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Climate Shocks and Migration: An Agent-Based Modeling Approach

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Abstract

This is a study of migration responses to climate shocks. We construct an agent-based model that incorporates dynamic linkages between demographic behaviors, such as migration, marriage, and births, and agriculture and land use, which depend on rainfall patterns. The rules and parameterization of our model are empirically derived from qualitative and quantitative analyses of a well-studied demographic field site, Nang Rong district, Northeast Thailand. With this model, we simulate patterns of migration under four weather regimes in a rice economy: 1) a reference, 'normal' scenario; 2) seven years of unusually wet weather; 3) seven years of unusually dry weather; and 4) seven years of extremely variable weather. Results show relatively small impacts on migration. Experiments with the model show that existing high migration rates and strong selection factors, which are unaffected by climate change, are likely responsible for the weak migration response.

Keywords

Migration; Climate change; Weather; Thailand; Agent-based model

The potential impacts of climate change on migration have been a subject of intense interest in the policy and academic arenas for some time. In general, there is an expectation that

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climate change will lead to a large amount of migration, with an estimated range of 50 to 200 million (Stern 2006; UN University 2005) climate-related migrants predicted for the coming decades. Although there has been burgeoning research on migration responses to climate change, a few of which we cite here (Bohra-Mishra et al. 2014; Curtis and Schneider 2011; Gray and Bilsborrow 2013; Gray and Mueller 2012a,b; Henry et al. 2004; Hunter et al. 2013a,b; Mueller et al. 2014; Stal 2011; Dun 2011; Shen and Gemenne 2011; Renaud et al. 2011; Marhiori and Schmacher 2011; Bardsley and Hugo 2010; McLeman 2010; Barbieri et al. 2010; Gutmann and Field 2010; Reuveny and Moore 2009), the mechanisms that drive this relationship remain unclear to date.

In this paper, we examine how climate shocks might affect migration in rural agricultural areas. Our aim is not to test any particular theory, but to investigate if, how, and why these two processes might be related. Thus, we use a broad social science theoretical perspective and a modeling strategy that allows for detailed analysis of the mechanisms by which climate could influence migration. Drawing on contemporary sociodemographic theories of migration, we consider a variety of factors that could reduce as well as increase the chances that individuals migrate. In contrast to the neo-classical economic theory, which would predict large migration response to climate shocks, several of these other perspectives suggest a counter-narrative wherein climate change would not be expected to increase levels of migration by very much.

Migration is a common behavior around the world, and periods of increased and decreased migration have been documented in most countries. Climate and weather are also, and have always been, variable and humans around the world long ago developed adaptive responses to floods, droughts, and monsoonal variability in general. At the same time, political or policy changes, population growth, and economic changes are regular occurrences that frequently coincide with climate change. Further, it is likely that climate shocks cause a range of responses, all of which could influence migration in the short and medium term. In short, climate shocks occur within a complex interactive social-ecological system making it difficult to isolate the effects of climate on migration independent of other pertinent factors and processes using observational data alone. Alternately, the agent-based model (ABM) in this study explicitly models the dynamic and interactive pathways through which a climate-migration relationship may operate. Functionally, it creates an experimental context within which we can test the effects of different weather scenarios, in the absence of other macro-level changes. Because the ABM explicitly models pathways through which climate might influence migration, we can also gain some insight into why a climate signal results in a large or small migration response. Thus, by using an ABM, we can circumvent important limitations of observational studies and also test competing theories in new ways.

Our study is based in the Nang Rong District of northeast Thailand. Our ABM uses empirical survey and ethnographic data from the Nang Rong Projects (Entwisle et al. 1998; Walsh et al. 2005) and includes exceptional detail on demographic behaviors– such as migration, marriage, and births – and spatial-environmental processes relating to agriculture, land use, and weather patterns. With this model, we simulate several climate scenarios, including ‘normal’ weather patterns as well as shocks, and analyze the impact of these scenarios on migration. The goal is not to make predictions, but rather to use the model to explore mechanisms. Our results and conclusions are generally relevant to rural agricultural areas and to potential consequences of significant droughts and serious flooding expected in unusually wet years. They are of course less applicable to urban areas and discrete onset events such as cyclones or hurricanes.

As a preview, our ABM results show a relatively weak impact of climate shocks on migration. This is in contrast to regression results using the same data, which we also present in this paper, that show relatively large migration responses to climate scenarios. Examining the mechanisms that might be responsible for this difference in results, our ABM shows climate change clearly affecting steps along the theoretical pathway linking climate change and migration. We find the possibility that climate shocks can influence migration at the individual level, but these effects do not aggregate to the macro-level or cumulate over time when interactive social processes are taken into account. Our results suggest that the study of population-environment interactions may benefit from more thorough engagement with sociodemographic theories, which anticipate a more limited migration response to climate change than anticipated in the climate change literature.

Theoretical background

Although it is often not explicitly stated in academic articles and policy reports, there is a consistent explanation connecting climate change to increased out-migration from rural agricultural areas. The idea is based on the notion that subsistence of households in rural agricultural areas is almost completely dependent on the land and weather. In the case of changes in weather, agricultural harvests might be reduced or ruined, making subsistence for these households difficult if not impossible, at least for the year in which the weather event occurred. Thus we can predict, with the support from the push-pull and neo-classical economics theories of migration (Massey et al. 1993; Sjaastad 1962; Todaro 1969), that in the absence of savings or some kind of insurance or other support, people will migrate away in order to search for economic gain elsewhere. While these hypotheses are logically grounded, they are also simplistic. They do not thoroughly reflect the realities of rural subsistence, especially adaptive strategies that may already be in place, and they do not take other sociological theories of migration into account.

Indeed, the literature on migration provides a wealth of complementary theories that highlight how the relationship between climate change and migration may not operate as assumed by simplistic push-pull models. In this study, we employ some of these theories to better elucidate how the mechanisms of existing migration patterns, feedbacks, and adaptation might moderate the climate-migration relationship. In general, our theoretical perspective is based on the understanding that in most rural agricultural areas of the world, there are already high rates of migration that are influenced by strong existing patterns. Any climate-induced migration would be a case of additional migration over these already high levels and at the same time need to overcome existing forces that encourage some people not to migrate.

Existing migration patterns

In rural agricultural societies, the possible climate change-migration relationship occurs within the context of existing marginality and strong selective pressures on migration. For instance, in rural northeast Thailand where this study is set, almost 40% of people between the ages of 10 and 29 who were born in the district were living outside of the district in 2000. Such high levels of baseline migration and the likelihood that migration has become a normative behavior for young adults (Ali 2007; Connell 2008; Horvath 2008), indicate the possibility that many if not most people who can migrate or would benefit from migrating already do so. In this case, we might not expect to find much additional migration in response to weather shocks.

In addition, there are often strong selection effects that drive migration but also keep some people at home. For instance, migration around the world has a strong age-gradient; those at risk of leaving are primarily young adults. Life-course events, such as marriage and childbearing also influence selectivity. The cumulative effect of these life-course transitions is to increase the myriad holding factors that would discourage individuals from leaving. We argue that where existing selective factors on migration (such as age, marital status, and childbearing) are strong, the effect of climate change on migration will be weaker.

