Climate Change and Migration: A Modelling Approach

C. Smith, Dominic R. Kniveton, S. Wood, and R. Black

Abstract Past estimates of the numbers of migrants caused to relocate as a result of climate change have ranged from millions to billions worldwide. Attempts to quantify the numbers of people affected have commonly been based around calculating the numbers of 'environmental refugees' by projecting physical climate changes, such as sea-level rise or rainfall decline, on an exposed population. These studies generally make simplistic assumptions about the ability of individuals to cope with variations in climate. However, empirical evidence of environmentally induced migration have not supported such an approach with the recognition that migration decisions are usually not mono-causal but influenced by multiple factors involving complex spatial interactions under heterogeneous conditions. In this context, agent based modelling offers a robust method to model autonomous decision making in relation to migration. In this chapter we discuss the theoretical development of an agent-based modelling approach to climate change-migration studies using the example of Burkina Faso. In doing so we cover questions of emergence, validation, and bounded rationality related to quantitative migration studies.

Keywords Burkina Faso · Climate change · Migration · Population changes · Adaptation · Agent-based modelling

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 (already uncertain themselves) upon livelihood processes such as migration flows are highly speculative. The Intergovernmental Panel on Climate Change (Wilbanks et al. 2007) suggest that current estimates of what they term 'environmental migrants' are, at best, 'guesswork'. This is primarily due to current estimates failing to take into account the

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multiple and complex reasons behind migratory decisions. The issue of disaggregating the causes of migration has proven highly problematic and led to considerable debate around the legal definition and existence of 'environmental refugees' (Black 2001). The element of guesswork involved in migrant forecasts is reflected in the wide range of current estimates of global migration induced by climate change that place numbers of displaced persons between 150–200 million (Stern 2007) and 1 billion (Christian & Aid 2007).

Environmental and climatic changes are increasingly seen as having impacts upon the movement of people on local, regional and global scales as a result of both shock events and slow-onset degradation. Numbers of migrants generated by environmental and climatic changes have commonly been calculated by projecting physical climate changes on an exposed population and inherently assume that a person's ability to cope with variations in climate is proportional to such structural indicators as GDP growth. Such large-scale approaches however fail to adequately acknowledge the local and individual components of migration behaviour and have not successfully isolated environmental influences from the multitude of other factors that influence migration. On a more local scale, 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. 2004). Although such local-scale approaches can provide a more nuanced assessment of the triggers of migration than their global counterparts, they often fail to acknowledge the complex, non-linear and emergent processes inherently involved in the behavioural aspect of any social phenomena. Despite this fact, some value can be gained from the findings of such studies in their contribution to identifying the factors most likely to increase the risk of out-migration from a location. 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 the ability to predict new flows of people and to simulate the impact of different policy responses on these flows.

An alternative approach is to research and construct the rules of behaviour that govern how individuals respond to complex combinations of multi-level stimuli. These rules can then be applied to situations where they govern the behaviour of the individuals according to their specific context and circumstances. As a result, simulations may be produced that focus on the individual decision-making aspect of migration and can therefore be applied to modelling responses to conditions outside of those previously witnessed. A technique well-suited to this style of rule-based predictive simulation is agent-based modelling (ABM). 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) describe the key features common to most agents as autonomy, heterogeneity and activity (including reaction, perception, interaction, communication, mobility, adaptive capacity/learning and bounded rationality). Through the interactions and feedbacks

determined by the constructed rules, an agent can learn from their environment and past experience and adapt their behaviour accordingly.

A major advantage of 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 (more than the sum of the parts), properties may arise from the simulation process that could not have been predicted through a simple linear analysis. The crux of a successful ABM lies in the formation of the rules of interaction 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 interaction 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 qualitative values used by individuals in the decision to migrate may be used as a predictive tool in quantifying the migration phenomenon resulting from environmental and climatic change. As a cognitive modelling technique that, in this context, deals with the bounded rationality of individuals, the first stage in developing an ABM is the construction of a conceptual framework. 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.

