go to Cote.
Most migrants from here choose to travel to other countries within Africa.
In this country there is only poverty so people must move to look for money.
Migrating away from home is difficult and makes people uneasy.
Migration is not always so successful when you remain in Africa.
Countries like Cote have 2 wet seasons.

INTERNATIONAL MIGRATION:
Migrating away from home is difficult and makes people uneasy.
Migration is generally very successful when you make it to the west.

FIRST TO MIGRATE:
Young people looking for jobs are the only ones to migrate.
Mainly young single men.
First leave at 18-20. Very often leave with another person – a brother or friend.

SUBJECTIVE NORM:

- People may not always vocalise what they intend to do. They may just go.
- Migration is a personal decision and not influenced by parents/friends.
- Family/friends cannot ask someone to migrate.
- 90% of families push their children to migrate because of poverty. 10% of families do not want the family unit to be separated.
- Parents cannot always control child’s movement. It is down to their own will.

- The decision is individual and depends upon what has pushed the migrant in the first place.
- People can persuade someone to stay in a location if there is work available there. If not then there are no grounds for persuasion.

PERCEIVED BEHAVIOURAL CONTROL:

- Migration to Cote is very expensive compared with internal migration. Bribes etc.
- Most migrants from here choose to travel to other countries within Africa. They are poor people and that is what they know they can achieve.
- Some migrants may want to go west but see it as outside their reach.
- Increased distance results in increased cost of migration. Cote is the furthest anyone migrates from here. Places between here and the border are the shortest distances anyone will travel.
- It will take average workers about 2 years to save enough to move abroad.
- Ability to move depends upon job and income. A gardener could sell all stock and go. His employee would have to save for a long time.
- Before you go you must be assured that you can have a job in your destination.

Appendix 3A - *Binary logit model outputs.*

<u>Age and Age^2</u>

```
. logit migrate age age2,  cluster(numqbio) or

Iteration 0:   log pseudolikelihood = -48732.893
Iteration 1:   log pseudolikelihood = -47272.198
Iteration 2:   log pseudolikelihood = -47074.733
Iteration 3:   log pseudolikelihood = -47073.644
Iteration 4:   log pseudolikelihood = -47073.643

Logistic regression                               Number of obs   =     171209
                                                  Wald chi2(2)    =     873.11
                                                  Prob > chi2     =     0.0000
Log pseudolikelihood = -47073.643                 Pseudo R2       =     0.0340

                              (Std. Err. adjusted for 7361 clusters in numqbio)
```

migrate	Odds Ratio	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
age	1.207697	.0077389	29.45	0.000	1.192624	1.222961
age2	.9957996	.0001424	-29.44	0.000	.9955205	.9960787
_cons	.0165518	.0010512	-64.58	0.000	.0146145	.0187459

<u>Gender</u>

```
. xi: logit migrate i.gender,  cluster(numqbio) or
i.gender          _Igender_1-2        (naturally coded; _Igender_1 omitted)

Iteration 0:   log pseudolikelihood = -48732.893
Iteration 1:   log pseudolikelihood =  -48626.61
Iteration 2:   log pseudolikelihood = -48626.303
Iteration 3:   log pseudolikelihood = -48626.303

Logistic regression                               Number of obs   =     171209
                                                  Wald chi2(1)    =     181.82
                                                  Prob > chi2     =     0.0000
Log pseudolikelihood = -48626.303                 Pseudo R2       =     0.0022

                              (Std. Err. adjusted for 7361 clusters in numqbio)
```

migrate	Odds Ratio	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
_Igender_2	.773388	.0147389	-13.48	0.000	.7450331	.802822
_cons	.1018737	.001409	-165.14	0.000	.0991492	.104673

Marital Status

```
. logit migrate marital,  cluster(numqbio) or

Iteration 0:   log pseudolikelihood = -48732.893
Iteration 1:   log pseudolikelihood =  -48659.11
Iteration 2:   log pseudolikelihood = -48658.963
Iteration 3:   log pseudolikelihood = -48658.963

Logistic regression                               Number of obs   =     171209
                                                  Wald chi2(1)    =     110.55
                                                  Prob > chi2     =     0.0000
Log pseudolikelihood = -48658.963                 Pseudo R2       =     0.0015

                             (Std. Err. adjusted for 7361 clusters in numqbio)
```

migrate	Odds Ratio	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
marital	.8072773	.0164375	-10.51	0.000	.7756947	.8401458
_cons	.099594	.0013143	-174.79	0.000	.097051	.1022037

Origin Location

```
. xi: logit migrate i.origin,  cluster(numqbio) or
i.origin          _Iorigin_1-5        (naturally coded; _Iorigin_1 omitted)

Iteration 0:   log pseudolikelihood = -48732.893
Iteration 1:   log pseudolikelihood = -48719.988
Iteration 2:   log pseudolikelihood = -48719.976
Iteration 3:   log pseudolikelihood = -48719.976

Logistic regression                               Number of obs   =     171209
                                                  Wald chi2(4)    =      21.55
                                                  Prob > chi2     =     0.0002
Log pseudolikelihood = -48719.976                 Pseudo R2       =     0.0003

                             (Std. Err. adjusted for 7361 clusters in numqbio)
```

migrate	Odds Ratio	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
_Iorigin_2	1.122831	.0372122	3.50	0.000	1.052215	1.198187
_Iorigin_3	1.147186	.0362908	4.34	0.000	1.078217	1.220566
_Iorigin_4	1.104462	.0347212	3.16	0.002	1.038464	1.174655
_Iorigin_5	1.063477	.0395174	1.66	0.098	.9887774	1.14382
_cons	.0819969	.0020692	-99.11	0.000	.07804	.0861544

Rainfall

```
. xi: logit migrate i.rainfall,  cluster(numqbio) or
i.rainfall        _Irainfall_1-3      (naturally coded; _Irainfall_1 omitted)

Iteration 0:   log pseudolikelihood = -48732.893
Iteration 1:   log pseudolikelihood = -48732.661
Iteration 2:   log pseudolikelihood = -48732.661

Logistic regression                               Number of obs   =     171209
                                                  Wald chi2(2)    =       0.45
                                                  Prob > chi2     =     0.7970
Log pseudolikelihood = -48732.661                 Pseudo R2       =     0.0000

                             (Std. Err. adjusted for 7361 clusters in numqbio)
```

migrate	Odds Ratio	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
_Irainfall_2	.9877394	.0211713	-0.58	0.565	.947104	1.030118
_Irainfall_3	.9993303	.0234195	-0.03	0.977	.9544672	1.046302
_cons	.0903471	.0015721	-138.16	0.000	.0873178	.0934814

Appendix 3B – *Multivariate binary logit model outputs.*

Age, Age^2, Gender, Marital Status, Origin Location, Rainfall

```
. xi: logit migrate age age2 i.gender marital i.origin i.rainfall,  cluster(num
> qbio) or
i.gender          _Igender_1-2        (naturally coded; _Igender_1 omitted)
i.origin          _Iorigin_1-5        (naturally coded; _Iorigin_1 omitted)
i.rainfall        _Irainfall_1-3      (naturally coded; _Irainfall_1 omitted)

Iteration 0:   log pseudolikelihood = -48732.893
Iteration 1:   log pseudolikelihood = -47210.734
Iteration 2:   log pseudolikelihood = -46931.667
Iteration 3:   log pseudolikelihood = -46927.376
Iteration 4:   log pseudolikelihood = -46927.376

Logistic regression                               Number of obs   =     171209
                                                  Wald chi2(10)   =    1129.09
                                                  Prob > chi2     =     0.0000
Log pseudolikelihood = -46927.376                 Pseudo R2       =     0.0370

                             (Std. Err. adjusted for 7361 clusters in numqbio)
```

migrate	Odds Ratio	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
age	1.201889	.0082121	26.91	0.000	1.185901	1.218093
age2	.9958358	.0001443	-28.80	0.000	.9955531	.9961186
_Igender_2	.7353639	.0153028	-14.77	0.000	.7059743	.765977
marital	1.067854	.034046	2.06	0.039	1.003167	1.136712
_Iorigin_2	1.141734	.0352621	4.29	0.000	1.074672	1.212981
_Iorigin_3	1.124627	.0336291	3.93	0.000	1.060609	1.192508
_Iorigin_4	1.13338	.032869	4.32	0.000	1.070755	1.199668
_Iorigin_5	1.087449	.0375739	2.43	0.015	1.016244	1.163644
_Irainfall_2	.9763635	.0210706	-1.11	0.268	.935927	1.018547
_Irainfall_3	1.021492	.0242841	0.89	0.371	.9749883	1.070214
_cons	.0184884	.001356	-54.41	0.000	.0160129	.0213467

Appendix 4 - *Complete range of ppt.mp30 behavioural attitude probability values displayed in five weight matrices.*

Weight matrix displaying behavioural attitude probabilities of individuals relocating from **Ouagadougou** to listed destinations. Calculated using *ppt.mp30*.

