Global Environmental Change 21S (2011) S34–S40

Contents lists available at SciVerse ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Agent-based model simulations of future changes in migration flows for Burkina Faso☆

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ARTICLE INFO

Article history:
Received 25 July 2011
Received in revised form 2 September 2011
Accepted 7 September 2011
Available online 20 October 2011

Keywords:
Agent-based model
Simulation
Decision-making
Theory of Planned Behaviour
Climate change
Human migration

ABSTRACT

Attempts to quantify the numbers of migrants generated by changes in climate have commonly been calculated by projecting physical climate changes on an exposed population. These studies generally make simplistic assumptions about the response of an individual to variations in climate. However, empirical evidence of environmentally induced migration does not support such a structural approach and recognises that migration decisions are usually both multi-causal and shaped through individual agency. As such, agent-based modelling offers a robust method to simulate the autonomous decision making process relating to environmental migration. The Theory of Planned Behaviour provides a basis that can be used to effectively break down the reasoning process relating to the development of a behavioural intention. By developing an agent-based model of environmental migration for Burkina Faso from the basis of a combination of such theoretical developments and data analysis we further investigate the role of the environment in the decision to migrate using scenarios of future demographic, economic, social, political, and climate change in a dryland context. We find that in terms of climate change, it can be seen that that change to a drier environment produces the largest total and international migration fluxes when combined with changes to inclusive and connected social and political governance. While the lowest international migration flows are produced under a wetter climate with exclusive and diverse governance scenarios. In summary this paper illustrates how agent-based models incorporating the Theory of Planned Behaviour can be used to project evidence based future changes in migration in response to future demographic, economic social and climate change.

1. Introduction

Climate change has become widely accepted as a challenge that the global community will face in the not-too-distant future and some already face today. Although uncertainty remains as to the precise nature and extent of these changes, scientific evidence suggests that they are inevitable (Boko et al., 2007). 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. As well as the large volume of research aimed at investigating the nature and occurrence of future climate change, much current research focuses on the challenges posed to society by climate change and the adaptations necessary for human populations to withstand them. One such adaptation strategy is the migration of people away from affected areas.

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 (TERI, 1996; Nicholls and Tol, 2006; Warren et al., 2006). These studies assume that a person's ability to cope with variations in climate is proportional to growth in Gross Domestic Product (GDP). 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 structural transformations that influence migration at the individual or household level. Modelling techniques present the only way to effectively simulate such a behavioural process and consider the scale of mobility 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

☆ While the Government Office for Science commissioned this review, the views are those of the author's, are independent of government, and do not constitute Government policy.

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doi:10.1016/j.gloenvcha.2011.09.006

response may be better understood. In creating such a model, the sensitivity and detail of the migratory process to climate variability and change may be further investigated and assessed.

Located in dryland Africa, Burkina Faso is one of the poorest countries in the world with a population (and economy) largely dependent upon rain-fed agriculture and cattle-raising for subsistence and development. Historically, migration forms one of many livelihood strategies employed to cope with environmental stresses and shocks of which (a lack of) rainfall induced drought is the most common. While there remains large uncertainty relating to the magnitude and even sign of changes in rainfall under different climate change scenarios in the future (Boko et al., 2007) Burkina Faso provides an appropriate case-study for investigation into the issue of environmentally induced migration due to the vulnerability of its population to changes in rainfall.

This paper presents the development and testing of an agent-based model (ABM) designed to replicate 1970–2000 climate migration in Burkina Faso and simulate migration flows forwards to 2060. Originally developed for use within commercial industries, the appeal of ABMs to social science has come about through their potential to facilitate generative explanations of the complex interactions evident in human systems through the unforeseen interaction of multiple agents (Epstein, 2005). ABMs therefore present a viable alternative approach to previous empirical approaches by considering the migration decision in terms of the rules of behaviour that govern the response of individuals to complex combinations of multi-level stimuli. Previous approaches to using ABMs in the social sciences have included work by Silveira et al. (2006) to investigate rural–urban migration and Ziervogel et al. (2005) to assess the role of seasonal climate forecasts on the behaviour of small-holders in Lesotho. The agent-based model we present has been developed using existing theoretical developments in the fields of 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 in 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 discussed.