2 Climate Change Migration Modelling

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. There are at least two distinct approaches to the explanation of migration decisions in the existing literature. These are referred to as the ‘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 social 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. 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. A meso-level of analysis provided by institutional influences bridges the divide between structural and individual approaches to conceptualising migration by incorporating both.

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

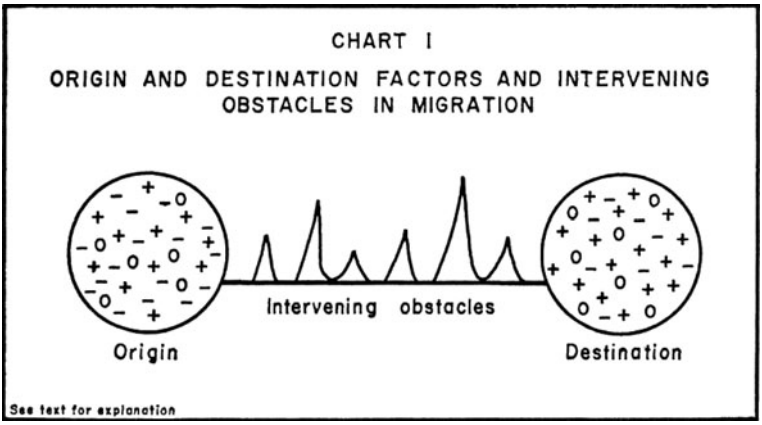

Fig. 1 Simple conceptual model of intervening obstacles (Lee 1966)

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 therefore generally mathematical, migration models, if mathematical at all, are described by Perch-Nielson (2004) as of 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) (Fig. 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 as well as identifying 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.

McLeman and Smit (2006) present a more contemporary conceptual model (Fig. 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.

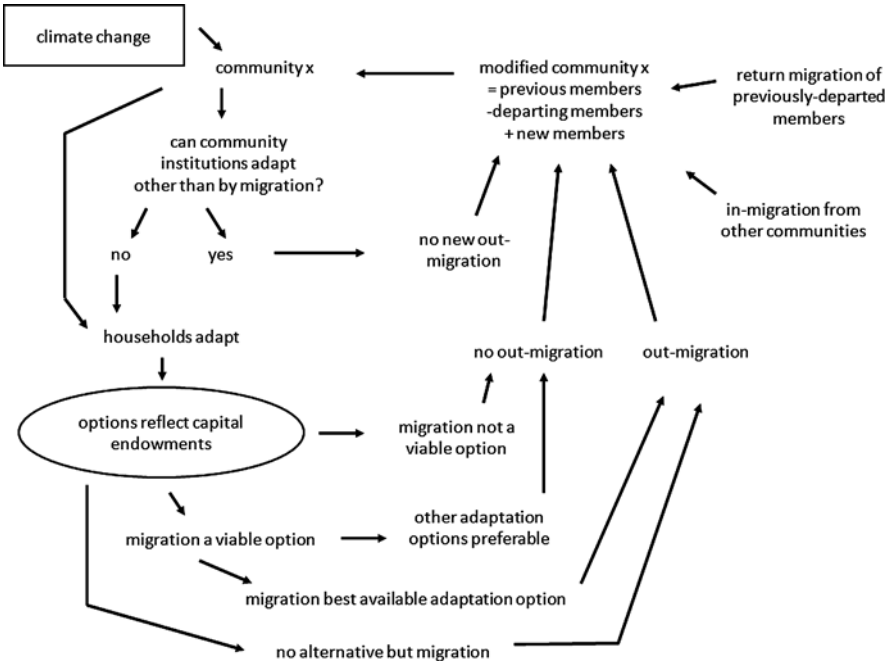

Fig. 2 Model of migration in response to climate change (McLeman and Smit 2006)

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. Incorporating societal and psychological components into a conceptual model of climate change migration, although increasing the apparent complexity of the model, creates 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. However, although this is true, the influence of capital endowments permitted by the model is only a small step-up from a binary analysis. 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 our purpose is limited by the causal nature of the model with no decision-making input. To incorporate the impact of decision-making into the conceptualisation of climate change migration, the impact of cognitive influences must be considered.