Feedbacks in the migration process

Migration occurs within existing social structures. Migrants move, provide information to others within their social network, and send remittances to their origin households. Theory and evidence suggest that these behaviors all function to increase or decrease the likelihood that other people migrate (Massey et al. 1987; Massey 1990a, 1990b).

Social networks and the existing pressures they exert on migration could counterbalance any additional motivations to migrate in the situation of climate change. For instance, it has long been argued that social networks in places of destination are an important factor leading individuals to out-migrate from rural areas (Curran et al. 2005; Massey et al. 1987; Massey 1990a, 1990b; Tilly and Brown 1967). Alternately, high-levels of out-migration can reduce the connectivity of origin networks, thereby disrupting connections between individuals and households that could otherwise be expected to share information (Entwisle et al. 2007). In the first case, we can expect social networks to function as potential feedbacks that may progressively increase the level of additional migration in response to climate change; in the second case we could expect that social networks would still function as feedbacks, but decrease the level of additional migration.

Similar to social networks, remittances might also function as a feedback mechanism that could dampen the influence of climate change on migration. If a migrant sends remittances back to the origin household, then there is less need for additional migration from that household. In this case, it is possible that a climate shock could initially lead to increased migration. However, once remittances flow back to origin households, we might not expect further migration, which could result in the empirical finding of little climate impact on migration.

Adaptation

A final consideration is that of the adaptive capacity of humans. The New Economics of Labor Migration (NELM) theory (Stark and Bloom 1985; Stark and Taylor 1989, 1991; Taylor 1986, 1987), describes migration as an adaptive strategy pursued by households to diversify income streams and risk. But it is important to recognize that migration is only one such adaptive strategy. Other adaptations could include diversification of crops as part of a "portfolio" approach, changing land use in response to or in anticipation of extreme weather events, and decreasing household expenditures when times are tough. As such, there are numerous ways that households can adapt to climate shocks, many of which might already be employed. To the extent that households and villages already have strategies in place to cope with climatic variability, we might not expect high levels of migration in response to specific events. Further, these strategies can often be even more aggressively pursued, which may further dampen potential climate impacts.

Data and Methods

Setting

This study is based in Nang Rong District of Northeast Thailand. For several decades, this area has served as a study site and laboratory to explore interactions among people, place, and environment in the social, natural, and spatial sciences (Entwisle et al. 1998; Walsh et al. 2005). The ability to draw on existing literature and extensive ethnographic, qualitative, spatial, and social survey data makes this study site an ideal location to implement a theoretically motivated and data informed agent-based model.

Nang Rong occupies approximately 1300 km^2 in Northeast Thailand. As a generally rural district, historically the economy was based on subsistence agriculture, but recent decades have seen increasing engagement in market agriculture with rice and upland crops such as cassava, sugar cane, eucalyptus, and rubber. The environmental setting is one of marginality with a limited natural resource base.

The climate in Nang Rong is monsoonal, with rains arriving in the late spring to early summer. Precipitation, however, is unpredictable in both timing and amount. As shown in Figure 1, a clear downward trend in annual rainfall with increased variance year-to-year characterizes the past 50 years. This historical record was the starting point for developing the weather scenarios that we assess (Walsh et al. 2013).

As already noted, migration, both permanent and temporary, is common in Nang Rong (Fuller, Lightfoot, and Kamnuansilpa 1985; Fuller, Kamnuansilpa, and Lightfoot 1990; Guest 1996; Korinek, Entwisle, and Jampaklay 2005). Because of the region's dependence on rain-fed paddy rice farming with minimal irrigation, Nang Rong farmers must deal with local weather shocks and also shocks originating in the national and international economy affecting the demand for agricultural products. Migration has long been a strategy that anticipates and responds to these shocks.

Overview of the Computational Model

Agent-based models, similar to the one we use here, are not unusual in geography and land use science (e.g., Deadman et al. 2004; Kelley and Evans 2011; Manson and Evans 2007; Parker et al. 2003), but they are still relatively new methodological tools in some social sciences. For this reason, we include a brief description and summary of the benefits of this method in supplementary online appendix A1. In this section we provide a brief overview of the ABM upon which this study is based. Online appendix Figures A1–A4 present flowcharts that detail how each process in the ABM works and further details of the model are available in Entwisle et al. 2008 and Walsh et al. 2013. Basic tools used to construct the model are available online at: (blinded for review).

The ABM includes multiple types of agents: individuals, land parcels, households, social networks, and villages. As shown in Figure 2, households are a point of integration for the model: individuals form households, which are embedded in social networks and villages. Land parcels are owned, managed or used by households. Villages are composed of households, and social networks consist of ties among those households.

Each individual agent has attributes, such as age, gender, marital status, etc. In addition to the compositional attributes determined by the particular individuals that live within each household, household agents have attributes such as assets, land ownership, centrality of the household in village networks, and ties to wealthy (top 10% in the distribution) households in the village. Land parcels also have attributes, such as size, distance from the village, flooding potential, land use type, and soil suitability for various agricultural uses. Finally, villages have attributes that aggregate individual, household, and parcel attributes (e.g., population size, migration prevalence) as well as a social network variable (connectivity).

Each individual agent can experience demographic, social, and/or economic processes including birth, death, out-migration, return migration, marriage, establishing a new residence locally, and, for women, giving birth. When not residing in the community, they can remit to the origin household, marry, or die. All of these behaviors depend on equations that utilize individuals' attributes. More detail about such equations is presented below for migration.

Households can rent and own land and accumulate assets and can pass them on to their kin when they die or reach old age. Depending on their attributes and resources, parcel characteristics, and environmental factors such as the timing and amount of rainfall, each household makes a choice about how to use its land parcels (for rice, sugar, or cassava cultivation) and inputs such as fertilizer. These parcels in turn experience levels of productivity which are based on those choices, land attributes such as soil quality, and rainfall patterns for that year. We also model household change, by allowing individuals to marry, change their residence after marriage, and for married couples to split from their parent households. Again, all of these processes are shown in detail Appendix Figures A1–A4.

An important aspect of our analysis is that we do not build a direct effect of climate change on migration into the model. Instead, our ABM models an indirect relationship: rainfall patterns affect crop yields, crop yields affect household annual income, household annual income affects accumulated assets, and assets affect migration. We could include a direct effect in the model, but given that it already incorporates the indirect effects, it is not clear what such a direct effect would mean. It is possible that some individuals simply do not like a particular kind of weather and leave according to this preference. Although this is certainly possible, all theories which address the weather- migration relationship predict an indirect relationship whereby weather directly affects one process (such as decreased crop yields), which in turn affects other processes that ultimately lead to changes in migration behaviors.

Climate Scenarios—We simulate four climate scenarios in the ABM: a reference scenario, a seven-year period of extremely dry weather, a seven-year period of extremely wet weather, and a seven-year period of variability between the two. Hereafter, we call these scenarios "reference", "drought", "flood", and "variability." We created these scenarios based on monthly rainfall data for Nang Rong from 1900–2008, accessed from the University of Delaware Center for Climate and Land Surface Change (Nickl et al. 2010). The reference scenario is composed of years that all experience average timing and amounts of monsoon rain based on the historical record (from 1900–2008). We call such years 'normal-normal' to reflect normal timing and normal amount amount of rainfall.[1] The drought, flood, and variability scenarios each include a single period of seven years (running from simulation years 10–17) which experiences extremely dry weather, or extremely wet weather, or alternating every two years. The dry years are drier than experienced in the historical record, but still provide enough rain to provide some yield of all crops in the model; the flood years are wetter than experienced in the historical record, but do not entirely flood the area and allow for some yield of all crops in the model. The seven-year drought or flood period is preceded by 10 years of normal-normal climate and followed by normal-normal climate in the remaining years. Thus, years 1–10 of the simulation of all scenarios are characterized by normal-normal climate, during years 11–17 we simulate the weather shocks, and in years 18–25 we simulate normal-normal climate in all scenarios. Further detail on creation of these extreme situations is provided in Walsh et al. 2013.