2. The decision to migrate

Migration has always been a fundamental component of human history. Following years of academic consideration the topic has been the subject of much theoretical debate. Such notions as those of the 'push' and 'pull' factors of origins and destinations and the "intervening obstacles" that stand between an individual and their migration aims (Lee, 1966) have been developed to provide a simplistic analysis of migrant motives. The decision made by an individual to move from one location to another is however a personal choice formed as a result of a unique combination of circumstances. While in-depth survey-based approaches have been developed that work to disentangle 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 approaches such as agent-based modelling provide a means to adjust various parameters to further investigate situational changes and future scenarios.

In modelling the migration decision, an agent can be used to represent either an individual or a household and is programmed to act on the stimuli they receive throughout the simulation. The agents used in an ABM are situated within a simulation environment that, in this instance, represents their geographic location within Burkina Faso. As they move around the environment agents come into contact and communicate with other agents whose circumstances and migration history may differ from their own. Through such agent-agent interaction, one individual may affect the later choices of another by, for example, sharing a positive experience (and access) of migration to location *l*, under rainfall conditions *rc*. An individual agent can therefore learn from their surroundings, personal experience and that of other agents through a rational thought process and adapt their behaviour accordingly. In order to represent agent-related processes and incorporate them into an agent-based model, we first develop a conceptual basis for individual decision making within the model.

Grothmann and Patt (2005) present a process model of private proactive adaptation to climate change (MPPACC) which separates out the psychological steps to taking action in response to perceptions of climate. The MPPACC provides a useful basis from which to develop a conceptual model of the reasoning undertaken by an agent in their migration decision. In seeking a basis from which to develop the MPPACC into a conceptual model to suit an ABM we draw upon theoretical developments made in the field of social psychology.

The Theory of Reasoned Action was developed by Fishbein and Ajzen (1980) as an expectancy-value model that recognises attitudes as just one determinant of behaviour. 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 individual's attitude towards the behaviour and their subjective norm (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) proposes 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. Including attitudes towards behaviour, a subjective norm and perceived behavioural control (as well as the beliefs held by an individual that make up these components), the Theory of Planned Behaviour can be used to effectively break down the reasoning process relating to the development of a behavioural intention in the context of the migration decision.

3. Conceptual model of migration adaptation to rainfall change

In Fig. 1 the Model of Migration Adaptation to Rainfall Change (MARC) displays the conceptual basis from which the ABM has been developed. Notably, the position of the role of rainfall variability and change is such that, rather than being identified as a separate driver of migration, it is shown as influencing the other drivers of migration. This follows the insights of fieldwork and analysis of survey data where only 27 of the 3517 households interviewed identified rainfall as a driver of migration; yet the statistical analysis of Henry et al. (2004) showed a statistically significant relationship between migration outcomes and rainfall variability. Thus the conceptual model indicates that rather than directly determining migration, rainfall's impact on migration is expressed via its influence on the other drivers of: differential employment opportunities; limited access to natural resources; national policies and incentives; ecological vulnerability, political instability and infrastructure. These drivers have social, economic, demographic, political and environmental dimensions and one of the functions of the ABM is to implicitly model the marginal influence of changes in rainfall on these drivers to explore how individual behaviour aggregates to a macro level response.

According to the conceptual model each individual considers their adaptation options on the basis of the three components borrowed from the Theory of Planned Behaviour: their attitude towards adaptation behaviours, their subjective norm (or assessment of the expectations of others), and their perceived behavioural control (or perceived adaptive capacity). The agent uses each of these components to consider each adaptation option available to them. On the basis of an individual's characteristics, migration probability values are used that reflect the normative likelihood of such an individual undertaking each adaptation option. For example, a young single male is more likely to migrate internationally than a married older woman and will be assigned the relevant attitude value to reflect this. The required probability values are derived from analysis of secondary data and represent an agent's attitude towards migration.

The subjective norm component of an individual's reasoning is based upon both visual changes to their surroundings and the choices made by their peers. An agent living in a particular location will therefore consider the actions of others (subjective norm) as a component for consideration in determining their chosen adaptation strategy. For example, if an individual is connected to ten others in a form of social network whereby information such as migration destinations is shared, the preferences of an agent's peers may influence, either positively or negatively, their perceptions of an adaptation option and therefore their willingness to follow that choice.

The final core component of the individual decision-making process is the perceived behavioural control, or the individual's perception of their ability to undertake a selected adaptation option. Determined here on the basis of an individual's ability to invest the necessary capital in migration and their previous experience of such activity, the conceptual model proposes that an individual perceives the ease with which they can undertake migration as an adaptation option. On the basis of this combination of the individual's attitude towards each adaptation option, subjective norm and perceived behavioural control, an individual assesses the options available to them and develops an intention to act according to the favoured option. This intention may, for example, result in an individual selecting international migration as the most appropriate adaptation strategy available to them in response to the structural conditions they are experiencing.