3 Proactive Conceptual Development

The context within which this paper addresses the concept of agent-based modelling of climate-induced migration comes from the country of Burkina Faso, in land-locked 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. 2004) 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 climate change 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 impacts of climate change forecast for West Africa.

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. One component that may contribute to an individual's perception of the risk posed by climate change is the availability of accurate forecasts. 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. In West Africa, Roncoli et al. (2003) report

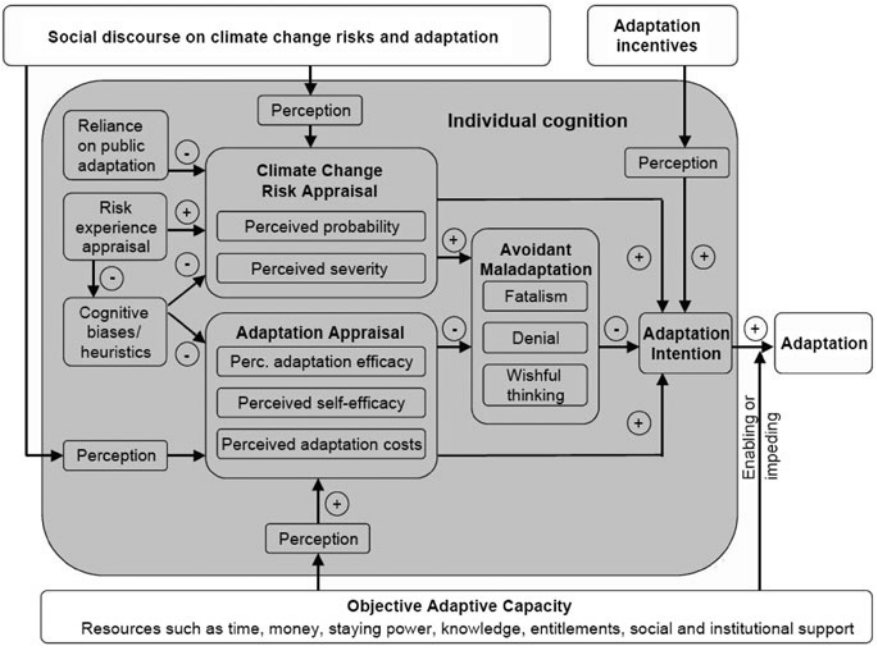

Fig. 3 Process model of private proactive adaptation to climate change (MPPACC) (Grothmann and Patt 2005)

that seasonal forecasts are delivered in May that predict total rainfall during July, August and September, the 3 month period at the core of the rainy season. In locations across much of rural Burkina Faso, however, the problem exists of how to present probabilistic forecasts to potential users in a manner that enables them to be used in livelihood planning.

Conceptualising climate change migration as occurring on the basis of prior information, such as seasonal rainfall forecasts, involves the individual decision-maker adopting a proactive approach to adaptation. As a result, migration may be decided upon as an active option that can alleviate the impact of an expected occurrence on the basis of anticipated outcomes. In 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) (Fig. 3). 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.

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 model 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, we present a conceptual agent-oriented model of the proactive adaptation to climate change (PACC) that, as a result of individual cognition, results in the selection of climate adaptation strategies, including migration (Fig. 4). The model incorporates the two major appraisals of *climate change risk* and *adaptation* used in the 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.