Crop Yields and Income—These weather patterns feed into a model of crop productivity called DSSAT (Decision Support System for Agrotechnology Transfer), which uses data on crop type, soil type and quality, amount of rainfall and planting time, and fertilization levels to produce the number of kilograms of that crop which would be grown per hectare for each particular plot of land (Cheyglinted et al. 2001; Piewthongngam et al. 2009; Matthews and Hunt 1994; Inman-Bamber 1995). With these features, the DSSAT model, embedded in the ABM, calculates the amount of rice, cassava, and sugar yielded by each plot of land each year of the simulation.

Income and Assets—Crop yields in turn influence household income and then assets. Specifically, as shown in equation 1 in Table 1, income is the net earnings of each household (in Thai baht), taking into account earnings from crop harvests and remittances from migrants, as well as expenses for fertilizer, regular household maintenance, changing land

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[1] We also tested a scenario with the actual recorded weather conditions from 1975–2000. Results from this scenario are substantively equivalent to those for the reference scenario and are not presented in this article.

use, and migrating. The prices earned for each crop were determined by market prices for crops from the 2000 Nang Rong surveys and records from the Thai Rice Exporters Association[2][3]. The amount of baht earned from remittances was determined by the Nang Rong surveys and that expended for other items in the equation comes from key informant interviews. Using the annual income, assets is simply the accumulation of income, and functions very much like a bank account to which positive income is added or negative income (i.e. expenses) are subtracted at the end of each year.

Migration—The rules for out- and return migration are based on a regression equation that is specified using multivariate analysis of Nang Rong survey data. Individuals between the ages of 10 and 29 are eligible to out-migrate and return migrate[4]. The coefficients from regression models are used in the agent-based simulation to calculate individual specific probabilities of out- and return migration in each simulated year. The calculated individual probability is then compared to a random number; if the probability is higher than then random number, then the individual migrates. The out-migration equation (shown in Table 1) is designed to incorporate predictors of migration that have shown to be important in the migration literature as well as in previous studies of migration in the Nang Rong area (e.g., Piotrowski and Tong 2010; Piotrowski et al. 2013; Rindfuss et al. 2012; Vanwey 2003), as well as characteristics important for our research questions, such as household assets, social networks, and village characteristics. In addition, all variables used to determine the migration probability have statistically significant effects (to $p<0.10$) on migration in the regression equation using Nang Rong survey data. Because predictors of migration vary for different age groups, we calculate migration probabilities for agents who are 10–19 years old and 20–29 years old in separate equations[5].

As we mention above and suggest in Figure 2, events and behaviors of individuals and households in one year influence their behaviors in subsequent years. An example of this is the case of migration. Notice that marital status, household assets, ties to migrants are variables in the equation determining whether an individual migrates. Thus, if a person gets married one year, this changes their marital status and thus their likelihood of migrating the next year. If a household makes a large amount of income one year, this increases the household accumulated assets and thus influences the likelihood of migration of each person in that household the next year. Characteristics of individuals, households, and villages are updated annually in the model.

Once a person has migrated, they are then subject to the possibility of return migration to Nang Rong each year. Return migration is calculated in a similar manner to migration. A regression equation to predict the probability of return is estimated using the Nang Rong survey data. Once the probability of return is calculated, it is compared to a random number

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[2] http://www.thairiceexporters.or.th

[3] Local prices of rice, cassava, and sugar are all affected by national and international markets. Thus we assume that any weather shocks that could influence local production of these crops will not influence local prices.

[4] This is the most common age range of migration in Nang Rong. In the 1994 Nang Rong Household survey, only one individual below the age of 10 was classified as a migrant and about 26% of all migrants were above the age of 29, a negligible fraction of whom returned by the time of the 2000 survey.

[5] Equation 2 shows the equation for those aged 10–19 only. A separate equation (with the same variables but different coefficients) is used for those aged 20–29.

in order to assign whether an individual does indeed return or not. Because each migrant is exposed to the possibility of return migrating each year, some return within a short period of time, a long period of time, or not at all. Thus, short-term, long-term, and permanent migration are all possible in this model. This reflects well the actual patterns of migration in the Nang Rong area, which are a mixture of all these types of migration.

Research Design and Approach

To address the research question in this study—how might climate events influence migration?—and to understand which mechanisms might be responsible, we designed a series of experiments with the ABM as described below.

Experiment A: Baseline model of migration

In our first experiment, we explore the extent to which prolonged droughts, floods, and variability influence migration. We compare simulations with climate change scenarios to the reference scenario. Conventional wisdom and the literature suggest that we should find a difference. Addressing the pathway from climate events to migration, we expect the extreme climate scenarios to result in decreased crop yields, resulting in lower household assets, and in turn, increased migration. However, as already previewed, we do not find a strong migration response. In order to understand why we do not find the expected response and to explore other theoretical perspectives on migration, we designed experiments B-E, as follows.

Experiment B: No individual effects on migration

Experiment B explores the possibility that individual characteristics drive migration to such an extent that they overwhelm the influences of the climate-migration pathway. In practice, this means that we set the coefficients for all individual characteristics (age, gender, marital status, and ties to current migrants) in the migration equation to zero for the entire period of simulation (from year 0–25) and all weather scenarios. Because the migration model includes particularly strong age effects, we expect that the removal of these coefficients could substantially alter the amount of migration and result in a larger effect of climate scenarios on migration.

Experiment C: No remittances

Experiment C tests whether remittances, an important feedback from migrants to households, alter the effect of climate events on migration. We accomplished this experiment through setting the amount of money that could be remitted to 0 baht for the entire simulation and all scenarios.

Experiment D: No social network effects on migration

Experiment D investigates to what extent social networks influence the effect of climate on migration, either accelerating it or counter-balancing it. To accomplish this experiment, we set all coefficients for variables related to social networks in the migration equation[6] to zero for years 0–25 in all scenarios.

Experiment E: Adaptation of migration, based on assets

The final experiment investigates an alternative scenario for how assets influence migration. Instead of using only the amount of *cumulative assets* a household owns, we also allow individuals to adapt their behavior if their household loses *income*. In this experiment, if a household loses money for three years in a row, each household member's risk of out-migrating is doubled. If income losses continue for four, five, or more years, the migration probability is multiplied by four, eight, sixteen, and so forth. This adaptation is exaggerated, thus we would expect it to have substantial impacts on migration in climate scenarios which decrease crop yields. Although a geometric increase is unlikely in reality, it serves to test the model with an upper bound of possibility to see if it can force greater migration effects. In Experiment E, this adaptation rule is implemented throughout the entire simulation period in all weather scenarios.