		1	2	3	4	5	6	7	8	9
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		15-20 married female			15-20 married male			15-20 single female		
1	Ouaga	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	Bobo	0.0025	0.0000	0.0049	0.0000	0.0000	0.0000	0.0017	0.0032	0.0056
3	Sahel	0.0385	0.0409	0.0482	0.0000	0.0875	0.0000	0.0000	0.0000	0.0026
4	Centre	0.0828	0.0849	0.0939	0.0179	0.0521	0.0000	0.0047	0.0059	0.0026
5	Southwest	0.0609	0.0646	0.0639	0.0357	0.0000	0.0000	0.0079	0.0167	0.0082
6	International	0.0089	0.0096	0.0153	0.0000	0.0833	0.0000	0.0000	0.0000	0.0000

		10	11	12	13	14	15	16	17	18
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		15-20 single male			21-35 married female			21-35 married male		
1	Ouaga	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	Bobo	0.0042	0.0083	0.0000	0.0012	0.0017	0.0005	0.0019	0.0047	0.0039
3	Sahel	0.0142	0.0148	0.0047	0.0028	0.0021	0.0067	0.0060	0.0070	0.0047
4	Centre	0.0307	0.0339	0.0291	0.0116	0.0087	0.0183	0.0220	0.0238	0.0181
5	Southwest	0.0230	0.0232	0.0175	0.0133	0.0105	0.0245	0.0065	0.0107	0.0131
6	International	0.0079	0.0079	0.0140	0.0076	0.0078	0.0147	0.0240	0.0290	0.0223

		19	20	21	22	23	24	25	26	27
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		21-35 single female			21-35 single male			35+ married female		
1	Ouaga	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	Bobo	0.0000	0.0104	0.0000	0.0039	0.0050	0.0028	0.0000	0.0000	0.0000
3	Sahel	0.0000	0.0000	0.0000	0.0106	0.0086	0.0093	0.0004	0.0009	0.0024
4	Centre	0.0143	0.0000	0.0000	0.0224	0.0301	0.0410	0.0043	0.0000	0.0031
5	Southwest	0.0238	0.0179	0.0375	0.0210	0.0144	0.0117	0.0017	0.0023	0.0025
6	International	0.0079	0.0275	0.0139	0.0352	0.0379	0.0257	0.0012	0.0022	0.0110

		28	29	30	31	32	33	34	35	36
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		35+ married male			35+ single female			35+ single male		
1	Ouaga	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	Bobo	0.0011	0.0000	0.0000	0.0000	0.0417	0.0000	0.0000	0.0000	0.0000
3	Sahel	0.0024	0.0026	0.0043	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	Centre	0.0074	0.0027	0.0043	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	Southwest	0.0051	0.0036	0.0044	0.0357	0.0000	0.0000	0.0000	0.0387	0.0000
6	International	0.0112	0.0047	0.0149	0.0000	0.0000	0.0000	0.0000	0.0000	0.0563

Weight matrix displaying behavioural attitude probabilities of individuals relocating from **Bobo Dioulasso** to listed destinations. Calculated using *ppt.mp30*.

		1	2	3	4	5	6	7	8	9
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		15-20 married female			15-20 married male			15-20 single female		
1	Ouaga	0.0211	0.0196	0.0218	0.0298	0.0000	0.0000	0.0020	0.0014	0.0072
2	Bobo	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	Sahel	0.0507	0.0495	0.0409	0.0595	0.0417	0.0741	0.0020	0.0018	0.0000
4	Centre	0.0793	0.0897	0.0779	0.0751	0.0000	0.0000	0.0199	0.0186	0.0098
5	Southwest	0.0171	0.0223	0.0216	0.0232	0.0833	0.0000	0.0081	0.0040	0.0167
6	International	0.0146	0.0051	0.0152	0.0657	0.0729	0.0000	0.0035	0.0034	0.0016

		10	11	12	13	14	15	16	17	18
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		15-20 single male			21-35 married female			21-35 married male		
1	Ouaga	0.0103	0.0051	0.0117	0.0068	0.0047	0.0107	0.0092	0.0143	0.0046
2	Bobo	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	Sahel	0.0169	0.0127	0.0056	0.0091	0.0075	0.0054	0.0196	0.0143	0.0083
4	Centre	0.0259	0.0302	0.0374	0.0127	0.0164	0.0134	0.0188	0.0130	0.0165
5	Southwest	0.0112	0.0068	0.0072	0.0057	0.0064	0.0064	0.0075	0.0063	0.0036
6	International	0.0159	0.0131	0.0084	0.0087	0.0076	0.0124	0.0208	0.0163	0.0179

		19	20	21	22	23	24	25	26	27
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		21-35 single female			21-35 single male			35+ married female		
1	Ouaga	0.0127	0.0141	0.0110	0.0128	0.0233	0.0143	0.0017	0.0018	0.0023
2	Bobo	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	Sahel	0.0000	0.0000	0.0000	0.0104	0.0084	0.0125	0.0017	0.0036	0.0029
4	Centre	0.0026	0.0000	0.0069	0.0202	0.0522	0.0211	0.0041	0.0084	0.0006
5	Southwest	0.0095	0.0000	0.0034	0.0079	0.0159	0.0042	0.0016	0.0008	0.0062
6	International	0.0000	0.0074	0.0000	0.0352	0.0145	0.0411	0.0187	0.0005	0.0048

		28	29	30	31	32	33	34	35	36
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		35+ married male			35+ single female			35+ single male		
1	Ouaga	0.0034	0.0043	0.0067	0.0000	0.0000	0.0000	0.0000	0.0139	0.0200
2	Bobo	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	Sahel	0.0073	0.0106	0.0028	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	Centre	0.0053	0.0022	0.0077	0.0000	0.0000	0.0000	0.0226	0.0000	0.0104
5	Southwest	0.0031	0.0032	0.0072	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	International	0.0123	0.0160	0.0090	0.0417	0.0000	0.0000	0.0167	0.0139	0.0409

Weight matrix displaying behavioural attitude probabilities of individuals relocating from **Sahel** to listed destinations. Calculated using *ppt.mp30*.

		1	2	3	4	5	6	7	8	9
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		15-20 married female			15-20 married male			15-20 single female		
1	Ouaga	0.0945	0.1013	0.1010	0.0794	0.0000	0.0313	0.0142	0.0224	0.0131
2	Bobo	0.0020	0.0018	0.0045	0.0000	0.0000	0.0000	0.0020	0.0022	0.0000
3	Sahel	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	Centre	0.0850	0.1035	0.0668	0.0151	0.0000	0.0625	0.0173	0.0108	0.0132
5	Southwest	0.0190	0.0049	0.0045	0.0000	0.0000	0.0000	0.0017	0.0000	0.0015
6	International	0.0131	0.0141	0.0176	0.0179	0.0417	0.0000	0.0006	0.0071	0.0000

		10	11	12	13	14	15	16	17	18
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		15-20 single male			21-35 married female			21-35 married male		
1	Ouaga	0.0218	0.0303	0.0162	0.0234	0.0320	0.0243	0.0195	0.0211	0.0264
2	Bobo	0.0039	0.0033	0.0008	0.0020	0.0012	0.0014	0.0012	0.0008	0.0026
3	Sahel	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	Centre	0.0358	0.0331	0.0372	0.0160	0.0083	0.0177	0.0228	0.0205	0.0195
5	Southwest	0.0029	0.0051	0.0011	0.0038	0.0045	0.0039	0.0036	0.0046	0.0075
6	International	0.0136	0.0093	0.0118	0.0088	0.0032	0.0072	0.0098	0.0133	0.0119

		19	20	21	22	23	24	25	26	27
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		21-35 single female			21-35 single male			35+ married female		
1	Ouaga	0.0110	0.0607	0.0096	0.0263	0.0403	0.0452	0.0049	0.0077	0.0096
2	Bobo	0.0000	0.0000	0.0042	0.0085	0.0066	0.0039	0.0009	0.0005	0.0000
3	Sahel	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	Centre	0.0087	0.0170	0.0739	0.0142	0.0197	0.0310	0.0045	0.0123	0.0043
5	Southwest	0.0000	0.0020	0.0000	0.0031	0.0097	0.0055	0.0019	0.0007	0.0000
6	International	0.0207	0.0041	0.0000	0.0249	0.0230	0.0168	0.0033	0.0017	0.0000

		28	29	30	31	32	33	34	35	36
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		35+ married male			35+ single female			35+ single male		
1	Ouaga	0.0135	0.0060	0.0054	0.0000	0.0000	0.0000	0.0258	0.0139	0.0000
2	Bobo	0.0038	0.0039	0.0013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	Sahel	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	Centre	0.0153	0.0138	0.0040	0.0000	0.0000	0.0313	0.0222	0.0000	0.0000
5	Southwest	0.0031	0.0030	0.0018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	International	0.0044	0.0037	0.0047	0.0000	0.0000	0.0000	0.0400	0.0000	0.0250

Weight matrix displaying behavioural attitude probabilities of individuals relocating from **Centre** to listed destinations. Calculated using *ppt.mp30*.