The decision-making process that each agent undertakes in their consideration of climate stimuli shown in Fig. 1, and their resulting selection of appropriate adaptation strategies, underpins the formation of the ABM in this paper. 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 translation of the conceptual processes defined in Fig. 1 into thresholds and attributes that inform the construction of an ABM is based on analysis of retrospective migration history data from Burkina Faso.

4. Defining agent attributes

The *Enquête Migration, Insertion Urbaine et Environnement au Burkina Faso* (EMIUB), a retrospective multi-level family-type survey conducted in 2000-2001, provides detailed spatio-temporal migration flow data relating to places of residence, work activities, matrimonial unions and offspring of respondents (Poirier et al., 2001). The data were collected as a nationwide representative survey from over 600 locations throughout the country and included over 8000 respondents from more than 3500 households. From this survey data the attributes (age, gender, marital status) of the initial modelled agents, their probability-based attitudes towards migration behaviours, and relevant peer opinion thresholds for subjective norm were defined.

The EMIUB dataset provides us with core attribute information relating to 8260 individuals recorded as living in Burkina Faso in 1970. These individuals can be divided into their five separate birth locations; Ouagadougou, Bobo Dioulasso, Sahel, Centre and Southwest. On model startup therefore we can locate each of these real agents into their respective zones and, from individual entries in the EMIUB dataset, assign them the three core attributes used in the modelled migration decision: age, gender and marital status. Using empirical observations to construct the attributes of agents initialised into the model provides both a solid basis from which to ground the ABM and an opportunity for a clear means of stringent model validation. These zones of origin form the basis for geographical representation throughout the model with different thresholds applying to agents in different zones. In addition to the initial attributes assigned to agents from the EMIUB data, statistical analysis of this resource also provides values for agent attitudes and subjective norms in the decision-making structure of the ABM.

The attitude value an agent in the model assigns to a particular migration option available to them is largely dependent upon their core characteristics. Through analysis of the EMIUB dataset, the probability of an agent born in a specific origin location, with specific current age, gender and marital status values, defines the attitude value of that agent. Probability values for each combination of agent origin zone (birthplace), potential migration destination and combination of attributes under wet, dry and average rainfall conditions are stored within the ABM and are referenced by agents according to the circumstances they are assessing. The subjective norm (or consideration of the expectations of others) values used by agents in the ABM are also determined through analysis of the EMIUB dataset. This component of the conceptual model deals with the interactions between agents and the influence of an individual's peers upon their own migration decision. Finally, the perceived behavioural control component of the migration decision is based upon two variables; experience of migration and assets. The initial experience rate of an agent is directly retrieved from the EMIUB data on model startup but can also be built upon throughout a model run by undertaking migration. Because temporal asset data is not available in the EMIUB, agent assets are assigned according to a rate of distribution calculated from the year 2000 data. The more assets and experience of migration an agent has, the greater the likelihood that they will perceive themselves capable of undertaking migration.

5. Model of agent migration adaptation to rainfall change

The Agent Migration Adaptation to Rainfall Change (AMARC) model presented here 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 either one of the other four origin zones or out of the country.

The control of time steps in AnyLogic ABMs is defined using an "event". Using a recurrent 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. 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 predefined marriage rate and death rate functions. Also controlled through the event component but, for