Results

Migration in a regression-based model format

Before presenting the results for migration from our ABM-based experiments, we present results from a regression-based prediction of the effect of climate change on migration. This should serve as a counterpoint with which to compare the ABM results. The prediction we present here uses the exact regression equation that governs migration behavior in the ABM. We calculate the predicted probability of migration for an "average" 15 year old male, meaning that we used values that represent the mean of the population distribution for all terms in the migration regression equation. To calculate the effects of climate scenarios on migration, we input the average household assets per year in the migration equation for each of the scenarios. Thus the difference in results between the scenarios is entirely a consequence of varying levels of assets in each climate scenario. The results are presented in Figure 3.

Using the regression-predicted migration, we find clear suggestion of pronounced migration responses to climate shocks, as would be predicted by push-pull and neo-classical economics theory. As assets decline from year 12 to 18, the predicted probability of migration increases. This increase is symmetrical with the changes in assets: there are larger increases in migration for the drought scenario, which also had the largest decreases in assets, and smaller increases in migration for the flood scenario, which had the smallest decreases in assets.

Agent-based model results

For all scenarios and experiments, the ABM was run on 41 villages within the Nang Rong study area. We focus on the dynamics for one model village, which we call by a pseudonym Lam Nuae, which was characterized by average population size and demographic and land use characteristics. Dynamics from the other 40 villages do not vary substantially or systematically from those shown here. For each scenario, experiment, and village, the model

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[6] These variables include: village connectivity, household centrality, ties to wealthy households, kinship dependency ratio, ties to current migrants, and the interaction between village migration prevalence and village connectivity.

was run 40 times to account for the possible impact of chance on the outcome. The results below show the averaged outcomes for Lam Nuae from 40 runs. Graphs showing migration rates are calculated by dividing the number of people who out-migrated from Lam Nuae each year of the simulation by the number of people eligible to migrate (i.e. ages 10–29) at the beginning of that simulation year.

Experiment A: Baseline model

In the models which follow, we test how much migration in the ABM differs between the four climate scenarios, in the baseline model. In order to understand the progression from climate to migration, we show each step of the pathway, from climate to crop yields, to assets, and finally migration. In other words, this procedure allows us to examine where along the pathway the climate 'signal' might be dampened or inflated.

Figure 4 shows the impacts of droughts, floods, variability and the reference climate scenario on total village rice, sugar, and cassava yields in Lam Nuae. Note that we are discussing total yields, rather than productivity (yields per hectare). Total village yield can increase (or decrease) as a result of changes in the productivity of a particular crop but also through shifts in land use from one crop to another. As shown in Figure 4, there is a nearly immediate impact of drought, flood, and variable conditions on total village rice, cassava, and sugar yields. At the end of the climate shock period (year 17), rice yields partially increase, although never reach parity with the reference scenario. Cassava and sugar yields however increase dramatically after the weather shocks end, remaining far above the reference scenario through year 25. Further explanation of these notable results is provided in online appendix A2. The key outcome here, in the analysis of migration outcomes, is that weather shocks produce dramatic and prolonged changes in crop yields for rice, cassava, and sugar.

Moving to the next step in the pathway from climate to migration, Figure 5 shows trends in total village assets in Lam Nuae for each climate scenario. This figure shows that climate and total village crop yields are closely connected to total village assets. In the reference scenario, assets increase progressively throughout the 25 years. In contrast, the seven years of flood lead to dramatically decreasing assets beginning in year 11, reaching a low of less than 50% of the assets of the normal climate in year 18. The seven years of drought lead to even larger decreases in assets, reaching about 0 in year 18. The variability scenario also results in decreased assets, between the levels of the flood and drought scenarios. Thus, even with changes in what crops are produced, assets are strongly affected by decreased yields in all sectors.

Migration in experiment A

We find much different consequences of climate scenarios on migration in the ABM compared to the regression predictions. As shown in Figure 6, migration rates are generally high in Lam Nuae, as in the other villages in the Nang Rong study area, and steadily climb from about 30% to a high of 45% in the reference scenario. Of course, return migration is also high, which sustains a reasonably sized village population. This difference between the regression and ABM predictions is not surprising, given that they are entirely different analytical methods. More specifically, the ABM incorporates interactivity between individuals, adaptations, and changes in a population over time, none of which care addressed with a regression-based prediction. We also note the initial instability in migration rates at the beginning of the ABM simulation. This is due to model burn-in, or the progression of the model from an entirely data-based population to a simulated population, which is not unusual for models of this type.

Turning to the climate scenarios, we expect that the large changes in assets, shown in Figure 5, will impact migration. However, as shown in Figure 6, we find only a small difference in out-migration between the normal, flood, drought, and variability scenarios. For example, in year 17 about 41.5% of eligible people migrated in the reference scenario and about 42.5% migrated in the seventh year of sustained climate shocks. Migration in the flood, drought, and variability scenarios is between about 101% and 103% of the reference migration level. Note again that the climate scenarios are intentionally created to be relatively strong and prolonged. Further, although they created expected and large declines in yields and assets, this translates to only a negligible change in migration. This result is unexpected and requires further interrogation.

Experiment B: No individual effects on migration

The first possibility we address, with results shown in Figure 7, is that the effects of individual characteristics are so important in determining migration outcomes that the influence of climate change and assets on migration is comparatively negligible. The overall effect of this test is to substantially decrease migration rates in the reference and all three climate scenarios compared to rates in experiment A. This indicates that the effect of individual characteristics is to increase migration substantially.

We also find that disregarding individual characteristics in the ABM does not have a different effect on migration outcomes in the climate scenarios. As shown in Figure 7, the climate scenarios produce slightly higher migration, at around 18% in year 17, compared to 17.5% for the reference scenario. In other words, the climate scenarios in this experiment result in migration that is consistently about 102% of the reference scenario. This suggests that while individual characteristics are an important component of migration, they do not have differential effects during extreme climate scenarios and thus do not help to explain the smaller than expected migration response to climate in experiment A.

Experiment C: No remittances

Experiment C tests if remittances might serve as an important feedback mechanism that depresses migration during climate disasters and thus explains the weak migration response. As shown in Figure 8, all scenarios result in almost the same migration rates as the baseline scenario. This result is similar in all 41 villages that were simulated. Consequently, it appears that remittances do not have any meaningful influence in explaining why we do not find a larger migration response to the climate scenarios.

Experiment D: No social network effects

In experiment D, we test if social networks create important feedbacks that could be responsible for the lack of migration response to the climate scenarios. As shown in Figure 9, when social networks are not included in calculating migration, the migration rate in the reference is about the same as it is in experiment A. However, the climate scenarios produce consistently lower migration rates. For example, migration is at about 42% in year 17 for the reference scenario, 40% for the flood and variability scenarios, and 39% for the drought.

If social network effects were a reason for the lack of climate impacts on migration, we would expect that the climate scenarios would produce higher rates of migration than the reference scenario in this experiment. This is exactly opposite of what we find here. Regardless, because the effects are in the opposite direction to what would be expected if network effects were suppressing the influence of climate change on migration, we conclude that social network effects were ***not*** responsible for the weak migration response to climate disasters in this model.