		1	2	3	4	5	6	7	8	9
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		15-20 married female			15-20 married male			15-20 single female		
1	Ouaga	0.0425	0.0424	0.0430	0.0102	0.0139	0.0000	0.0020	0.0132	0.0072
2	Bobo	0.0032	0.0086	0.0051	0.0000	0.0000	0.0000	0.0009	0.0036	0.0031
3	Sahel	0.0103	0.0075	0.0157	0.0065	0.0000	0.0000	0.0000	0.0000	0.0000
4	Centre	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	Southwest	0.0371	0.0398	0.0252	0.0000	0.0764	0.0417	0.0047	0.0036	0.0054
6	International	0.0246	0.0193	0.0187	0.0613	0.0125	0.0193	0.0022	0.0067	0.0017

		10	11	12	13	14	15	16	17	18
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		15-20 single male			21-35 married female			21-35 married male		
1	Ouaga	0.0158	0.0156	0.0160	0.0117	0.0103	0.0118	0.0175	0.0175	0.0227
2	Bobo	0.0031	0.0044	0.0035	0.0021	0.0017	0.0019	0.0021	0.0032	0.0026
3	Sahel	0.0032	0.0063	0.0055	0.0012	0.0013	0.0007	0.0027	0.0020	0.0066
4	Centre	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	Southwest	0.0113	0.0078	0.0102	0.0057	0.0063	0.0042	0.0123	0.0088	0.0083
6	International	0.0126	0.0095	0.0082	0.0137	0.0155	0.0088	0.0245	0.0303	0.0147

		19	20	21	22	23	24	25	26	27
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		21-35 single female			21-35 single male			35+ married female		
1	Ouaga	0.0036	0.0208	0.0000	0.0324	0.0281	0.0158	0.0068	0.0009	0.0065
2	Bobo	0.0000	0.0139	0.0000	0.0053	0.0086	0.0065	0.0017	0.0009	0.0017
3	Sahel	0.0000	0.0000	0.0000	0.0026	0.0025	0.0036	0.0012	0.0000	0.0003
4	Centre	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	Southwest	0.0102	0.0114	0.0050	0.0119	0.0095	0.0085	0.0028	0.0027	0.0005
6	International	0.0000	0.0313	0.0114	0.0295	0.0448	0.0322	0.0023	0.0044	0.0176

		28	29	30	31	32	33	34	35	36
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		35+ married male			35+ single female			35+ single male		
1	Ouaga	0.0125	0.0070	0.0073	0.0714	0.0000	0.0000	0.0000	0.0357	0.0096
2	Bobo	0.0038	0.0032	0.0012	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	Sahel	0.0019	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	Centre	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	Southwest	0.0019	0.0025	0.0049	0.0000	0.0000	0.0000	0.0151	0.0000	0.0000
6	International	0.0060	0.0076	0.0138	0.0357	0.0000	0.0000	0.0298	0.0217	0.0000

Weight matrix displaying behavioural attitude probabilities of individuals relocating from **Southwest** to listed destinations. Calculated using *ppt.mp30*.

		1	2	3	4	5	6	7	8	9
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		15-20 married female			15-20 married male			15-20 single female		
1	Ouaga	0.0206	0.0315	0.0305	0.0000	0.0000	0.0000	0.0000	0.0089	0.0035
2	Bobo	0.0036	0.0033	0.0114	0.0000	0.0000	0.0000	0.0000	0.0027	0.0037
3	Sahel	0.0154	0.0174	0.0341	0.0286	0.0000	0.0625	0.0024	0.0000	0.0000
4	Centre	0.1135	0.1308	0.1269	0.0357	0.0625	0.0625	0.0332	0.0319	0.0172
5	Southwest	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	International	0.0272	0.0074	0.0129	0.0500	0.0625	0.0625	0.0034	0.0087	0.0083

		10	11	12	13	14	15	16	17	18
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		15-20 single male			21-35 married female			21-35 married male		
1	Ouaga	0.0032	0.0054	0.0120	0.0094	0.0050	0.0072	0.0168	0.0120	0.0154
2	Bobo	0.0041	0.0096	0.0020	0.0035	0.0052	0.0046	0.0089	0.0065	0.0049
3	Sahel	0.0090	0.0095	0.0139	0.0054	0.0046	0.0026	0.0033	0.0071	0.0198
4	Centre	0.0696	0.0677	0.0401	0.0137	0.0179	0.0220	0.0288	0.0268	0.0292
5	Southwest	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	International	0.0054	0.0144	0.0066	0.0064	0.0098	0.0083	0.0146	0.0155	0.0198

		19	20	21	22	23	24	25	26	27
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		21-35 single female			21-35 single male			35+ married female		
1	Ouaga	0.0186	0.0078	0.0000	0.0244	0.0334	0.0262	0.0005	0.0020	0.0104
2	Bobo	0.0000	0.0179	0.0000	0.0082	0.0099	0.0060	0.0000	0.0014	0.0000
3	Sahel	0.0065	0.0000	0.0000	0.0070	0.0022	0.0027	0.0004	0.0000	0.0007
4	Centre	0.0255	0.0179	0.0382	0.0457	0.0422	0.0465	0.0160	0.0047	0.0280
5	Southwest	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	International	0.0119	0.0000	0.0000	0.0352	0.0276	0.0208	0.0144	0.0036	0.0063

		28	29	30	31	32	33	34	35	36
		Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry
		35+ married male			35+ single female			35+ single male		
1	Ouaga	0.0058	0.0042	0.0065	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	Bobo	0.0021	0.0031	0.0027	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	Sahel	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0238	0.0000	0.0000
4	Centre	0.0109	0.0010	0.0043	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	Southwest	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	International	0.0090	0.0034	0.0041	0.0000	0.0000	0.0000	0.0000	0.0000	0.0417

Appendix 5 - *Tabulated observed and modelled migration flows referred to in Chapter 6.*