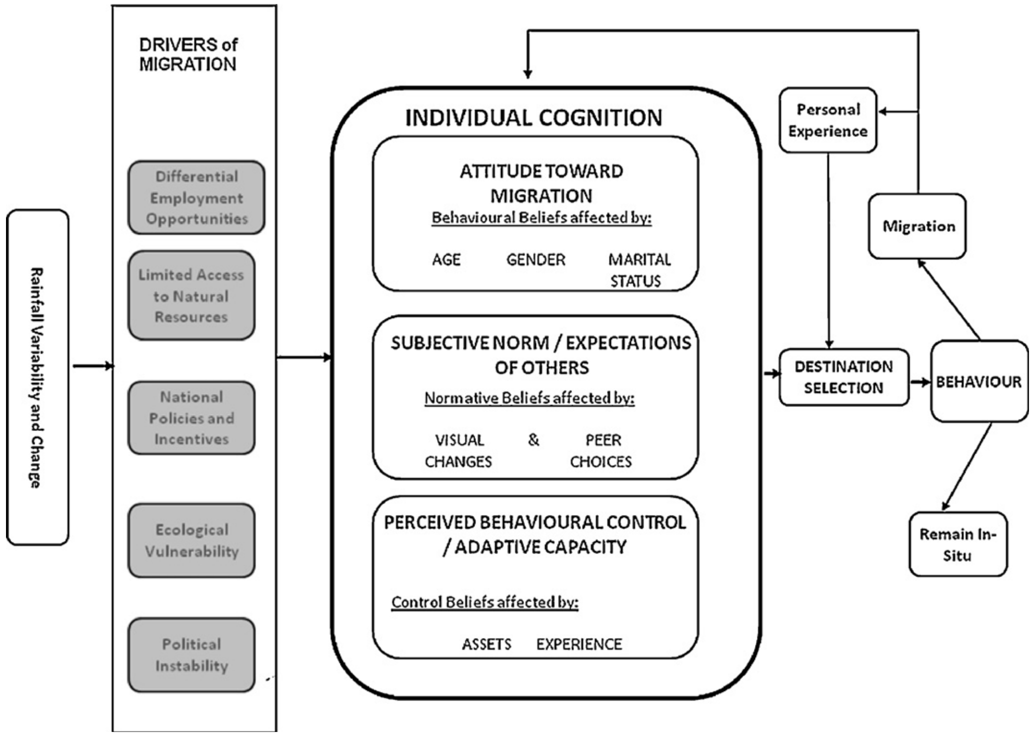

Fig. 1. Conceptual model of Migration Adaptation to Rainfall Change (MARC) displaying the role of rainfall change on an individual's consideration of the migration decision.

simplicity's sake, only occurring once a year at the end of the wet season in September, is the migration decision undertaken by agents. Taken on the basis of the structural rainfall conditions affecting an agent's location, this migration decision follows the basis of the decision-making structure presented by MARC in Fig. 1 in the manner presented by the AMARC class diagram in Fig. 2. Numeric notations adjacent to each model class in Fig. 2 indicate the multiplicity of that class (five (1.5) origin zones, five (1.5) destination zones and zero or more (0.*) agents but only one (1) migration decision per agent) while the lifecycle dependency between classes is indicated by a hollow or filled diamond shape. A hollow shape indicates an aggregation relationship where no strong life cycle dependency exists. For example, networked agents will still exist whether they receive a peer communication or not. A filled diamond, such as that seen between agents and their migration decision, indicates composition where a strong life cycle dependency exists between the classes. Removal of the agents will, for example, remove the occurrence of the migration decision.

As shown in Fig. 2 the migration decision of an agent within any origin zone of the model is therefore developed upon the basis of the agent's core attributes; age, gender, marital status, assets, migration experience and peer opinions, and the rainfall conditions affecting the zone. Used to inform the three core components of the migration decision; behavioural attitude, subjective norm and perceived behavioural control, these attributes contribute to the behavioural intentions an agent forms towards each available migration option. In order to identify a preferred course of action in response to the structural rainfall conditions affecting an individual, each agent will score the five active options (migrate to one of the four other zones, or migrate internationally) available to them. Following the development of behavioural intention values, an agent selects a preferred course of action: remain in situ, or migrate to one of the available destinations. A direct comparison of behavioural intention values allows an agent to rank their options before selecting a destination. The destination zone selected by an agent thus receives a temporary addition to its population while the chosen option is communicated to networked peers, thereby affecting their later decisions. Following their stay in a chosen location the agent returns to their origin location before the start of the following wet season.

For ease of computation, in this version of the model, the migration decision is only performed once a year. Focus group interviews conducted across Burkina Faso revealed that a common approach to seasonal migration involves assessing the success of the annual harvest at the end of the wet season and, if necessary, migrating in September. However, in reality, and in future versions of the model, an individual will continually assess the options available to them for some time prior to actually being placed in the situation where migration may become a necessity.

The behavioural attitude, subjective norm, and perceived behavioural control values calculated by each agent contributes to their behavioural intention towards the migration option being considered. An 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. An indication of the ability of how well the model is able to simulate migration flows is shown in Fig. 3 where five-run-averaged total migration flows are compared directly with the observed EMIUB record and show a correlation coefficient of 0.93 (0.995 significance level) and normalised root mean square deviation of 12.7%. The agents modelled for these data were initialised using the EMIUB data and only include those people who were present throughout the 30 year survey period from 1970 to 1999. As a result, the version of the AMARC model used for validation in Fig. 3 includes no function for agent birth or death, thereby attempting to directly replicate the migration decisions of the 4449 individuals alive in 1970 and surveyed in 2000.

