Climate Change, Migration and Agent-Based Modelling:

Modelling the impact of climate change on forced migration in Burkina Faso

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Introduction

The likely manifestations of climate change include rising sea levels, deforestation, dryland degradation and natural disasters. Such environmental events and processes are expected to pose significant challenges for society in terms of their effect on development and livelihoods, settlement options, food production and disease. It has been predicted that these challenges to livelihoods in vulnerable regions worldwide will lead to the large-scale displacement of people, both internally and internationally with estimates of some 200 million to 1 billion climate change induced migrants by 2050[1 2 3].

The variation of the migratory response to climate has been shown by a number of events. At one extreme, the experience of the US Gulf coast with Hurricane Katrina in 2005 showed the ability of a single climate event to induce considerable displacement of the human population. By contrast, studies of migration of agricultural populations in the Sahel have shown that rather than encouraging migration, decreases in rainfall (and the subsequent bad harvests) tend to limit the ability of households to invest in long-distance movement[4 5]. As a result it has been argued that there is considerable uncertainty in the prediction of climate change induced migration[6 7]. The first major source for this uncertainty results from ambiguities in the extent and magnitude of the climate signals responsible for pushing and pulling migrants. The second contributing source of uncertainty results from variation in the individual contexts, perceptions and behaviour of the people upon whom the climate signals act.

Studies of climate-induced migration in the past have commonly calculated the numbers of 'environmental refugees' by projecting physical climate changes, such as sea-level rise, on an exposed population[8 9 10] . These studies assume that a person's ability to cope with variations in climate is proportional to GDP growth. In reality 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 factors that influence migration at the individual or household level. Empirical modelling techniques present the only way to effectively simulate such a behavioural process and predict the scale and impact of displacement as a result of climate change. By applying an agent-based modelling technique to the migration and climate change nexus, the influence of environmental factors upon the migratory response may be better understood. Also, in creating such a model, the sensitivity of the migratory process to climate variability and change may be further investigated and assessed.

Agent-Based Modelling

In an agent-based model (ABM) the effect of decision-making upon behaviour is modelled using virtual agents. In this context, these agents can be used to represent either individuals or households and are programmed to act on the stimuli they receive throughout the simulation. The key features common to most agents used in any simulation are autonomy, heterogeneity and activity (including reaction, perception, interaction, communication, mobility, adaptation, learning and rationality). The agents used in an ABM are located within a simulation environment which, in this instance, represents the geographic region which agents inhabit. For example, in a simulation of internal migration within Burkina Faso, the simulation environment would represent the geographic extent of the country. By moving within and interacting with the simulated environment agents are able to perceive their surroundings and form a decision to relocate on the basis of programmed geographical stimuli such as land degradation. In moving around the simulation environment agents are also able to interact with other agents within their vicinity. As a result of such interaction, agents may communicate their views on the severity of an environmental feature such as land degradation and influence the perceptions of other agents. An individual agent can therefore learn from their surroundings, experience and other agents through a rational thought process and adapt their behaviour accordingly.

The major inherent advantage of an ABM is the understanding that the result of a series of interactions between individuals may result in more complex outcomes than could have been predicted by aggregating individual agent behaviours . ABMs are therefore an effective means of analysis for systems that are both composed of interacting heterogeneous agents and exhibit emergent properties (properties that arise from agent interactions that cannot be deduced simply by combining the known properties). Multiple interacting agents situated within a model or simulation environment therefore comprise the basis of an ABM. By assigning a set of rules to the agents within a system, agent-agent and agent-environment relationships are specified that form the basis of the resulting interactions. According to the rules created for a particular simulation, each agent individually assesses its personal situation and makes decisions which result in the execution of various actions/behaviours appropriate to their aims. Even a simple agent-based model can exhibit complex emergent behavioural patterns as a result of the interactions specified by the user.

Migration

The latest IPCC report[11] suggests that in Africa projected reductions in yield in some countries could be as much as 50 per cent by 2020. With small-scale farmers being the most likely to be affected the impact of this reduction in yield upon human settlements is likely to be significant. As one of the poorest countries in the world, the population and economy of Burkina Faso depend largely upon rain-fed agriculture and cattle-raising. The large number of people who rely upon subsistence agriculture and small-scale farming are thus very sensitive to changes in climate. Burkina Faso has long been characterised by intense mobility with long and short-term rainfall conditions thought to influence both temporary and permanent migrations. As a nation with a historically mobile population whose livelihoods are sensitive to changes in climate variables such as rainfall, Burkina Faso presents an appropriate case-study for investigation into the issue of environmentally induced displacement.