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest	Total
1970	16 (2.42)	29 (3.25)	25 (2.78)	27 (1.98)	24 (3.79)	121 (2.94)
1971	19 (2.87)	20 (2.24)	18 (2.00)	22 (1.61)	16 (2.52)	104 (2.34)
1972	19 (2.87)	25 (2.80)	22 (2.45)	27 (1.98)	22 (3.47)	125 (2.81)
1973	18 (2.72)	27 (3.02)	22 (2.45)	23 (1.69)	20 (3.15)	120 (2.70)
1974	26 (3.93)	22 (2.46)	29 3.23()	31 (2.27)	29 (4.57)	149 (3.35)
1975	23 (3.48)	29 (3.25)	35 (3.90)	33 (2.42)	29 (4.57)	162 (3.64)
1976	27 (4.08)	34 (3.81)	37 (4.12)	28 (2.05)	27 (4.26)	167 (3.75)
1977	34 (5.14)	22 (2.46)	48 (5.35)	22 (1.61)	30 (4.73)	171 (3.84)
1978	29 (4.39)	25 (2.80)	31 (3.45)	52 (3.82)	41 (6.47)	192 (4.32)
1979	27 (4.08)	28 (3.14)	42 (4.68)	49 (3.60)	38 (5.99)	199 (4.47)
1980	44 (6.66)	43 (4.82)	53 (5.90)	73 (5.36)	44 (6.94)	280 (6.29)
1981	31 (4.69)	35 (3.92)	35 (3.90)	42 (3.08)	42 (6.62)	201 (4.52)
1982	38 (5.75)	34 (3.81)	39 (4.34)	56 (4.11)	43 (6.78)	228 (5.12)
1983	39 (5.90)	46 (5.15)	54 (6.01)	43 (3.15)	33 (5.21)	235 (5.28)
1984	43 (6.51)	48 (5.38)	51 (5.68)	52 (3.82)	47 (7.41)	262 (5.89)
1985	40 (6.05)	54 (6.05)	67 (7.46)	74 (5.43)	24 (3.79)	284 (6.38)
1986	38 (5.75)	45 (5.04)	58 (6.46)	69 (5.06)	28 (4.42)	260 (5.84)
1987	37 (5.60)	42 (4.70)	60 (6.68)	71 (5.21)	36 (5.68)	268 (6.02)
1988	32 (4.84)	39 (4.37)	60 (6.68)	62 (4.55)	34 (5.36)	247 (5.55)
1989	24 (3.63)	36 (4.03)	38 (4.23)	57 (4.18)	27 (4.26)	198 (4.45)
1990	44 (6.66)	49 (5.49)	61 (6.79)	67 (4.92)	28 (4.42)	273 (6.24)
1991	25 (3.78)	34 (3.81)	28 (3.12)	39 (2.86)	18 (2.84)	158 (3.55)
1992	25 (3.78)	33 (3.70)	30 (3.34)	39 (2.86)	30 (4.73)	171 (3.84)
1993	17 (2.57)	20 (2.24)	35 (3.90)	36 (2.64)	23 (3.63)	142 (3.19)
1994	35 (5.30)	29 (3.25)	39 (4.34)	45 (3.30)	19 (3.00)	183 (4.11)
1995	23 (3.48)	24 (2.69)	36 (4.01)	56 (4.11)	33 (5.21)	186 (4.18)
1996	28 (4.24)	25 (2.80)	31 (3.45)	32 (2.35)	38 (5.99)	167 (3.75)
1997	18 (2.72)	32 (3.58)	25 (2.78)	32 (2.35)	25 (3.94)	143 (3.21)
1998	16 (2.42)	33 (3.70)	50 (5.57)	41 (3.01)	27 (4.26)	182 (4.09)
1999	17 (2.57)	24 (2.69)	39 (4.34)	39 (2.86)	16 (2.52)	147 (3.30)
Ave.:	28 (4.30)	33 (3.68)	40 (4.45)	45 (3.27)	30 (4.68)	191 (4.30)

Appendix 5, Table 1: Annual populations of agents recorded by the EMIUB1 data as alive in 1970 and leaving each origin zone between 1970 and 1999. Percentage of total population that migrants represent shown in (brackets).

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest	Total
1970	3 (0.45)	19 (2.13)	32 (3.53)	10 (0.76)	4 (0.63)	68 (1.53)
1971	11 (1.71)	24 (2.69)	31 (3.49)	16 (1.17)	12 (1.84)	94 (2.12)
1972	14 (2.12)	21 (2.31)	27 (2.97)	17 (1.22)	15 (2.31)	93 (2.08)
1973	9 (1.41)	30 (3.36)	21 (2.34)	17 (1.25)	13 (2.00)	90 (2.02)
1974	23 (3.53)	33 (3.70)	32 (3.60)	29 (2.10)	22 (3.42)	139 (3.12)
1975	29 (4.39)	37 (4.18)	30 (3.34)	30 (2.18)	30 (4.78)	156 (3.51)
1976	29 (4.39)	41(4.59)	34 (3.79)	36 (2.62)	24 (3.84)	164 (3.68)
1977	24 (3.63)	37 (4.11)	36 (4.01)	36 (2.64)	29 (4.63)	162 (3.64)
1978	36 (5.40)	43 (4.78)	36 (3.97)	44 (3.25)	33 (5.15)	191 (4.29)
1979	34 (5.09)	44 (4.89)	47 (5.27)	54 (3.99)	39 (6.10)	218 (4.89)
1980	46 (6.91)	54 (6.01)	44 (4.90)	63 (4.60)	42 (6.68)	248 (5.58)
1981	44 (6.71)	69 (7.73)	53 (5.94)	72 (5.26)	46 (7.20)	284 (6.38)
1982	47 (7.06)	47 (5.23)	60 (6.68)	62 (4.55)	45 (7.05)	260 (5.84)
1983	46 (6.91)	50 (5.56)	57 (6.38)	59 (4.35)	49 (7.78)	261 (5.87)
1984	54 (8.12)	57 (6.42)	58 (6.42)	67 (4.89)	43 (6.73)	278 (6.25)
1985	57 (8.62)	57 (6.42)	67 (7.42)	72 (5.31)	56 (8.78)	309 (6.95)
1986	59 (8.88)	87 (9.71)	63 (7.05)	79 (5.77)	49 (7.78)	337 (7.57)
1987	54 (8.17)	76 (8.55)	72 (7.98)	81 (5.97)	57 (8.94)	340 (7.64)
1988	55 (8.37)	69 (7.69)	80 (8.87)	79 (5.82)	53 (8.36)	336 (7.55)
1989	57 (8.67)	79 (8.81)	88 (9.76)	86 (6.29)	54 (8.57)	364 (8.17)
1990	70 (10.64)	88 (9.82)	79 (8.80)	83 (6.09)	53 (8.31)	373 (8.38)
1991	49 (7.46)	75 (8.40)	61 (6.76)	70 (5.11)	36 (5.68)	291 (6.53)
1992	43 (6.56)	64 (7.17)	66 (7.31)	72 (5.28)	50 (7.94)	295 (6.64)
1993	64 (9.63)	82 (9.18)	66 (7.35)	72 (5.26)	52 (8.25)	336 (7.54)
1994	43 (6.56)	75 (8.44)	68 (7.54)	70 (5.11)	47 (7.47)	303 (6.82)
1995	43 (6.51)	54 (6.01)	62 (6.94)	77 (5.67)	48 (7.52)	284 (6.38)
1996	59 (8.98)	59 (6.57)	61 (6.76)	59 (4.33)	49 (7.73)	287 (6.44)
1997	55 (8.27)	66 (7.39)	51 (5.72)	67 (4.94)	43 (6.78)	282 (6.35)
1998	43 (6.51)	49 (5.45)	51 (5.68)	60 (4.40)	31 (4.89)	234 (5.25)
1999	32 (4.84)	66 (7.43)	54 (6.01)	58 (4.26)	24 (3.73)	234 (5.26)
Ave.:	41 (6.21)	55 (6.16)	53 (5.89)	57 (4.15)	38 (6.03)	244 (5.48)

Appendix 5, Table 2: Annual populations of agents modelled by AMARC1 as leaving each origin zone between 1970 and 1999. Percentage of total relevant population that migrants represent shown in (brackets).

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest	TOTAL
1970	16	29	25	27	24	121
1971	19	20	18	22	16	95
1972	19	25	22	27	22	115
1973	18	27	22	23	20	110
1974	26	22	29	31	29	137
1975	23	29	35	33	29	149
1976	27	34	37	28	27	153
1977	34	22	48	22	30	156
1978	29	25	31	52	41	178
1979	27	28	42	49	38	184
1980	44	43	53	73	44	257
1981	31	35	35	42	42	185
1982	38	34	39	56	43	210
1983	39	46	54	43	33	215
1984	43	48	51	52	47	241
1985	40	54	67	74	32	267
1986	39	50	61	69	30	249
1987	42	49	70	74	38	273
1988	39	48	81	72	40	280
1989	38	53	54	64	35	244
1990	63	74	96	86	50	369
1991	39	64	56	54	40	253
1992	49	60	67	60	56	292
1993	38	53	72	63	41	267
1994	71	67	74	80	32	324
1995	56	63	92	88	59	358
1996	58	70	89	72	62	351
1997	53	82	99	68	45	347
1998	60	91	128	90	57	426
1999	60	110	140	110	62	482

Appendix 5, Table 3: Annual populations of all agents recorded by the EMIUB2 data as leaving each origin zone between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest	TOTAL
1970	4	23	31	9	4	71
1971	13	27	29	13	12	94
1972	11	19	29	16	14	89
1973	11	28	26	17	13	96
1974	19	31	27	24	24	125
1975	19	33	32	29	24	138
1976	21	34	30	28	19	131
1977	14	27	30	31	25	126
1978	20	40	38	29	21	147
1979	26	25	39	35	26	151
1980	29	35	38	28	26	157
1981	22	37	48	38	29	174
1982	29	28	45	41	31	175
1983	22	34	41	35	28	160
1984	28	38	43	34	34	177
1985	28	38	50	44	27	187
1986	29	49	50	46	35	209
1987	32	52	64	37	36	220
1988	33	51	73	49	29	235
1989	35	48	74	49	39	244
1990	46	62	81	57	36	282
1991	39	61	79	57	38	273
1992	34	64	89	49	43	279
1993	38	70	89	46	48	292
1994	44	73	91	63	44	315
1995	41	76	102	71	53	343
1996	57	85	98	73	57	370
1997	62	78	113	75	55	383
1998	53	97	122	78	51	401
1999	46	104	123	81	56	409

Appendix 5, Table 4: Annual populations of agents modelled by the AMARC2 model as leaving each origin zone between 1970 and 1999.