This surprising result is not what we would expect at first glance. However, the equation that governs migration in our ABM reflects a more complex situation where ties to migrants can increase the likelihood of migration but migration of other community members disrupts connections between different households in a village and can thereby decrease migration. The equation also includes a variable *ties to wealthy households*, which incorporates both changes in the origin village social network and changes in the distribution of wealth. Thus, different characteristics of social networks (such as such as *ties to current migrants*, *household centrality*, *migration prevalence*, *village connectivity*, and *ties to wealthy households*) influence migration in both positive and negative ways in any scenario, making it hard to predict a priori the empirical difference between any two scenarios.

Experiment E: Adaptation of migration, based on assets

This final test, shown in Figure 10, allows households to adapt to consecutive years of extreme conditions and income losses. Given that the adaptations are intentionally drastic and implemented in intentionally prolonged climate scenarios, we would expect large migration effects. Results indeed show much higher migration rates than in experiment A.

In addition, we find large increases above the reference in the climate scenarios. At the end of the climate disaster period (in year 17), migration reaches 53% in the reference scenario, 57% in the flood and variability scenarios, and 63% in the drought scenario. These differences from the reference persist for several years after the climate disasters, through year 25. This result is what one might expect to find in the case of climate events. However, note again that this experiment creates an exceptional situation where the climate scenarios are intense and prolonged and the adaptation is exceptionally large and likely unrealistic, with doubling, quadrupling, etc. of migration probabilities for each year of income loss.

Is Lam Nuae typical? – Results for 41 villages

Thus far, we have presented results for only one model village, Lam Nuae. It is of course possible that the weak migration response to climate change simulated for Lam Nuae could be an anomaly. In fact, this is not the case. Table 2 shows the results of experiment A for Lam Nuae and the averaged results for all 41 villages. This table shows the ratio of the migration rate in each climate scenario compared to the reference scenario. As noted above and shown again in Table 2, in year 17, the extreme flood scenario created about 2% higher migration in Lam Nuae (ratio of 1.017), the extreme drought almost 1% higher, and extreme variability about 3% higher. When the results for all 41 villages are averaged, the differences are even smaller. The climate scenarios produced an average of 0.3% to 0.5% difference in migration in year 17. From this result, we conclude two things. First, Lam Nuae is not an anomaly in terms of migration responses to climate in the Nang Rong study area. Second, because we replicated these findings in 41 villages with different contextual conditions, our confidence is increased in stating that we find weak migration responses to drastic climate events in this area.

Discussion and Conclusion

This article described a study of how climate shocks affect migration in rural agricultural areas. We investigated the extent of migration during prolonged periods of extremely wet weather, droughts, and variable climate scenarios. We used an agent-based model, a relatively new methodology in the social sciences, which allows us to directly examine some of the dynamic pathways and mechanisms through which extreme weather events influence migration.

Our results showed clear effects of weather shocks on crop choice, yields, and household assets. Nonetheless, they also showed a weak migration response in a rural area of northeast Thailand during and after a rather extreme set of climate scenarios, including seven years of flooding, drought, and variability compared to a reference weather scenario. This outcome occurred despite the fact that total village assets declined more than 50% over this period. Such changes in asset levels led to substantial differences in migration rates in a regression-based analysis of migration. Yet, they did not produce this effect on population level migration with the dynamic ABM analysis.

In seeking to understand reasons for this unexpected result, we drew on a broad range of social science theories and tested the influence of several mechanisms that might connect climate disasters to migration. The strongest outcome we found is an experiment where agents in our model are allowed to drastically increase their migration probability in response to income losses. Results from this experiment indicated that a migration response to climate is indeed possible. However, even with the unrealistically extreme climate scenarios and unrealistically extreme adaptive response, the change in migration is only modest. Other experiments show that existing selection effects on migration and social networks provide a slight explanation for the lack of large migration responses to climate disasters.

The importance of the pre-existing condition of extremely high migration rates during periods of ‘normal’ weather is perhaps the most significant factor that we uncover in this study. Our model results in over 40% of age-eligible people migrating each year in the reference scenario, a level that is realistic for northeast Thailand. In this situation, we argue that most people who are able and could benefit from migration might already do so. As such, it should not be surprising that the addition of climate events had little impact on migration rates. Given that many agricultural areas around the world also experience high rates of migration, this consideration could go a long way in explaining a weaker than expected migration response to climate change in other countries.

Our results and conclusions in this paper are based on an empirically grounded ABM, with simulations run 40 times on each of 41 villages. The fact that we find similar results for all 41 different villages increases our confidence. Of course, these results and conclusions are based on a particular model and reflect the particular theories, assumptions, and design choices that make the model distinctive and unique. We also emphasize that our results come from a model which is intended to explore theories and processes and not intended to create predictions. Although the model clearly shows very little migration response to extreme climate events in Nang Rong, it is an open question of whether this will happen in reality should such weather events occur in Nang Rong.

The conclusions from this study indicate the continued necessity for further theoretical developments to better understand the mechanisms connecting climate change and migration. Much of the current literature draws on “push-pull” models of migration and is heavily focused on economic factors. In contrast, we consider a variety of sociodemographic theories of migration, feedbacks, and selective factors that might reduce migration in response to climate change. These theories lead to several explanations for why climate change might not influence increased migration and we find empirical support for some of these explanations with the ABM. Further research might benefit from a broader theoretical base, consideration of existing patterns that govern migration, consideration for reasons why people do not migrate, and improved methodological strategies to explicitly test hypotheses.

In thinking about the generalizability, or external validity, of this study, we highlight our main conclusions. First, we find a weak migration response to climate events. Second, this is most likely caused by the already high pre-existing rates of migration, the marginal environment, and the likelihood that households have already instituted adaptations to cope with this environment. Given these broad conclusions, we argue that one would likely find a similarly weak migration response in other areas that experience high migration rates, marginal livelihoods, and the likelihood of pre-existing adaptations. There are many such areas around the world.

Alternately, in areas that are not characterized as such, our findings do not suggest a low migration response. For example, although many coastal areas in the eastern and south-eastern US are prone to flooding, they are not characterized by high migration, marginality, and adaptive capacities. Thus it is possible that higher rates of migration might be found in response to drastic climate events in these areas, compared to marginal areas such as Nang Rong. However, we note that permanent out-migration was not large after such examples as the recent and devastating Hurricane Katrina in New Orleans and Hurricane Sandy in New York City. In fact, humans have been living in disaster prone areas for centuries, in rural and urban configurations, in marginal and wealthy conditions. For example, a significant portion of the Netherlands, one of the most densely populated areas in the world, is under sea level.