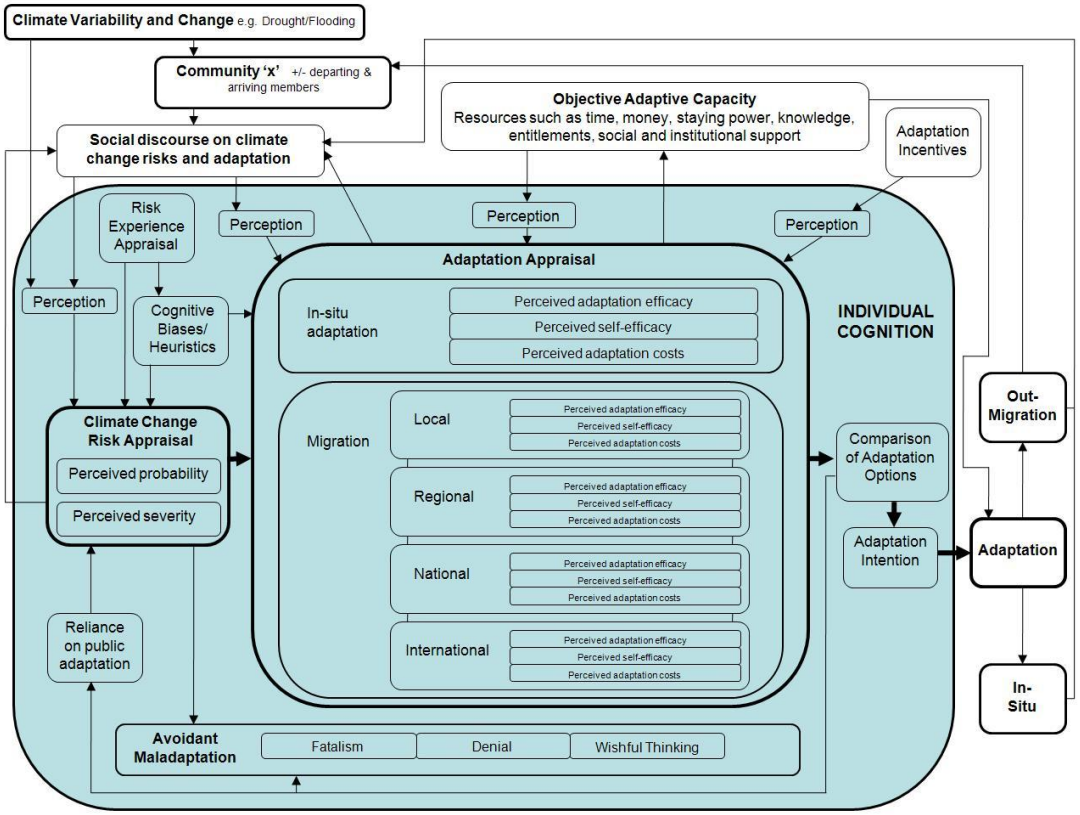
In developing an agent-based model designed to simulate a real-world process such as individual choice, the set of rules that define agent actions and interactions must be constructed in an objective and empirical manner. For much of the world there is no time-sensitive migration flow data available from which factors at one point in time can be used to explain migration at another. However, in the context of Burkina Faso, a retrospective survey[12] conducted in 2000-2001 provides detailed spatio-temporal information relating to places of residence, work activities, matrimonial unions and offspring as well as the motives given for any recorded relocation over the period from 1942 to 2000. The longitudinal data (covering an extended period of time) was collected as a nationwide representative survey from over 600 locations throughout the country and included over 8,000 respondents from more than 3,500 households. From this survey data the rules of interaction required for an ABM of the influence of climate change upon migration can be developed.

Migration has always been a fundamental component of human history. Following years of academic consideration the topic has been the subject of considerable theoretical debate. Such notions as those of the 'push' and 'pull' factors of origins and destinations have been developed to provide a simplistic analysis of migrant motives. More in-depth approaches to understanding local to international scale contexts for migration behaviour include the Sustainable Livelihoods Approach (SLA) and the New Economics of Labour Migration (NELM). The SLA seeks to explain livelihood choices in terms of assets and coping strategies available to households while the NELM more directly addresses the process of household migration decision-making. While these approaches provide a means of possibly disentangling the multiple factors influencing migration at the household/individual level, they do not allow predictions of migrant numbers in the future or under different conditions from those under which the original surveys were performed. However, dynamic modelling approaches such as ABMs provide a means to adjust various parameters to further investigate situational changes and future scenarios.