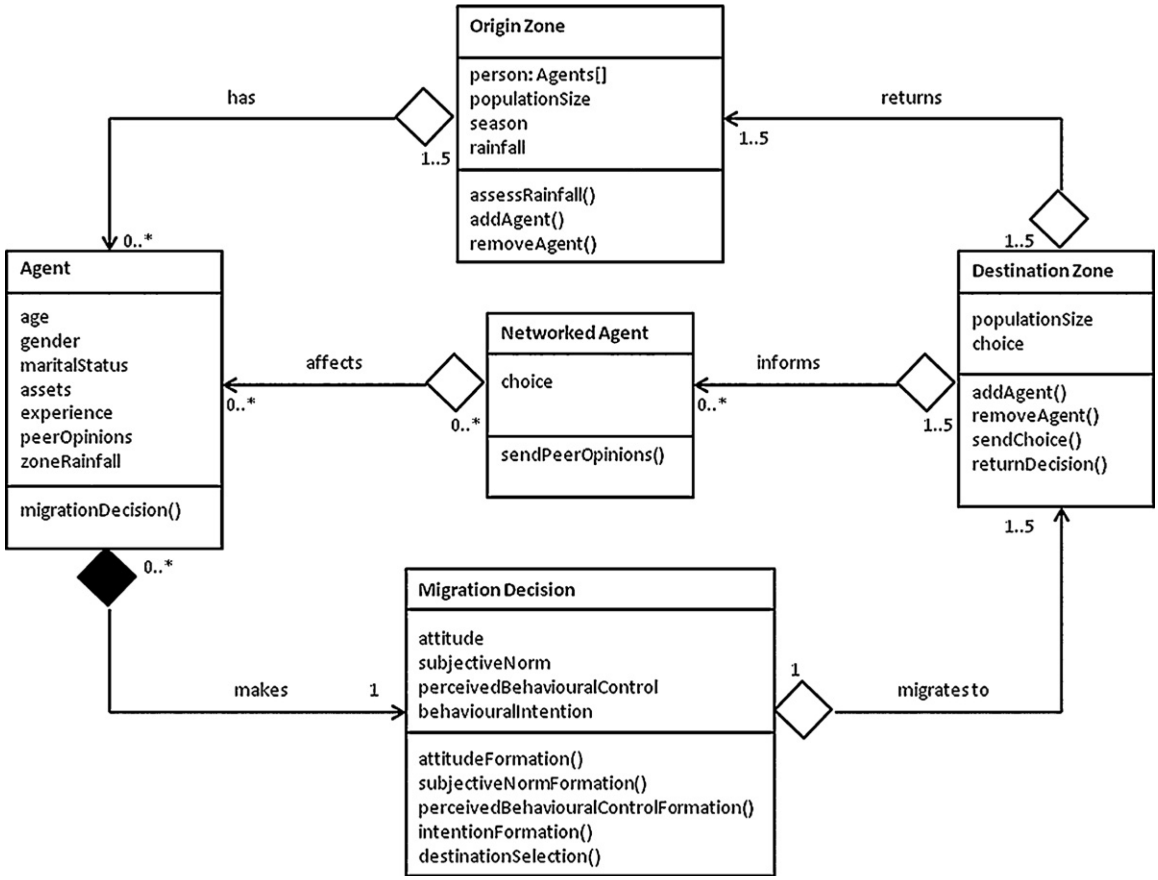

Fig. 2. Agent Migration Adaptation to Rainfall Change (AMARC) class diagram (see text for explanation).

6. Future scenarios

The future scenarios used in this study comprise four narratives and scenarios of demographic, economic, social, political and environmental change running to 2060 developed as part of the Global Environmental Migration Project of the Foresight Project of the UK Government Office for Science at the Department for Business Innovation and Skills. Scenario A describes high global growth and exclusive local social, political and economic governance; scenario B describes high global growth, and inclusive local social political and economic governance; scenario C describes low global growth and exclusive local social political and economic governance; and scenario D describes low global growth and inclusive local social, political and economic governance (see Table 1 and Black et al., in this issue; hereinafter referred to as the Foresight scenarios). While the ABM explicitly models the influence of demography and climate change, the economic, social and political dimensions controlling migration behaviour are contained within the Behavioural Attitude probability value. In scenario A the migration outcomes of the economic, social and political transformations can be broadly summarised as an increase in migration probabilities for educated individuals migrating to international destinations with other migration probabilities remaining static. In scenario B, the migration outcomes of the economic, social and political transformations can be broadly summarised as an increase in migration probabilities for all types of migration. For scenario C, reductions in all migration probabilities are anticipated while for scenario D, increases in all migration probabilities are foreseen. For scenarios A and C we use the higher variant population projections from UNDP to simulate changes in the demography of Burkina Faso, while for scenarios B and D we use the lower variant. Demographic