The Maldives and several island nations in the Pacific could experience severe or total land loss due to sea level rise in the coming years, yet they remain some of the most densely populated countries in the world. These situations, in conjunction with our detailed results from the ABM in rural Thailand, suggest that humans living under many different conditions might be less migratory and more sedentary in situations of disaster than previously assumed. In the case of rural Thailand, we suggest several theoretically derived and empirically tested reasons for this pattern. Further research and theoretical development will be necessary to understand this apparent pattern in urban and densely populated areas as well. In either case, research might benefit from a paradigm shift away from viewing humans as innately migratory and willing to move towards any other place that might be better in any way than their current residence.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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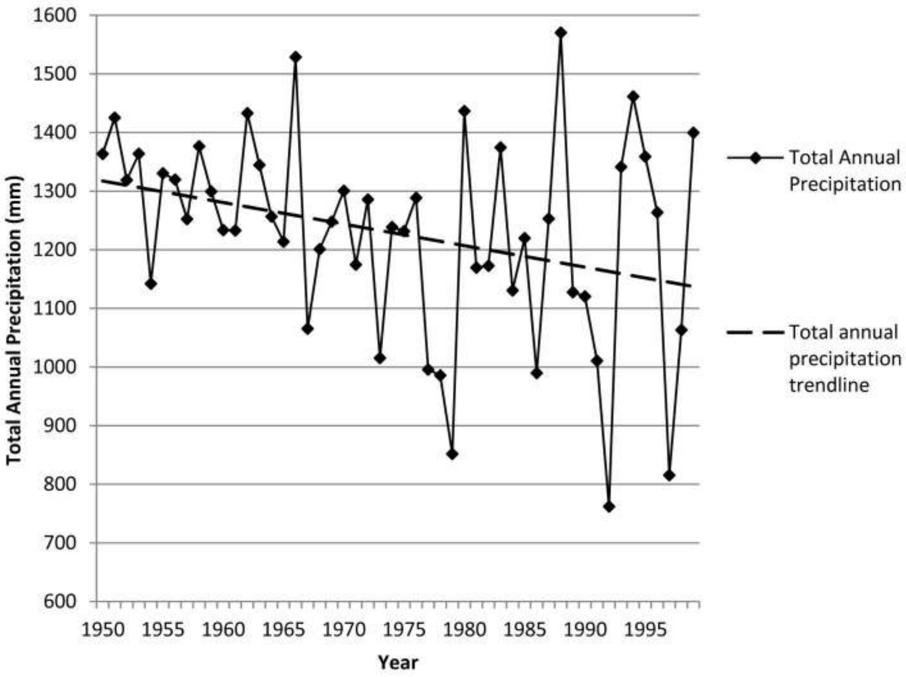

Figure 1.

Rainfall patterns in Nang Rong district Thailand, 1950–2000.

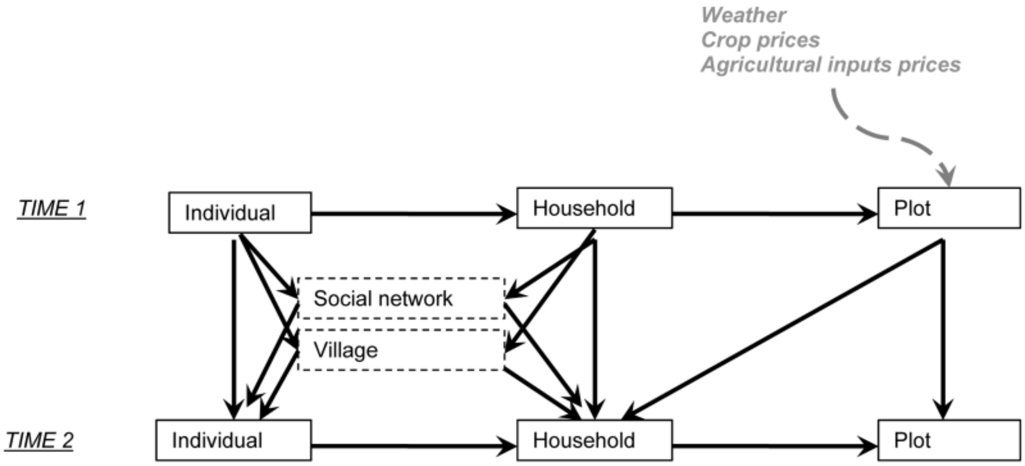

Figure 2.

Overview and interactivity of agents in the ABM

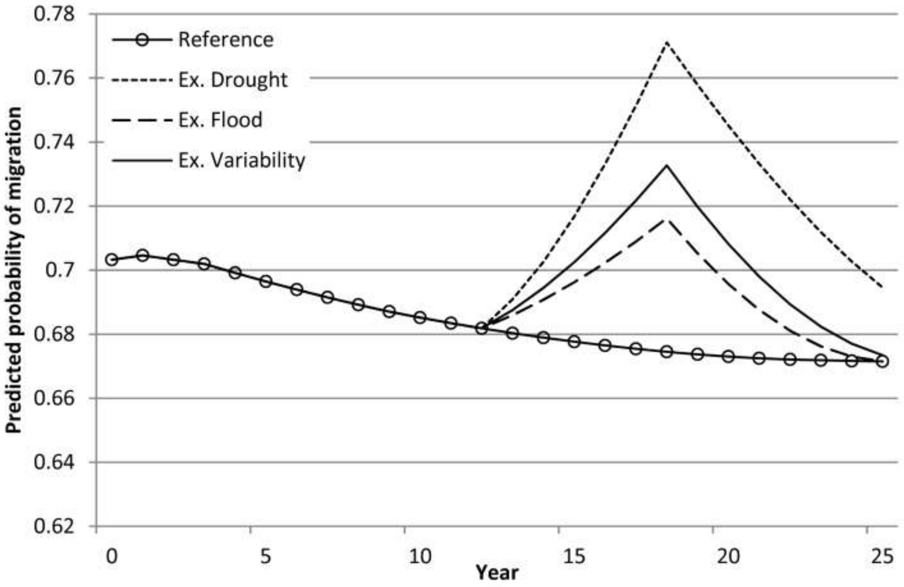

Figure 3.

Regression-based predicted probability of migration for “average” 15 year old male each year from Lam Nuae village.

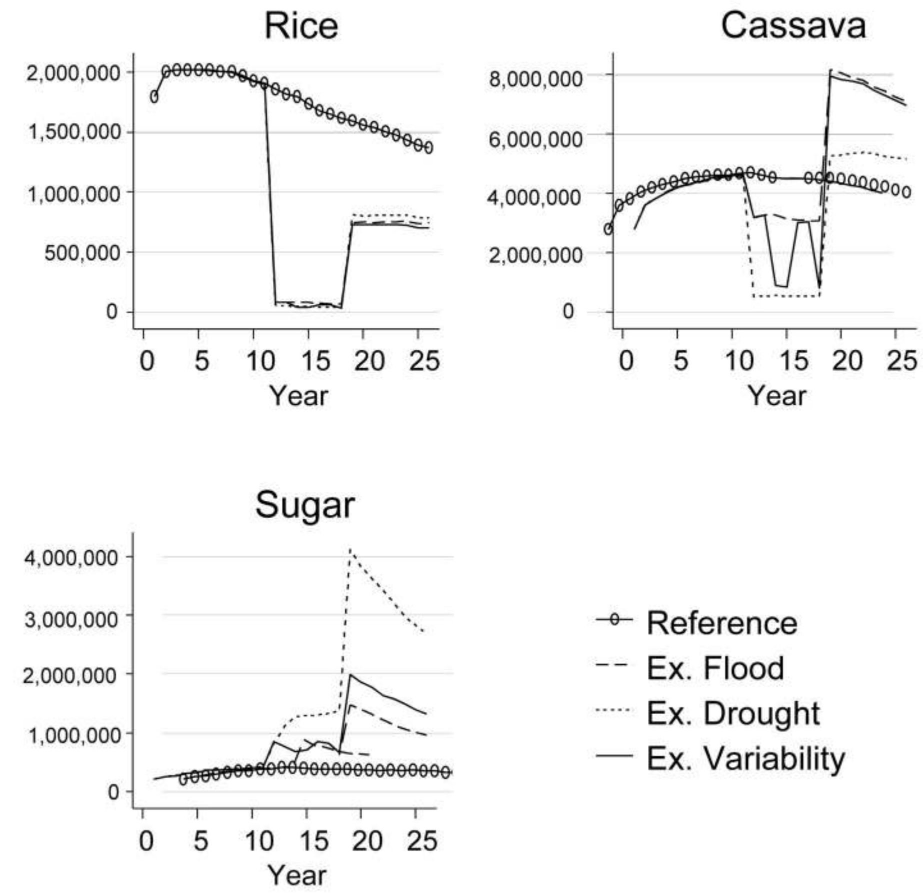

Figure 4.