	Bobo Dioulasso	Sahel	Centre	Southwest	International	Total
1970	0	3	5	4	4	16
1971	0	4	6	3	6	19
1972	0	1	11	2	5	19
1973	0	1	11	2	4	18
1974	1	4	10	5	6	26
1975	0	8	6	3	6	23
1976	0	0	14	5	8	27
1977	3	4	13	9	5	34
1978	1	3	15	6	4	29
1979	0	5	10	5	7	27
1980	1	5	15	10	13	44
1981	1	4	10	10	6	31
1982	0	2	17	9	10	38
1983	3	6	13	10	7	39
1984	1	9	13	10	10	43
1985	0	2	15	17	6	40
1986	1	4	12	12	10	39
1987	0	7	9	18	8	42
1988	4	2	10	13	10	39
1989	0	6	17	12	3	38
1990	1	8	22	12	15	58
1991	1	4	14	11	9	39
1992	2	4	24	13	6	49
1993	1	4	14	9	10	38
1994	4	15	18	16	18	71
1995	5	7	18	14	12	56
1996	2	8	16	16	16	58
1997	3	7	12	19	12	53
1998	3	8	20	16	13	60
1999	6	7	7	23	17	60
Total:	44 (3.75%)	152 (12.96%)	397 (33.84%)	314 (26.77%)	266 (22.68%)	1173

Appendix 5, Table 5: Annual populations of agents recorded in the EMIUB2 data as leaving Ouagadougou for each destination option between 1970 and 1999.

	Bobo Dioulasso	Sahel	Centre	Southwest	International	Total
1970	0	1	1	1	1	4
1971	0	1	7	2	3	13
1972	0	1	5	2	3	11
1973	0	1	7	1	3	11
1974	0	1	7	2	8	19
1975	0	2	7	2	8	19
1976	0	1	8	2	10	21
1977	0	0	6	2	6	14
1978	0	0	9	4	7	20
1979	0	0	11	3	12	26
1980	0	2	10	4	12	29
1981	0	1	10	3	8	22
1982	0	2	10	5	13	29
1983	0	2	10	2	7	22
1984	0	1	12	4	11	28
1985	0	1	15	4	8	28
1986	0	1	16	3	9	29
1987	0	1	14	7	9	32
1988	1	2	15	4	11	33
1989	1	1	17	5	11	35
1990	0	2	17	4	23	46
1991	0	1	17	5	15	39
1992	0	2	14	3	15	34
1993	1	2	13	5	18	38
1994	2	2	20	6	13	44
1995	1	2	17	5	17	41
1996	0	4	19	8	26	57
1997	0	1	24	6	30	62
1998	0	2	22	6	23	53
1999	1	2	18	6	19	46
Total:	10 (1.10%)	44 (4.82%)	379 (41.90%)	114 (12.59%)	358 (39.58%)	905

Appendix 5, Table 6: Annual populations of agents modelled by AMARC2 as leaving Ouagadougou for each destination option between 1970 and 1999.

	Ouagadougou	Sahel	Centre	Southwest	International	Total
1970	1	7	15	1	5	29
1971	1	1	12	0	6	20
1972	2	6	10	2	5	25
1973	2	8	5	1	11	27
1974	3	4	10	4	1	22
1975	3	10	7	7	2	29
1976	0	13	7	2	12	34
1977	1	2	12	2	5	22
1978	6	4	5	5	5	25
1979	2	5	10	8	3	28
1980	4	11	19	5	4	43
1981	5	8	11	3	8	35
1982	5	6	11	4	8	34
1983	10	5	12	9	10	46
1984	10	8	9	6	15	48
1985	6	17	15	3	13	54
1986	10	9	18	5	8	50
1987	8	8	16	7	10	49
1988	8	8	19	5	8	48
1989	7	5	22	9	10	53
1990	8	13	30	9	12	72
1991	6	9	31	6	12	64
1992	10	6	24	9	11	60
1993	8	10	16	10	9	53
1994	16	17	12	8	14	67
1995	13	11	21	11	7	63
1996	13	16	19	6	16	70
1997	19	14	26	6	17	82
1998	19	20	28	9	15	91
1999	23	18	35	14	20	110
Total:	229 (15.76%)	279 (19.20%)	487 (33.52%)	176 (12.11%)	282 (19.41%)	1453

Appendix 5, Table 7: Annual populations of agents recorded in the EMIUB2 data as leaving Bobo Dioulasso for each destination option between 1970 and 1999.

	Ouagadougou	Sahel	Centre	Southwest	International	Total
1970	2	4	6	2	10	23
1971	2	3	9	1	11	27
1972	2	3	6	2	6	19
1973	2	3	11	2	11	28
1974	3	4	12	4	8	31
1975	4	4	9	4	13	33
1976	5	3	11	3	12	34
1977	3	2	7	5	9	27
1978	3	4	10	3	19	40
1979	2	3	10	1	7	25
1980	5	5	9	3	13	35
1981	3	4	14	3	14	37
1982	4	2	8	4	11	28
1983	6	3	11	5	8	34
1984	6	4	10	7	11	38
1985	3	6	15	2	12	38
1986	5	8	16	4	15	49
1987	6	6	14	7	20	52
1988	5	9	18	5	15	51
1989	7	5	17	5	14	48
1990	5	13	21	4	19	62
1991	6	8	26	3	18	61
1992	9	8	29	4	14	64
1993	8	9	29	2	23	70
1994	7	8	29	4	25	73
1995	11	8	31	3	22	76
1996	9	6	37	11	21	85
1997	12	6	33	9	18	78
1998	14	11	43	5	24	97
1999	10	14	39	8	32	104
	170 (11.57%)	177 (12.10%)	539 (36.79%)	125 (8.53%)	455 (31.01%)	1453

Appendix 5, Table 8: Annual populations of agents modelled by AMARC2 as leaving Bobo Dioulasso for each destination option between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Centre	Southwest	International	Total
1970	4	1	13	2	5	25
1971	7	0	7	2	2	18
1972	4	1	12	0	5	22
1973	7	1	11	1	2	22
1974	12	0	9	2	6	29
1975	12	1	13	0	9	35
1976	8	0	18	4	7	37
1977	11	1	22	4	10	48
1978	10	1	11	2	7	31
1979	12	0	17	4	9	42
1980	18	3	30	1	1	53
1981	9	0	17	3	6	35
1982	18	1	14	3	3	39
1983	27	0	18	2	7	54
1984	21	7	14	3	6	51
1985	29	3	21	5	9	67
1986	30	1	21	2	7	61
1987	38	1	21	3	7	70
1988	34	3	29	4	11	81
1989	28	1	15	5	5	54
1990	46	5	27	5	12	95
1991	24	1	20	2	9	56
1992	32	5	17	5	8	67
1993	40	1	24	3	4	72
1994	28	3	19	10	14	74
1995	51	7	16	5	13	92
1996	43	5	27	7	7	89
1997	54	7	24	3	11	99
1998	70	5	30	7	16	128
1999	66	6	38	10	20	140
Total:	793 (44.40%)	71 (3.98%)	575 (32.19%)	109 (6.10%)	238 (13.33%)	1786