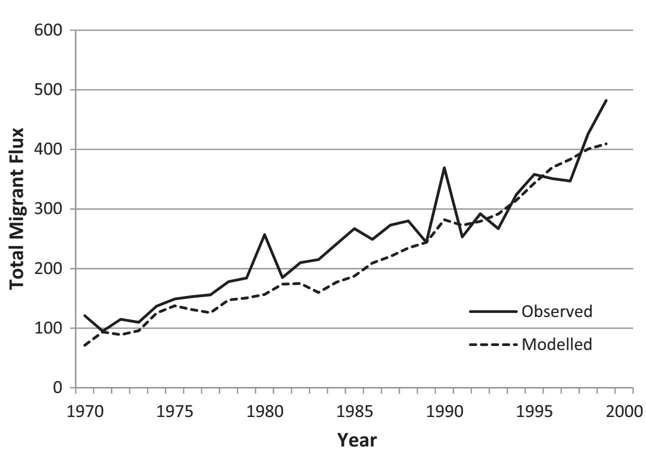

Fig. 3. Simulated and observed total migration fluxes in Burkina Faso from 1970 to 1999 for individual migrants recorded by the EMIUB survey.

Table 1
Demographic, economic, and social and political governance aspects of foresight scenarios.

Scenario	Demographic	Economic	Social and political governance
A	High	High	Exclusive and diverse
B	Low	High	Inclusive and connected
C	High	Low	Exclusive and diverse
D	Low	Low	Inclusive and connected

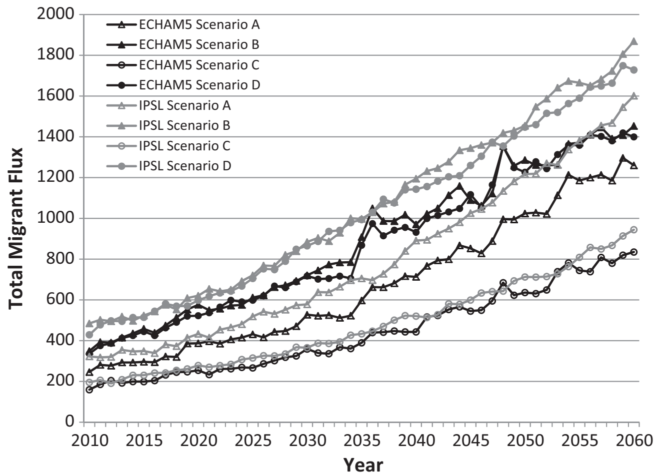

Fig. 4. Modelled total (internal and international) migration flux in Burkina Faso from 2010 to 2060 for scenarios A, B, C, and D (see text) and climate change scenarios from ECHAM5 and IPSL models, for a model population of 4449 agents.

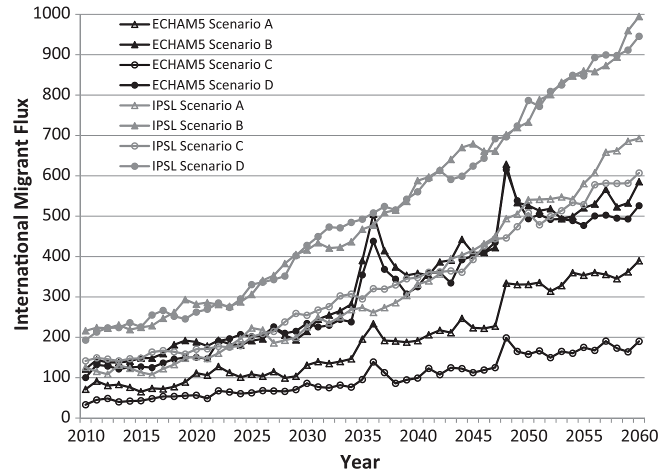

Fig. 5. International migrant flux from Burkina Faso from 2010 to 2060 for scenarios A, B, C, and D (see text) and climate change scenarios from ECHAM5 and IPSL models, for a model population of 4449 agents.