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 both what the individual knows about the climate risk, their *objective adaptive capacity* in the face of such risk, 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

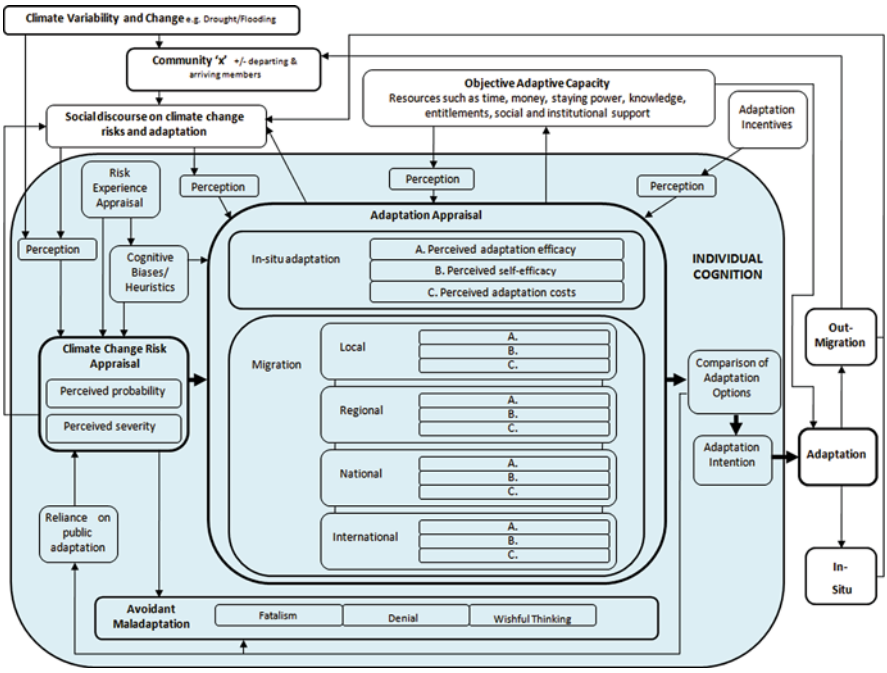

Fig. 4 Conceptual agent-oriented model of proactive adaptation to climate change (PACC)

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. The PACC model therefore presents a good first step in working towards and understanding of the climate-migration decision-making process.

Although the PACC model makes a valuable contribution to understanding the process of climate change migration it is limited in its capacity to suit this research as a result of two issues. 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 input 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 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 of 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 reactive also presents advantages in terms of the ability of people to make rational decisions on the basis of the information available to them.

4 Bounded Rationality

Human beings 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: 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. In order to incorporate the limitations of human capabilities it is therefore important to start with a conceptual basis within which the bounded rationality of human decision-makers is 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 means that climate variability is 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 it is necessary to incorporate this concept of bounded rationality. Therefore, in the context of proactive model development, information available to the agent's network can be controlled to realistically limit their perception of, for example, a 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 it is intended that the decision-making process can be modelled in a more realistic cognitive manner.

5 Reactive Conceptual Development

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 we draw 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 theoretical model to incorporate the additional parameter of *perceived behavioural control*, Ajzen (1991) created 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.

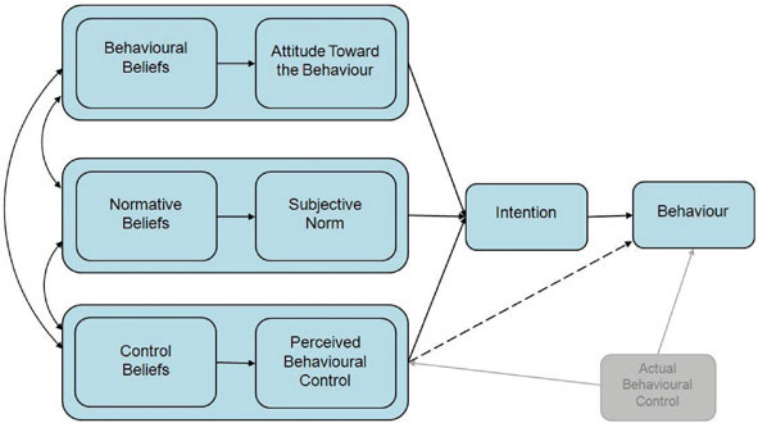

Fig. 5 Theory of planned behaviour, adapted from (Ajzen 2006)

This concept of perceived behavioural control takes the place of the perceived self-efficacy 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 (Fig. 5) can be used to effectively break down the cognitive process relating to the development of a behavioural intention.