Appendix 5, Table 9: Annual populations of agents recorded in the EMIUB2 data as leaving Sahel for each destination option between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Centre	Southwest	International	Total
1970	5	0	24	1	1	31
1971	7	0	21	1	1	29
1972	5	1	20	0	2	29
1973	6	0	17	1	3	26
1974	12	0	10	0	4	27
1975	11	0	17	2	2	32
1976	12	1	9	3	5	30
1977	11	1	12	1	4	30
1978	13	2	18	2	3	38
1979	13	1	19	2	5	39
1980	15	1	16	2	4	38
1981	19	1	21	3	5	48
1982	18	0	20	2	4	45
1983	16	0	17	2	6	41
1984	20	1	18	0	4	43
1985	19	1	20	3	6	50
1986	24	1	17	0	7	50
1987	27	1	26	4	6	64
1988	33	2	29	3	5	73
1989	31	1	33	2	8	74
1990	38	2	34	3	5	81
1991	34	2	30	3	10	79
1992	34	2	36	4	13	89
1993	30	3	38	2	15	89
1994	41	1	39	2	7	91
1995	38	3	43	5	13	102
1996	34	4	45	4	12	98
1997	42	4	49	4	14	113
1998	52	2	49	6	13	122
1999	50	3	51	4	14	123
Total:	710 (38.97%)	41 (2.23%)	797 (43.70%)	75 (4.11%)	200 (10.99%)	1,823

Appendix 5, Table 10: Annual populations of agents modelled by AMARC2 as leaving Sahel for each destination option between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Sahel	Southwest	International	Total
1970	6	1	1	6	13	27
1971	5	2	2	3	10	22
1972	6	3	5	3	10	27
1973	5	0	2	5	11	23
1974	7	0	0	7	17	31
1975	10	1	1	5	16	33
1976	7	1	4	6	10	28
1977	3	3	1	6	9	22
1978	17	3	2	14	16	52
1979	15	0	6	10	18	49
1980	24	4	7	14	24	73
1981	10	2	3	10	17	42
1982	17	4	4	11	20	56
1983	17	4	3	9	10	43
1984	22	4	3	8	15	52
1985	29	2	4	14	25	74
1986	23	4	5	15	22	69
1987	31	6	1	12	24	74
1988	23	6	1	20	22	72
1989	22	9	4	11	18	64
1990	31	5	6	11	32	85
1991	24	2	3	9	16	54
1992	22	6	0	19	13	60
1993	31	5	4	9	14	63
1994	29	11	6	13	21	80
1995	34	6	5	15	28	88
1996	35	4	4	14	15	72
1997	29	6	3	16	14	68
1998	29	4	8	13	36	90
1999	37	12	4	17	40	110
Total:	600 (35.23%)	120 (7.05%)	102 (5.99%)	325 (19.08%)	556 (32.65%)	1703

Appendix 5, Table 11: Annual populations of agents recorded in the EMIUB2 data as leaving Centre for each destination option between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Sahel	Southwest	International	Total
1970	2	1	0	6	0	9
1971	4	0	1	5	2	13
1972	9	0	1	3	3	16
1973	7	0	1	3	6	17
1974	9	2	1	6	6	24
1975	10	1	1	7	11	29
1976	14	0	2	2	9	28
1977	13	1	1	5	11	31
1978	13	1	1	4	10	29
1979	14	2	1	6	13	35
1980	10	3	1	5	9	28
1981	14	1	1	7	15	38
1982	20	2	2	6	11	41
1983	16	2	2	6	9	35
1984	15	1	1	5	11	34
1985	18	2	2	10	12	44
1986	18	2	2	11	15	46
1987	17	2	1	7	10	37
1988	18	3	1	9	19	49
1989	18	3	1	7	20	49
1990	25	3	4	11	15	57
1991	25	2	2	7	20	57
1992	19	2	2	7	18	49
1993	20	3	2	8	13	46
1994	25	5	2	8	24	63
1995	26	4	3	10	29	71
1996	30	3	4	9	26	73
1997	33	3	3	9	27	75
1998	34	4	6	10	25	78
1999	27	5	4	11	34	81
Total:	521 (40.70%)	62 (4.87%)	56 (4.37%)	206 (16.11%)	435 (33.96%)	1281

Appendix 5, Table 12: Annual populations of agents modelled by AMARC2 as leaving Centre for each destination option between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	International	Total
1970	3	1	4	12	4	24
1971	0	1	0	9	6	16
1972	1	1	1	15	4	22
1973	0	2	2	13	3	20
1974	2	2	3	14	8	29
1975	5	2	2	14	6	29
1976	3	1	5	15	3	27
1977	4	2	3	16	5	30
1978	4	0	3	27	7	41
1979	6	1	3	18	10	38
1980	9	2	4	21	8	44
1981	9	3	5	18	7	42
1982	6	2	4	22	9	43
1983	8	1	6	15	3	33
1984	10	2	5	21	9	47
1985	2	1	3	21	5	32
1986	3	0	4	16	7	30
1987	9	4	1	16	8	38
1988	9	6	0	20	5	40
1989	7	2	2	16	8	35
1990	12	4	3	26	5	50
1991	11	3	2	19	5	40
1992	6	7	9	29	5	56
1993	8	3	2	19	9	41
1994	9	0	1	15	7	32
1995	18	5	5	22	9	59
1996	13	4	6	27	12	62
1997	5	7	4	20	9	45
1998	16	4	3	25	9	57
1999	16	7	4	25	10	62
Total:	214 (18.38%)	80 (6.87%)	99 (8.51%)	566 (48.63%)	205 (17.61%)	1164

Appendix 5, Table 13: Annual populations of agents recorded in the EMIUB2 data as leaving Southwest for each destination option between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	International	Total
1970	1	1	0	3	0	4
1971	2	0	0	8	2	12
1972	1	1	2	9	1	14
1973	2	0	1	9	2	13
1974	2	0	0	15	7	24
1975	3	1	0	13	7	24
1976	4	0	1	10	4	19
1977	4	1	0	15	4	25
1978	4	0	1	11	5	21
1979	3	2	1	14	7	26
1980	4	0	0	15	6	26
1981	4	2	2	16	5	29
1982	6	1	3	13	8	31
1983	5	1	2	14	6	28
1984	6	2	4	17	6	34
1985	3	2	0	18	4	27
1986	6	1	1	19	7	35
1987	5	0	1	20	9	36
1988	3	1	1	18	6	29
1989	3	2	0	27	6	39
1990	5	2	1	21	7	36
1991	6	1	1	21	9	38
1992	6	4	1	28	5	43
1993	7	2	1	28	10	48
1994	6	3	1	27	7	44
1995	9	2	4	27	12	53
1996	5	1	3	34	15	57
1997	10	1	3	27	14	55
1998	5	2	1	32	11	51
1999	9	2	1	31	14	56
Total:	140 (14.36%)	37 (3.75%)	38 (3.89%)	557 (57.05%)	205 (20.95%)	977

Appendix 5, Table 14: Annual populations of agents modelled by AMARC2 as leaving Southwest for each destination option between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest	Total
1970	4	18	29	11	6	68
1971	9	25	33	19	8	95
1972	8	20	31	15	14	87
1973	10	25	22	15	12	85
1974	22	31	23	23	22	120
1975	19	37	32	27	18	134
1976	20	39	33	31	24	147
1977	25	31	27	32	24	140
1978	21	32	32	30	26	141
1979	22	28	41	33	25	149
1980	26	38	41	41	25	172
1981	23	34	49	39	31	175
1982	23	30	44	37	29	164
1983	28	37	44	38	25	172
1984	32	39	45	42	30	187
1985	25	36	53	46	35	196
1986	34	44	52	40	33	203
1987	28	48	59	45	31	211
1988	27	44	71	50	28	220
1989	33	49	79	44	40	244
1990	47	64	72	57	40	280
1991	34	60	81	53	42	270
1992	35	69	78	55	46	284
1993	50	83	93	57	50	332
1994	38	87	93	67	58	343
1995	45	76	96	72	55	345
1996	51	84	105	73	51	364
1997	50	79	95	81	50	356
1998	46	82	100	70	51	349
1999	40	106	119	76	53	394

Appendix 5, Table 15: Annual populations of agents modelled by the 1990-1999 probability version of AMARC2 (AMARC2.mp10) as leaving each origin zone between 1970 and 1999.