changes in the ABM are simulated by birth and death rates altered to represent the United Nations World Population Prospects (United Nations, 2011). Instead of using the Foresight scenario based interpretation of the climate model based scenarios we use the two time series of climate change according to the raw model output from two climate models; ECHAM5[1] and IPSL.[2] Broadly speaking the IPSL model depicts a dry rainfall scenario for Burkina Faso, while ECHAM5 depicts a relatively wet alternative with the respective increases (decreases) and decreases (increases) in dry (wet) years. The choice of a wet and dry scenario serves to give some indication of the range of migration futures possible in a location where future projections of precipitation change are recognised by the latest assessment of the Intergovernmental Panel on Climate Change as being highly uncertain (Solomon et al., 2007).

7. Model results

While the Foresight scenarios provide qualitative changes in migration behaviour, they do not indicate the magnitude of these changes. Sensitivity of the ABM results to different levels of change in the migration probabilities from the changes in social, economic and political factors for a single climate scenario (not shown) revealed significant differences in aggregate migration fluxes at changes of 25% and above. Using the arbitrary level of change of 25% (increases and decreases) in migration probabilities for the different scenarios and the above demographic changes, ensemble runs of the ABM were performed for the ECHAM5 and IPSL model outputs. In Fig. 4 the change in the total migration flux including all internal and international migrants is shown for an original population of 4,449 agents (those identified from EMIUB as alive in 1970). Each model run was started in the year 1970 to allow "spin up" of the model and results are shown for ensemble runs of the ABM with 4 members. Fig. 4 reveals that by 2060 scenarios A, B and D show similar patterns of change and scenario C the least change in both climate model projections. This indicates that low global economic growth, high population growth and exclusive local social, political and economic governance reduce migration flows compared to other combinations of non climate drivers. Comparing migration outcomes between climate model runs it can be seen that scenarios A and B show the highest differences compared to scenarios C and D, such that the marginal impact of climate change is greatest for high global economic growth. Overall it can be seen that the dry climate scenario produces increased migration fluxes compared to the wet scenario.

In Fig. 5 migration flows are shown for international migration from Burkina Faso. As with the total flows discussed above, three pathways emerge from the agent-based modelling approach. The lowest migration fluxes over time are produced by the combination of low global economic growth, high population growth and exclusive local social, political and economic governance with both wet and dry climate scenarios. Highest international migrant flows are shown with the dry climate scenarios.

8. Discussion and conclusion

The agent-based model simulations shown in this paper illustrate the dependence of future migration outcomes on the interplay of demographic, economic, social, political and climatic changes. Interestingly, a future dry climate for Burkina Faso is modelled to produce the largest total and international migration flows when combined with low demographic growth and inclusive and connected social and political governance. While the lowest total migration flows occur for future change that is characterised as having high demographic change, low economic growth and exclusive and diverse social and political governance, irrespective of climate change. The lowest international migration flows are produced by future scenarios characterised as moving towards a wetter climate with high demographic growth and exclusive and diverse social and political governance, irrespective of economic growth. The response of internal migration flows to a drier climate was anticipated from the previous study of Henry et al. (2004), on whose data the ABM was parametrised, who found that short distance migration to larger agglomerations increased during drought years, as women and children left in search of work to contribute to household incomes. However, the same response to dry conditions was not expected with international migration, where the empirical evidence from the past indicated that drought was associated with decreases in international, long-distance migration as food scarcity during drought leads to

[1] ECHAM5 is the fifth-generation atmospheric general circulation model developed at the Max Planck Institute for Meteorology (MPIM). The ECHAM models are based on the spectral weather prediction model of the European Centre for Medium Range Weather Forecasts (see http://www.mpimet.mpg.de/en/science/models/echam/echam5.html).

[2] The IPSl climate model was developed at Institut Pierre Simon Laplace des Sciences de l'Environnement Global by the Pôle de Modélisation (see http://igcmg.ipsl.jussieu.fr/Doc/IPSLCM4/).

increased prices, forcing people to spend more money on their basic needs rather than on long-distance migration (Henry et al., 2004). One possible explanation for this discrepancy could be an over-sensitivity of the model to the influence of others upon agent behaviour. While this is a possibility the ability of the model to simulate the observed migration flows argues against such an explanation. Alternatively, the reasoning could be that while the findings of Henry et al. (2004) are generally true for people in the Sahel and central regions they do not apply to international migration from the urban centres nor the south west of Burkina Faso to Ghana and the Ivory Coast.