Although the longitudinal data available for Burkina Faso provides a valuable resource for development of an ABM, some theoretical input to the development is important to capture the wider context within which individual migration decisions are formed. There are at least two distinct approaches to the explanation of migration decisions in the existing literature. These can be distinguished as approaches that place social structures at the centre of analysis and those that focus upon notions of creativity/humanism. When considered in the context of larger structures (such as economic markets), all individuals are thought to respond to the same pressures in the same way without individual autonomy. By contrast, approaches that focus upon the power of creativity/humanism suggest that individuals act independently on the basis of their own freedom of choice. An intermediate approach is also provided that bridges the divide between perspectives through the shared consideration of both social structures and the autonomous nature of individuals. This intermediate-scale approach is considered to regulate the exchanges between individuals by enabling social structures and individual freedom to be considered together. In developing an ABM to simulate the impact of climate change upon migration, it is therefore important to consider the influence of social structures, individual agency and intermediate institutional influences upon individual actions.

Conceptual Model Design

The construction of a conceptual cognitive model provides a good opportunity to set out the basic structure that the decision-making process of an agent within an ABM is likely to follow. Grothmann and Patt[13] present a process model of private proactive adaptation to climate change (MPPACC) which separates out the psychological steps to taking action in response to their perceptions of climate. Developed from the structure proposed by Grothmann and Patt the diagram below presents an agent-oriented model of the individual cognitive response to climate change in the selection of migration as an appropriate adaptation strategy.



As a result of both *climate variability and change* and the *social discourse on climate risks and adaptation* undertaken by *community 'x'*, the model shows that individuals are thought to first perform a *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 specified threshold, the individual considers 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 the advantages to them of 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. This involves a consideration of

scale of relocation on the basis of their perceptions of *adaptation efficacy*, *self-efficacy* and *adaptation costs*. Both an individual's adaptive capacity and any available *adaptation incentives* are considered by this model to contribute to the adaptation appraisal from which the individual undertakes a comparison of their options and develops an adaptation intention. The decision made by the individual may return an intention to then pursue in-situ or migratory adaptation strategies, rely on public adaptation, or pursue an avoidant maladaptation strategy such as denial or ineffective livelihood adjustments. The chosen adaptation strategy then both impacts upon the social discourse on climate change risk and affects the size of community 'x'.

The basic cognitive process that each agent undertakes in their consideration of climate stimuli, and their resulting selection of appropriate adaptation strategies, underpins the formation of the ABM. However, the individual context of each agent's unique combination of experiences, biases, assets and perceptions defines the heterogeneity of agents and their different responses to both environmental stimuli and the actions of others. The process of developing a conceptual model such as this into an ABM requires careful development of the rule-base that governs the actions of each modelled agent.

Model Refinement

In order to refine the agent attributes and rules of interaction within an ABM, detailed country-specific knowledge is required. A major advantage of the existing Burkina Faso data is the record of individual motives given for both work-related and residential relocations. Thresholds for agent actions can be set on the basis of these clearly stated motives. However, the likelihood that an individual will provide a succinct explanation for their actions in one given motive is low as many factors contribute to the decision to relocate. As a result, further survey work in Burkina Faso is required to develop a full understanding of the precise role climate plays in the decision to migrate. With adequate data from which to develop the rules of interaction and thresholds for action of agents, the response of a community to a given/forecasted climate scenario may be undertaken to provide a simulation of how that community will respond on both the individual/household and community levels.

The Future of ABM

Previous attempts to model the impact of climate stimuli on human migration have been largely inadequate. This is, in the main, as a result of the issues associated with modelling such a complex and multifaceted process. 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 and manipulate these variables in order to obtain simulations of future migration patterns. The influence of the unique responses and attitudes of individuals towards manifestations of climate is of considerable importance in identifying the livelihood impact they perceive and the importance of these in their current and future existence.

By developing an agent-based model from comprehensive data such as that available for Burkina Faso, the degree to which recent migratory movements have been affected by climate stimuli can be assessed. This can be achieved by fully understanding the decision made by

individuals to migrate and isolating the influence of climate from the multiple drivers behind migration. Developing a model to simulate existing migrant flows provides an opportunity to investigate both the sensitivity of drivers of migration to climate and the thresholds and ranges of climate conditions that lead to migration. As a result of these findings such a model can also be used to identify scenarios when there is a significant likelihood that communities and individuals will migrate. Following on from such ABM development, the final hurdle is to use information on the climate sensitivities and thresholds of specific communities to enable an agent-based modelling approach that can produce a more detailed prediction of the number of migrants driven to relocate as a result of environmental conditions than has been possible in previous studies.

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