Experiment A (baseline model): Total village crop yields for Lam Nuae village.

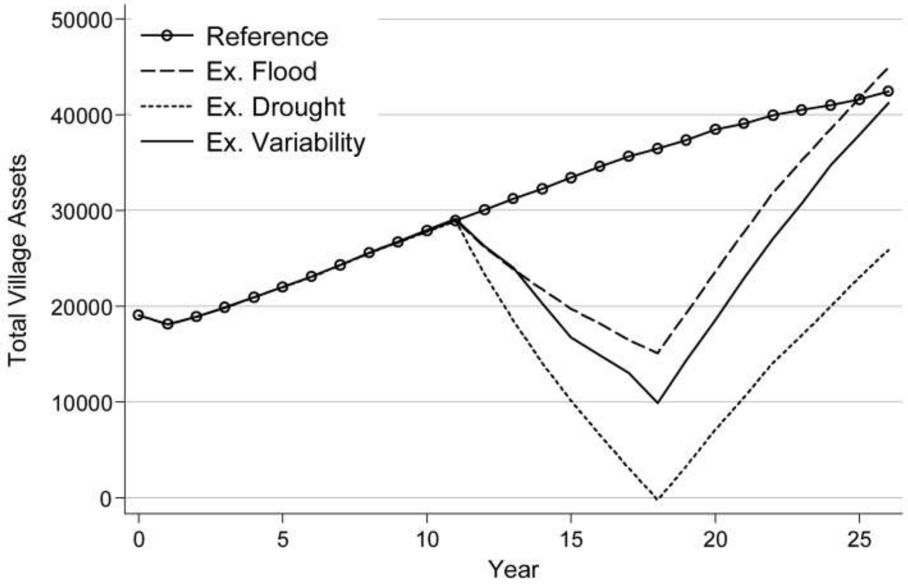

Figure 5.

Experiment A (baseline model): Total village assets (in Thai baht) for Lam Nuae village, each year of ABM simulation.

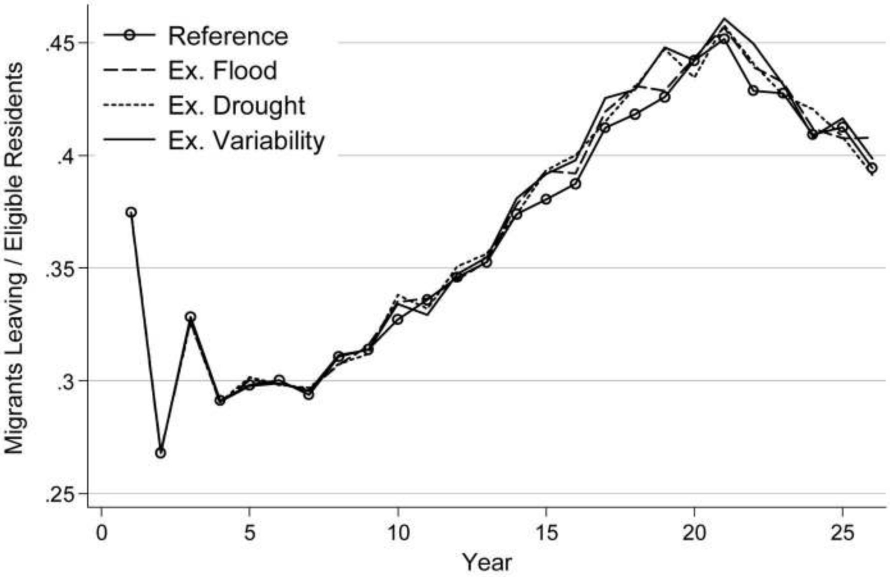

Figure 6.

Experiment A (baseline model): Migration rate (percentage of eligible people who migrated from Lam Nuae village each year of ABM simulation).

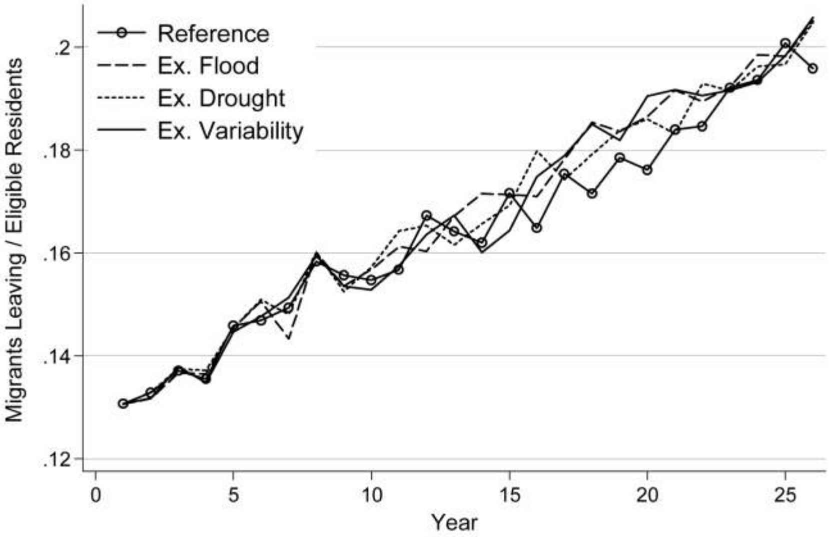

Figure 7.

Experiment B (no individual characteristics): Migration rate (percentage of eligible people who migrated from Lam Nuae village each year of ABM simulation).