Most previous applications of the theory of planned behaviour investigate 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 of 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 can be 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

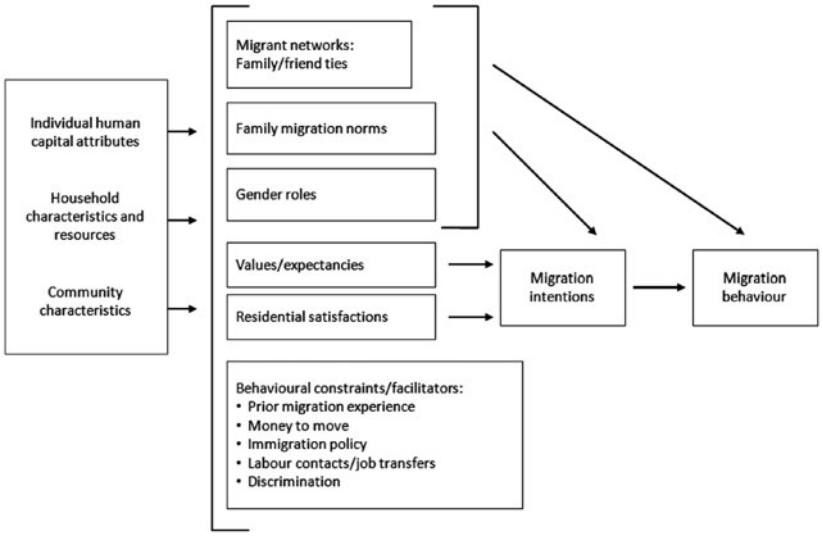

Fig. 6 General model of migration decision-making (De Jong 2000)

family norms about migration behaviours (the 'behavioural beliefs' and 'normative beliefs' from Fig. 5) are the major determinants of migration decisions. Although identified by De Jong as not having a direct effect on migration behaviour (as a result of being mediated as constructs of the theory), traditional explanatory factors such as age, education, marital status, dependents and income have, in many cases been empirically shown to contribute to determining migration. As a result, in adapting and applying the theory of planned behaviour to migration decision-making (Fig. 6), De Jong has not discarded such factors as determinants.

In De Jong's model, individual, household and community characteristics contribute to six concepts that he has identified as uniquely relevant to migration decision-making: migrant networks; family migration norms; gender roles; values/expectancies; 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 agent-based model of the diffusion of organic farming practices (Kaufmann et al. 2008), the theory has some background in the topic. However, although De Jong 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 model does not provide an explicit description of the agent decision-making process. As a result, although theoretically useful in conceptualising migration, the application of the model to the construction of an ABM is limited. In addition, De Jong's model does not show how the different adaptation options available to an individual are selected between to generate migration as an active outcome. By incorporating the value of Ajzen's (1991) theory of planned behaviour, and the conceptual advances on this made by De Jong's (2000) model of migration decision-making, we can work towards the development of a reactive model of climate change adaptation that is more suited to translation into an ABM.

6 Conceptual 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 purely reactive on the continuum ranging from purely proactive to reactive migration. In developing a conceptual model of adaptation to climate change from which an ABM will be constructed, a reactive approach to adaptation will be adopted. The first proactive conceptual model presented here, the PACC was constructed from the basis provided by Grothmann and Patt's (2005) MPPACC. As well as being a proactive model identified as inappropriate to the situation being modelled, the PACC was not directly based on any accepted theoretical model of proactive adaptation. In constructing a conceptual model of reactive adaptation to climate change therefore the development of a reactive conceptual model has been approached through the avenue of accepted social psychological theory.