Appendix 6 - *Tabulated observed and modelled migration flows referred to in Chapter 7.*

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest	TOTAL
1970	2	19	30	9	4	65
1971	11	24	29	17	16	96
1972	9	23	26	15	15	88
1973	9	27	22	13	8	80
1974	21	27	27	24	24	123
1975	23	35	36	29	18	141
1976	22	36	29	33	25	144
1977	22	35	36	34	26	154
1978	18	42	40	28	30	158
1979	29	34	41	43	28	176
1980	33	40	46	44	28	191
1981	24	44	52	46	32	198
1982	31	39	52	43	35	201
1983	32	41	53	50	38	214
1984	38	42	50	48	36	215
1985	36	37	67	51	31	222
1986	41	48	59	53	43	244
1987	40	56	65	55	42	258
1988	45	46	68	66	40	266
1989	35	57	88	58	50	287
1990	52	62	84	70	47	315
1991	40	67	72	70	44	294
1992	36	50	75	67	42	270
1993	47	65	78	65	39	295
1994	46	66	73	76	49	309
1995	39	59	74	65	43	281
1996	43	52	71	61	48	275
1997	44	48	80	68	42	282
1998	38	46	80	61	36	261
1999	41	69	74	60	40	284
Total:	947 (14.83%)	1,339 (20.97%)	1,680 (26.30%)	1,422 (22.26%)	998 (15.63%)	6,386

Appendix 6, Table 1: Annual populations of agents modelled by the AMARC3 model as leaving each origin zone between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest	Total
1970	5	17	30	8	3	63
1971	13	28	30	12	13	96
1972	10	23	31	13	17	94
1973	10	23	24	17	12	87
1974	27	23	34	22	22	129
1975	20	32	32	27	24	135
1976	24	32	38	34	21	148
1977	23	50	35	27	27	162
1978	22	34	37	36	32	161
1979	28	28	36	41	31	163
1980	29	34	50	39	33	185
1981	39	36	48	43	29	195
1982	30	54	53	48	36	221
1983	34	57	53	53	37	235
1984	39	72	50	58	43	263
1985	35	36	60	61	38	231
1986	41	45	58	66	39	249
1987	36	52	66	62	49	265
1988	44	43	74	63	42	265
1989	36	68	83	61	48	295
1990	37	61	78	65	48	289
1991	40	56	84	59	41	280
1992	40	44	66	68	45	262
1993	39	52	69	67	40	268
1994	40	57	81	60	48	286
1995	33	39	65	63	37	237
1996	39	83	68	58	37	286
1997	46	91	70	58	38	303
1998	46	44	80	60	41	271
1999	33	63	84	64	40	284
Total:	939 (14.65%)	1,379 (21.51%)	1,668 (26.02%)	1,413 (22.04%)	1,011 (15.77%)	6,409

Appendix 6, Table 2: Annual populations of agents modelled by the three year rainfall classification version of AMARC3 (AMARC3ppt3) model as leaving each origin zone between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest	Total
1970	3	17	26	11	6	62
1971	11	19	28	14	16	88
1972	10	17	25	13	19	84
1973	10	17	19	12	13	72
1974	11	26	27	19	17	100
1975	17	23	23	21	19	103
1976	18	28	26	29	22	123
1977	17	31	31	28	27	134
1978	20	31	31	31	24	136
1979	26	28	32	31	29	145
1980	26	33	36	35	25	155
1981	25	29	33	43	29	159
1982	27	38	40	40	31	175
1983	33	41	44	41	30	188
1984	31	35	46	52	31	195
1985	31	41	51	49	29	201
1986	32	47	45	48	38	210
1987	40	47	55	56	40	239
1988	48	49	58	56	40	251
1989	43	52	57	65	46	264
1990	50	50	54	62	40	255
1991	45	54	53	57	40	248
1992	46	47	48	60	38	240
1993	53	50	46	58	35	243
1994	51	56	51	56	39	252
1995	50	50	48	59	38	245
1996	48	55	54	53	41	252
1997	46	54	54	57	38	249
1998	49	57	44	61	43	254
1999	46	57	43	68	44	258
Total:	962 (17.24%)	1,179 (21.11%)	1,232 (22.07%)	1,285 (23.01%)	925 (16.57%)	5,583

Appendix 6, Table 3: Annual populations of agents modelled by the AMARC3_Dry model as leaving each origin zone between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest	Total
1970	3	20	37	11	3	74
1971	7	28	30	15	14	94
1972	10	28	33	14	11	96
1973	11	24	26	17	12	90
1974	15	37	39	20	21	132
1975	18	36	29	30	22	135
1976	18	36	30	34	23	142
1977	20	39	33	34	22	147
1978	29	38	39	33	29	168
1979	26	46	44	34	30	180
1980	31	42	47	41	31	193
1981	34	52	46	46	37	215
1982	38	41	49	57	35	220
1983	34	57	54	54	35	234
1984	37	54	61	58	42	253
1985	38	52	66	65	41	262
1986	46	65	69	67	48	296
1987	44	69	74	64	55	306
1988	37	67	68	70	50	293
1989	40	65	73	64	45	288
1990	44	63	76	62	54	300
1991	39	69	63	70	45	286
1992	46	61	67	57	41	273
1993	43	71	69	71	44	298
1994	42	66	66	66	47	287
1995	36	69	64	69	48	285
1996	37	64	73	63	47	284
1997	42	73	73	59	45	292
1998	38	71	69	61	45	284
1999	38	72	69	60	45	284
Total:	942 (14.08%)	1,576 (23.57%)	1,636 (24.46%)	1,467 (21.94%)	1,067 (15.96%)	6,688

Appendix 6, Table 4: Annual populations of agents modelled by the AMARC4_Wet model as leaving each origin zone between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest	Total
1970	4	17	39	10	6	76
1971	18	22	19	17	13	90
1972	15	22	19	18	13	87
1973	13	21	21	17	11	83
1974	20	28	24	27	18	117
1975	20	32	30	36	20	138
1976	18	32	38	32	28	148
1977	21	32	40	36	24	153
1978	18	28	38	38	28	150
1979	27	29	45	41	33	175
1980	23	36	49	45	27	181
1981	31	31	52	48	36	199
1982	30	42	51	52	36	212
1983	37	41	62	57	35	231
1984	40	45	67	57	38	247
1985	40	42	63	56	39	240
1986	46	47	77	59	47	276
1987	43	47	74	52	40	256
1988	38	49	88	64	39	279
1989	44	56	77	65	47	290
1990	46	61	80	60	39	285
1991	40	57	67	65	42	270
1992	38	55	68	63	35	259
1993	40	50	72	59	35	257
1994	35	52	67	63	35	252
1995	36	48	71	58	35	247
1996	34	54	71	54	39	252
1997	35	50	72	56	31	244
1998	40	56	73	59	32	260
1999	35	58	71	47	28	239
Total:	924 (14.92%)	1,242 (20.06%)	1,684 (27.19%)	1,413 (22.81%)	929 (15.01%)	6,192

Appendix 6, Table 5: Annual populations of agents modelled by the AMARC3_Wet model as leaving each origin zone between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest	International	Total
1970	11	1	4	29	9	9	63
1971	16	1	7	38	8	18	88
1972	14	2	6	41	7	15	85
1973	15	1	5	29	10	13	73
1974	22	1	8	35	16	18	100
1975	23	2	7	35	15	22	104
1976	31	4	6	42	15	26	124
1977	35	3	7	44	18	28	135
1978	37	3	9	43	15	30	137
1979	37	1	7	52	16	32	145
1980	45	2	7	48	17	36	155
1981	45	1	7	51	15	40	159
1982	49	3	8	51	17	47	175
1983	55	3	8	52	13	57	188
1984	57	4	9	58	16	51	195
1985	60	4	10	53	21	53	201
1986	52	4	8	62	16	68	210
1987	60	3	11	67	23	75	239
1988	70	5	9	68	21	79	252
1989	67	4	9	79	20	85	264
1990	72	2	12	66	21	82	255
1991	58	3	12	63	23	89	248
1992	56	3	10	57	19	95	240
1993	53	4	8	54	17	107	243
1994	52	4	7	65	20	105	253
1995	56	2	6	60	23	98	245
1996	58	2	10	61	22	98	251
1997	56	3	11	59	21	98	248
1998	57	4	10	51	26	106	254
1999	60	4	11	58	21	105	259
Total:	1,379	83	249	1,571	521	1,785	