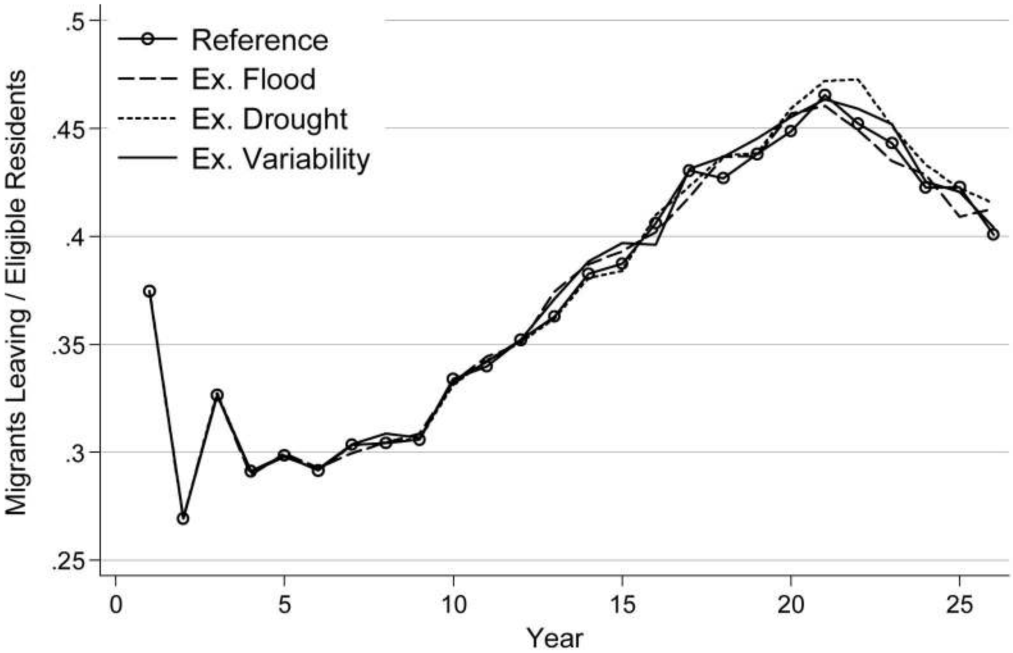

Figure 8.

Experiment C (no remittances): Migration rate (percentage of eligible people who migrated from Lam Nuae village each year of ABM simulation).

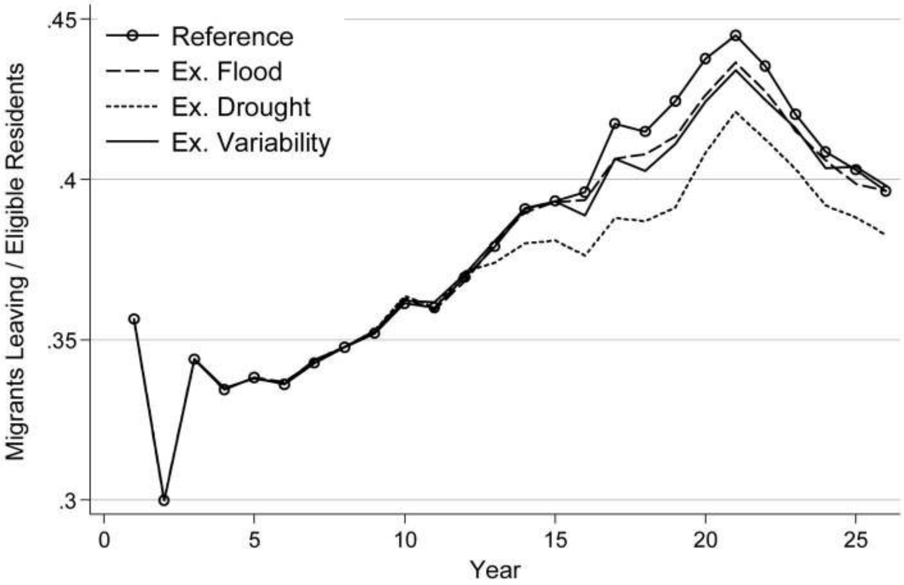

Figure 9.

Experiment D (no social networks): Migration rate (percentage of eligible people who migrated from Lam Nuae village each year of ABM simulation).

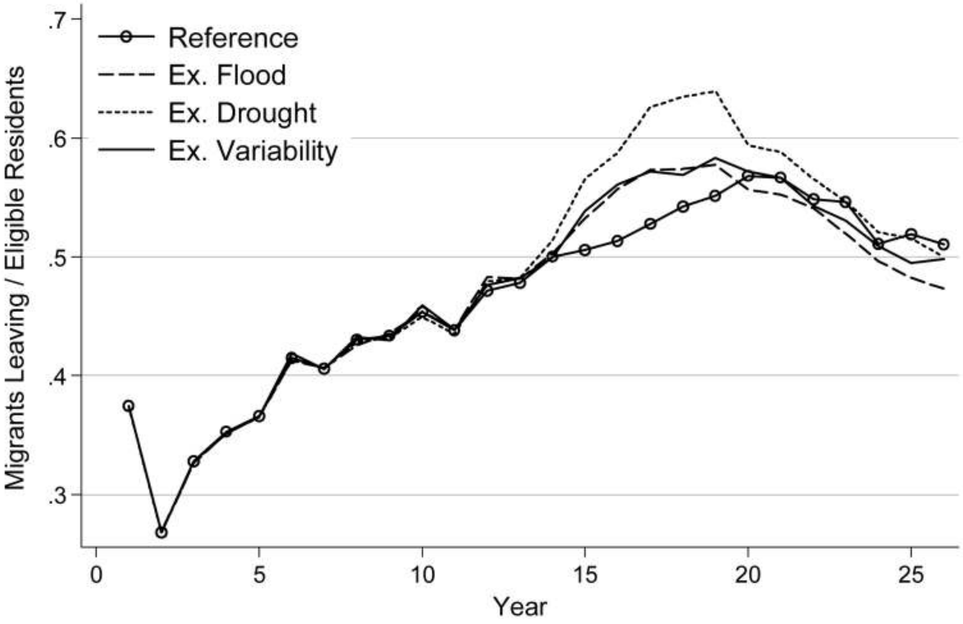

Figure 10.

Experiment E (income adaptation): Migration rate (percentage of eligible people who migrated from Lam Nuae village each year of ABM simulation).

Table 1

Key equations in the agent-based model

Income equation	**(equation 1)**
Change in assets =	
3.8 x kg jasmine rice	– 1800 x household size
+ 4.0 x kg heavy rice	+ 12,000 x number of remitters
+ 0.7 x kg cassava	– 3000 x number of migrants
+ 0.4 x kg sugar	– 600 x if changed land to rice
– 340 x fertilizer amount x rice area planted	– 650 if changed land to cassava or sugar
– 1000 x fertilizer amount x cassava area planted	
– 700 x fertilizer amount x sugar area planted	
Migration equation: ln (odds of migration) =	**(equation 2)**
1.731	
– 0.28 ln of village population	+ 0.08*female
+ 0.002 percent village grows cassava	– 0.27*ever married
– 0.01 x percent village has pump	+ 0.43*kinship dependency ratio
+ 0.01 x percent village has TV	+ 0.05*ties to current migrants
– 0.001 x percent village has vehicle	+ 0.44*age11
+ 0.08 x distance to nearest village	+ 0.91*age12
– 0.04 x migration prevalence	+ 1.23*age13
– 0.59 x village connectivity	+ 1.77*age14
+ 0.01 x migration prevalence x connectivity	+ 1.71*age15
– 0.12 x has land deed	+ 1.93*age16
– 0.01 x household centrality	+ 1.66*age17
– 0.16 x ties to wealthy household	+ 1.43*age18
– 0.00005 x assets (if assets $\leq$200)	+ 1.42*age19
– 0.000011 x assets^2 (if 0 $\leq$assets $\leq$200)	
– 0.44 (if assets > 200)	
– 0.000003 x assets (if assets> 200)	

Table 2

Experiment A: Ratios of out-migration rates in climate scenarios to reference scenarios.

	Extreme flood	Extreme drought	Extreme variability
Lam Nuae village			
Year 17	1.017	1.007	1.032
Year 25	0.988	0.990	1.010
All 41 villages			
Year 17	1.003	0.995	0.995
Year 25	1.004	1.002	1.008