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), we present a conceptual agent-oriented model of reactive adaptation to climate change (RACC) (Fig. 7). As a result of the individual cognition presented in the RACC, it is considered that the reactive decision to migrate may be appropriately represented, at least from a theoretical standpoint. By translating this into a rule-based model such as an ABM it is proposed that a quantitative community output may be produced from a series of specified qualitative inputs. The RACC model incorporates much of the external structure used in the PACC with the most significant changes present in the process of individual cognition. However, as a result of the reactive nature of the model, the individual climate change risk appraisal process of the PACC has 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, individual and household components to aid

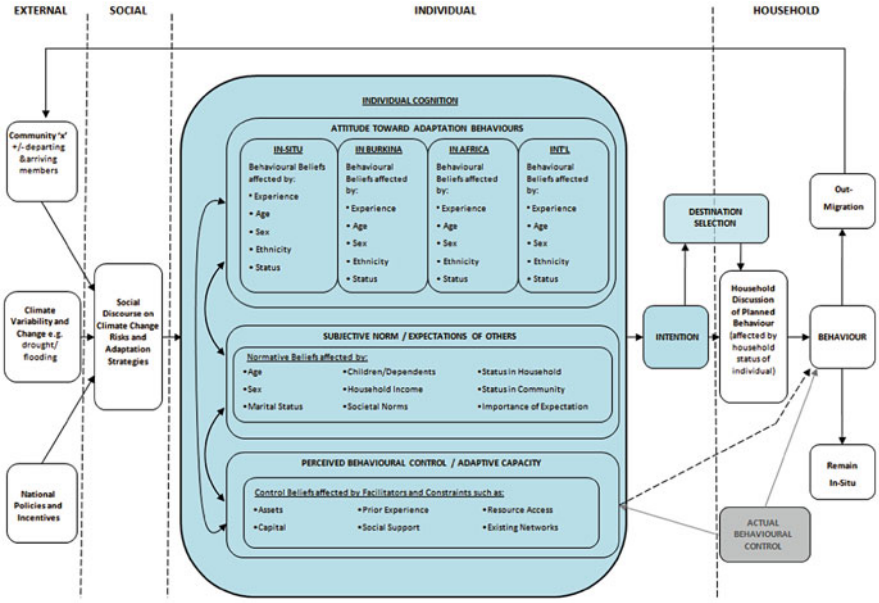

Fig. 7 Conceptual agent-oriented model of reactive adaptation to climate change (RACC)

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.

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.

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 led 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 rainy 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 contributes to the social discourse on climate change risks and adaptation strategies. When undertaking reactive adaptive behaviour, it is proposed that an individual is more likely to undertake a process of acceptance or denial of the social discourse on risks and adaptation that is available to them than an individual appraisal. 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 the 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: the simultaneous 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. These beliefs are characterised by an individual's previous experience of the behaviour (De Jong 2000), their age, sex, ethnicity and status, and how these components are affected by the social discourse. The *subjective norm* component of the cognition represents the expectations of others and is developed from a series of normative beliefs. These beliefs are characterised by an individual's age, sex, marital status, and dependents, 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 also incorporates their 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.

The nature of the RACC model as incorporating both individual cognition and the external factors that contribute-to, and result-from, that cognition (in a feedback loop) allows it to form the basic structure that each agent in an agent-based model can be hypothesised to follow. Constructing a conceptual model of agent cognition prior to in-depth investigation of the actual circumstances occurring on the ground is however a top-down approach to the issue. Although useful to investigate theoretical influences, the actual process of constructing an agent-based model that represents a real-world phenomenon can also adopt a more bottom-up approach. In the case of

modelling climate change migration in Burkina Faso, the RACC model provides a good conceptual basis from which to investigate further how climate change affects the cognitive process behind migration. It is useful to approach fieldwork intended for agent-based model data collection with some 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 agent-based model it is therefore possible to guide interviewees towards the issues you are investigating (which may be informed by theoretical developments such as RACC) but important to avoid leading their responses. In order to avoid purely top-down development of a model however, it is important not to reveal to respondents the cognitive outcomes that you anticipate from the top-down component of the research.