In relation to non-climate drivers of migration it can be seen that for international and total mobility the lowest future flows seem to be produced by diverse and exclusive social and political governance. Interesting population growth is shown as inversely related to migration flows in these simulations however it should be recognised that this is due to the large changes in migration probabilities (up to 25%) attributed to the social, political and economic scenarios compared to the differences in demographic change projections and so should not be taken as indicative of the influence of population change on migration. Greater definition of the economic, social and political change and the availability of relevant data would provide a means by which their role in migration decision-making could be investigated using this ABM. Lastly it can be seen that large positive deviations from the general trend of migration are shown from 2035-2040 and 2047-2050 for both total and international flows in a wetter climate when combined with inclusive and connected social and political governance reflecting the possibility of sudden mass migrations in these circumstances. These deviations are not apparent for drier climate change.

Given the complex nature of how climate change impacts influence migratory decision making both directly and, probably more importantly, indirectly through political, social and economic factors, agent-based modelling offers a heuristic device to help map out the characteristics of future migration flows with regard to different scenarios. The future scenarios described by the Foresight project provide a test bed to assess the impact of changes in global economic growth, political, social and economic governance, demographic change and different climate scenarios on migration.

References

Ajzen, I., 1991. The theory of planned behavior. Organizational Behavior and Human Decision Processes 50, 179–211.

Black et al., 2001. (This special issue).

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R., Yanda, P., 2007. Africa. Climate Change 2007: Impacts, Adaptation and Vulnerability. Intergovernmental Panel on Climate Change, Cambridge.

Epstein, J.M., 2005. Remarks on the foundations of agent-based generative social science. In: Judd, K., Tesfastion, L. (Eds.), Handbook on Computational Economics, vol. II. North Holland Press.

Fishbein, M., Ajzen, I., 1980. Understanding Attitudes and Predicting Social Behaviour. Prentice-Hall, Englewood Cliffs, NJ.

Grothmann, T., Patt, A., 2005. Adaptive capacity and human cognition: the process of individual adaptation to climate change. Global Environmental Change 15 (3), 199–213.

Henry, S., Schoumaker, B., Beauchemin, C., 2004. The impact of rainfall on the first out-migration: a multi-level event history analysis on Burkina Faso. Population and Environment 25, 423–460.

Lee, E., 1966. A theory of migration. Demography 3, 47–57.

Nicholls, R.J., Tol, R.S.J., 2006. Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the twenty-first century. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 364, 1073–1095.

Poirier, J., Piché, V., LeJeune, G., Dabiré, B., Wane, H.R., 2001. Projet d'étude des strategies de reproduction des populations sahéliennes à partir de l'enquête "Dynamique migratoire, insertion urbaine et environnement au Burkina Faso". Cahiers Québécois de Démographie 30 (2), 289–309.

Silveira, J.J., Espindola, A.L., Penna, T.J.P., 2006. Agent-based model to rural–urban migration analysis. Physica A: Statistical Mechanics and Its Applications 364, 445–456.

Solomon, S., Qin, D., Manning, M., Alley, R.B., Berntsen, T., Bindoff, N.L., Chen, Z., Chidthaisong, A., Gregory, J.M., Hegerl, G.C., Heimann, M., Hewitson, B., Hoskins, B.J., Joos, F., Jouzel, J., Kattsov, V., Lohmann, U., Matsuno, T., Molina, M., Nicholls, N., Overpeck, J., Raga, G., Ramaswamy, V., Ren, J., Rusticucci, M., Somerville, R., Stocker, T.F., Whetton, P., Wood, R.A., Wratt, D., 2007. Technical summary. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom/New York, NY, USA.

TERI, 1996. The Economic Impact of a One-metre Sea Level Rise on the Indian Coastline: Method and Case Studies from New Delhi. Tata Energy Research Institute, Bangalore.

United Nations, Department of Economic and Social Affairs, Population Division, 2011. World Population Prospects: The 2010 Revision. New York (comprehensive Excel tables accessed from http://data.un.org/; 1st June 2011).

Warren, R., Arnell, N., Nicholls, R.J., Levy, P., Price, J., 2006. Understanding the regional impacts of climate change Research report prepared for the Stern Review. Tyndall Centre, Norwich.

Ziervogel, G., Bithell, M., Washington, R., Downing, T., 2005. Agent-based social simulation: a method for assessing the impact of seasonal climate forecast applications among smallholder farmers. Agricultural Systems 83 (1), 1–26.