Appendix 6, Table 6: Annual populations of agents modelled by the AMARC3_Dry model as arriving at each destination zone between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest	International	Total
1970	15	1	4	36	12	6	74
1971	20	1	5	48	5	16	95
1972	14	1	8	46	6	20	95
1973	15	1	5	42	6	21	90
1974	24	2	10	58	10	29	133
1975	27	2	7	51	10	38	135
1976	31	2	9	48	10	41	141
1977	22	3	6	51	12	54	148
1978	28	1	7	59	11	61	167
1979	33	3	8	65	15	56	180
1980	33	3	12	63	13	70	194
1981	39	4	8	73	12	80	216
1982	39	4	9	65	13	89	219
1983	47	2	12	69	13	90	233
1984	52	2	11	73	18	98	254
1985	55	4	10	67	21	105	262
1986	49	5	11	85	23	122	295
1987	56	4	7	84	18	136	305
1988	55	5	9	78	15	130	292
1989	62	3	9	72	13	129	288
1990	61	5	11	72	19	132	300
1991	52	6	9	67	17	135	286
1992	55	7	10	57	18	126	273
1993	53	5	11	64	20	146	299
1994	51	6	9	67	19	135	287
1995	64	6	12	65	15	124	286
1996	62	1	11	65	17	128	284
1997	59	2	14	69	17	131	292
1998	64	4	12	69	20	115	284
1999	63	5	11	77	17	111	284
Total:	1,300	100	277	1,905	435	2,674	

Appendix 6, Table 7: Annual populations of agents modelled by the AMARC3_Ave model as arriving at each destination zone between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest	International	Total
1970	16	0	5	39	8	8	76
1971	17	2	5	39	12	15	90
1972	14	2	5	32	13	20	86
1973	13	1	6	27	12	25	84
1974	23	1	7	31	16	38	116
1975	31	3	11	42	13	39	139
1976	40	3	8	48	9	41	149
1977	43	3	7	49	10	41	153
1978	36	5	6	48	12	43	150
1979	43	5	8	54	14	52	176
1980	42	4	9	60	14	52	181
1981	53	2	10	63	13	57	198
1982	55	3	6	70	15	63	212
1983	59	3	13	72	13	70	230
1984	60	5	11	82	18	70	246
1985	56	5	11	75	15	78	240
1986	58	7	14	92	20	85	276
1987	60	5	11	83	17	81	257
1988	73	4	12	78	18	94	279
1989	68	4	16	87	13	101	289
1990	71	6	13	84	17	95	286
1991	61	7	11	83	14	94	270
1992	59	4	9	74	17	95	258
1993	57	5	11	65	21	98	257
1994	59	7	11	62	15	98	252
1995	54	5	9	70	18	92	248
1996	62	7	13	75	13	82	252
1997	57	5	10	79	17	78	246
1998	57	6	13	83	19	82	260
1999	53	6	11	77	17	76	240
Total:	1,450	125	292	1923	443	1,963	

Appendix 6, Table 8: Annual populations of agents modelled by the AMARC3_Wet model as arriving at each destination zone between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest	Total
1970	4	19	32	10	5	70
1971	9	23	28	19	15	94
1972	11	16	27	14	18	86
1973	9	22	21	15	10	77
1974	21	26	26	18	21	112
1975	16	34	33	28	20	131
1976	19	45	33	27	24	148
1977	23	41	33	31	27	155
1978	24	40	40	39	32	175
1979	29	38	47	43	32	189
1980	30	49	50	48	29	206
1981	39	55	57	46	42	238
1982	40	52	53	46	38	229
1983	35	44	51	53	42	225
1984	51	47	52	60	47	257
1985	42	54	52	58	43	248
1986	47	69	60	61	49	287
1987	45	71	59	64	39	278
1988	43	62	65	69	46	285
1989	44	67	70	72	48	301
1990	56	71	66	71	52	317
1991	42	63	51	63	30	248
1992	37	47	51	59	41	235
1993	54	56	54	57	36	257
1994	36	64	45	50	38	233
1995	33	46	53	51	37	219
1996	41	41	47	45	35	209
1997	41	41	47	54	32	215
1998	30	41	36	40	18	165
1999	19	48	40	49	15	171
Total:	969 (15.99)	1,393 (22.99)	1,375 (22.69)	1,360 (22.44)	963 (15.89)	6,060

Appendix 6, Table 9: Annual populations of agents modelled AMARC3_birthDeath as leaving each origin zone between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest	Total
1970	3	20	29	10	5	67
1971	17	23	30	18	10	97
1972	18	21	23	13	16	90
1973	18	30	24	13	11	97
1974	33	32	29	22	15	130
1975	45	42	29	31	21	168
1976	38	57	34	20	25	174
1977	49	36	38	35	25	183
1978	47	55	41	40	29	213
1979	45	47	41	46	29	208
1980	61	57	39	44	23	224
1981	58	59	53	57	36	263
1982	67	47	53	42	37	246
1983	56	60	55	52	31	254
1984	71	47	50	51	38	257
1985	56	56	59	50	39	261
1986	59	72	61	62	42	296
1987	68	63	54	58	42	285
1988	61	75	69	61	30	296
1989	67	68	75	68	39	317
1990	87	85	71	61	45	349
1991	64	86	75	61	34	320
1992	65	70	71	63	43	311
1993	89	80	64	60	33	325
1994	68	94	64	74	42	342
1995	69	70	68	61	44	312
1996	94	79	64	63	40	340
1997	86	80	84	63	45	358
1998	72	82	75	70	34	334
1999	73	98	78	64	31	344
Total:	1,706 (22.88)	1,790 (24.00)	1,597 (21.41)	1,431 (19.18)	935 (12.53)	7,459

Appendix 6, Table 10: Annual populations of agents modelled AMARC3_scaleFree as leaving each origin zone between 1970 and 1999.

	Ouagadougou	Bobo Dioulasso	Sahel	Centre	Southwest	Total
1970	2	19	29	9	6	65
1971	5	20	29	17	8	79
1972	4	21	27	10	6	69
1973	6	21	20	7	8	62
1974	10	26	21	12	14	82
1975	16	30	25	12	16	99
1976	15	37	30	13	17	113
1977	16	26	30	19	22	114
1978	21	35	35	19	18	128
1979	20	38	37	20	22	137
1980	22	43	42	23	20	149
1981	23	47	48	22	28	169
1982	27	36	53	21	24	162
1983	32	31	52	25	21	161
1984	40	38	55	29	26	188
1985	44	41	55	32	32	203
1986	50	50	56	35	31	222
1987	43	56	58	33	25	215
1988	45	55	75	36	30	241
1989	48	46	88	33	24	239
1990	62	53	89	36	26	266
1991	50	58	78	34	27	247
1992	54	45	71	41	26	237
1993	62	56	84	40	25	267
1994	52	65	84	33	30	264
1995	51	55	79	32	29	245
1996	68	56	80	34	28	266
1997	69	54	81	34	32	270
1998	52	57	81	34	27	251
1999	45	79	84	29	25	263
Total:	1,056 (19.30)	1,293 (23.63)	1,677 (30.63)	773 (14.31)	674 (12.32)	5,474

Appendix 6, Table 11: Annual populations of agents modelled AMARC3_ringLattice as leaving each origin zone between 1970 and 1999.

	AMARC3_ random(10)	AMARC3_ random(25)	AMARC3_ random(50)	AMARC3_ random(75)	AMARC3_ random(100)
1970	69	66	65	84	77
1971	73	87	96	116	118
1972	70	79	88	88	105
1973	55	63	80	95	109
1974	91	90	123	132	160
1975	78	84	141	161	193
1976	95	105	144	177	218
1977	78	100	154	166	221
1978	85	109	158	167	217
1979	106	111	176	194	240
1980	94	118	191	247	255
1981	104	125	198	249	276
1982	102	127	201	253	296
1983	95	127	214	242	281
1984	112	130	215	277	322
1985	128	158	222	275	290
1986	141	154	244	320	341
1987	128	144	258	332	342
1988	123	129	266	333	353
1989	143	157	287	351	378
1990	160	156	315	364	403
1991	130	173	294	375	379
1992	122	155	270	355	363
1993	143	176	295	363	366
1994	147	154	309	346	385
1995	130	141	281	333	366
1996	124	165	275	310	383
1997	132	173	282	359	382
1998	125	167	261	286	367
1999	176	157	284	271	388
Total:	3,359	3,880	6,385	7,621	8,547

Appendix 6, Table 12: Annual populations of agents modelled by the AMARC3_random model as leaving each origin zone between 1970 and 1999 using network sizes ranging from 10 to 100.