7 Translation into An Agent-Based Model

The process of developing an ABM from a cognitive structure such as the RACC model may therefore be informed by theory, data collection, or a combination of both. Whatever the situation, the cognitive representation constructed must be translated into an agent-based model through the development of rules that govern the important interactions of agents. The obvious advantage of constructing an ABM from evidence gained from a real-world scenario is the greater reliance that can be placed in the cognitive instruments included due to the manner in which the rules of interaction have been verified. Unlike the PACC model, the RACC breaks down complex components such as *perceived self-efficacy*, into the simpler underlying components – such as the assets, capital and prior experience which underlay *perceived behavioural control*. In constructing the rules of interaction that arise from a conceptual model, a major advantage of the RACC is therefore the relative ease with which the simple underlying features of complex components can be worked with. Keeping the basic rules of interaction as simple as possible in an agent-based model is important to ensure that the underlying interactions of emergent properties that arise from the model can be easily traced and understood. Computationally less intensive than more complex alternatives, even a simple agent-based model can exhibit complex behavioural patterns as a result of the interactions specified.

Constructing the rules of interaction that make up the basis of an agent-based model generally takes the form of a series of 'if' statements that combine to result in the calculation of a value which, if above or below a set threshold, determines behaviour. Kaufmann et al. (2008) present an agent-based model of organic farming adoption in two new EU Member States. Characterised by attributes adopted from the Theory of Planned Behaviour, their model calculates the behavioural intention I of agent i from their attitude a_i, subjective norm s_i, and perceived behavioural control p_i. Each of the three attributes ranges from –1 (extremely negative) to +1

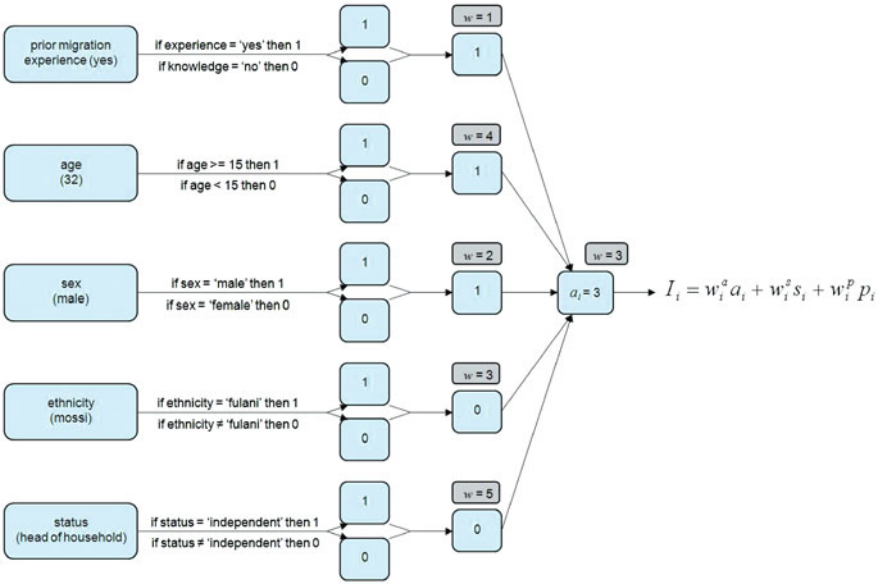

Fig. 8 Diagram of rule structure behind adaptation attitude

(extremely positive) and is weighted by its relative contribution towards calculating the intention ($w_i{}^a$, $w_i{}^s$, $w_i{}^p$ accordingly). The weights defining the relative contributions of each predictor are derived empirically by means of regression analysis.

$$I_i = w_i^a a_i + w_i^s s_i + w_i^p p_i \tag{1}$$

If the resulting intention developed by an agent exceeds an empirically defined threshold then that agent is defined as having the intention to adopt organic farming practices. Basing an agent-based model of climate change migration behaviour upon the theory of planned behaviour, permits a similar calculation of intention to be used. It is however, the rule basis behind such a calculation that determines the outcomes and their value for further application. Figure 8 shows the 'if' statements that may be constructed to calculate the attitude toward adaptation behaviour in the RACC conceptual model and contribute an a_i value for a calculation such as that in Equation 1.

The statements that contribute to a value of a_i in Fig. 8 give an example of how individual agent components can be combined to deduce values that are of use in quantifying a process resulting from decisions that relate to known characteristics. In this case the output values from each 'if' statement relate to a binary output of 1 or 0 and are constructed on a purely theoretical basis. The weight of influence of each of these upon the final value of a_i is specified above each binary output. When developing a final model the outcomes of such statements may be graduated (on a scale from –1 to 1 for example) to assign more detail to a particular phenomenon.

To aid in representing the real-world phenomenon under study these graded values can be developed on the basis of evidence gained through either data analysis or field observations. By calculating values for each of the components included in Equation 1 (a_i, s_i and p_i), and assigning weights to these values, an agent-based model may be constructed that simulates the decision-making process of agents in response to climate change according to the theory of planned behaviour. From such a simulation that incorporates the climate variability and change impacting a location such as Burkina Faso, the phenomenon of climate change migration as a viable adaptation strategy may be hypothetically quantified.

8 Model Validation

Following the construction of an agent-based model 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 climate 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 experimental 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 is the use of linear correlations (r or r2 values) to capture relative trend magnitude and root mean square deviations (RMSD) to show deviations in 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, 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 agent-based model it is 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. 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 the different interactions undertaken. 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. Finally, to ensure external validation of a model, providing sufficient implementation details in publications permits other researchers to reproduce the results generated.

9 Conclusion

The level of human migration resulting from climate change is a concept that is currently receiving widespread recognition within both humanitarian and policy discourses on an international scale. Forecasting the numbers of such migrants presents a significant challenge in terms of identifying the people displaced by climate change scenarios. As a rule-based simulation technique that has found recent success within the social sciences, agent-based modelling presents a potentially useful means of modelling climate change migration by focussing on the cognitive decision-making process behind migration. Indeed, one of the key advantages of an agent-based modelling architecture is the potential for models to generate unforeseen emergent properties that, through the interactions specified, are more than the sum of the parts. In developing a conceptual basis from which to model the migration decision we first investigate the proactive response to climate change. Incorporating a climate change risk appraisal, which involves perceptions of the probability and severity of climate change, the model of proactive adaptation to climate change (PACC) was developed from Grothmann and Patt's (2005) model of private proactive adaptation to climate change (MPPACC).

As a result of Richmond's (1993) assertions on the nature of reactive migration and the complexity involved in some of the internal components of the PACC we turn to social psychological theory in search of a theoretical basis for a reactive model. The resulting model of reactive adaptation to climate change (RACC) is developed from theoretical advances made by the theory of planned behaviour. By incorporating the three major components of individual cognition identified by the theory, the RACC provides a conceptual model that explicitly shows the cognitive process considered to occur. In doing so the RACC also maintains a level of

simplicity appropriate to agent-based modelling and considers the limits of human rationality. From the conceptual basis provided by the RACC model, an agent-based model of climate change migration may be constructed using rules of interaction developed from field evidence.

The final component in constructing an agent-based model is the process of validation necessary to assess the value of the model outputs to society. In the context of climate change migration, the successful development of an agent-based model that can simulate the human displacement resulting from climatic change is of great value if the model can be reliably validated. If the outcomes of such agent-based models are to be of value to humanitarians and policy makers, their outcomes must be of representative value to stakeholders. To ensure such value the processes of model development and validation require careful control. However, by achieving reliable outputs, agent-based modelling may assist in developing appropriate adaptation strategies that can alleviate the pressures imposed on livelihoods by climate change.

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