Climate Change and Migration: New Insights from a Dynamic Model of Out-Migration and Return Migration[1]

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In popular accounts, stories of environmental refugees convey a bleak picture of the impacts of climate change on migration. Scholarly research is less conclusive, with studies finding varying effects. This article uses an agent-based model (ABM) of land use, social networks, and household dynamics to examine how extreme floods and droughts affect migration in Northeast Thailand. The ABM explicitly models the dynamic and interactive pathways through which climate-migration relationships might operate, including coupled out and return streams. Results suggest minimal effects on out-migration but marked negative effects on return. Social networks play a pivotal role in producing these patterns. In all, the portrait of climate change and migration painted by focusing only on environmental refugees is too simple. Climate change operates on already established migration processes that are part and parcel of the life course, embedded in dynamic social networks, and incorporated in larger interactive systems where out-migration and return migration are integrally connected.

Many people view the ongoing environmental challenges stemming from global climate change as an important and growing influence on human

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migration. According to a 2010 Gallup Poll estimate reported in the *New York Times*, 500 million people across the globe expect to move in the next five years because of severe environmental problems (Benko 2017). If climate-related environmental problems induce such mobility, it would represent a fundamental shift in global migration systems and settlement patterns. To contextualize the magnitude, consider that estimates suggest there were 244 million international migrants living outside of their country of birth in 2015 (United Nations 2015) and that an additional 763 million internal migrants were living within their birth country but outside of their birth region in 2005 (Bell and Charles-Edwards 2013). Though expectations do not always result in actual migration (De Jong, et al. 1985; De Jong 2000; Coulter, Van Ham, and Feijten 2011), the possibility that climate change may influence migrant flows equivalent to half of the world's current lifetime migrant stock is an extraordinary proposition. The media, the general public, and policy makers around the world are increasingly attuned to this unfolding story. Thus, it is not surprising that narratives of climate change impacts on migration in the popular literature—and the images in the public's eye—are dominated by stories of environmental refugees: people pushed out of their homes and livelihoods by desertification, warming and rising seas, and extreme weather events. The mayor of a town in Bolivia sitting in a boat on the dried-up bed of a lake that used to provide his livelihood, a young woman pushing through water waist-deep as she tours her neighbor's flooded taro plot in Kirabati, the halving of storm-ravaged New Orleans's population, and the recent decimation of Puerto Rico offer dramatic examples of migration responses to extreme weather events.[2]

In contrast, the scholarly literature has produced a more nuanced picture relating climate change to migration patterns (McLeman 2014; Hunter,

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[2] https://www.nytimes.com/slideshow/2016/12/28/blogs/photographing-climate-change-refugees-by-drone-and-on-foot/s/28-lens-haner-slide-RBR5.html; http://www.economist.com/node/7833886; https://www.nytimes.com/2017/11/17/us/puerto-ricans-orlando.html.

Luna, and Norton 2015; Gioli et al. 2016). Several studies document clear migration responses to climate change (e.g., Feng, Kreuger, and Oppenheimer 2010; Marchiori, Maystadt, and Schumacher 2012; Dillon, Mueller, and Salu 2011; Bohra-Mishra, Oppenheimer, and Hsiang 2014; Nawrotski et al. 2016; Bohra-Mishra et al. 2017; Leyk et al. 2017). But in others, response depends on resources (e.g., Kubik and Maurel 2016; Loebach 2016; Call et al. 2017), livelihoods and the availability of adaptive responses in situ (e.g., Morrissey 2013; Thiede and Gray 2017), and perceptions of the nature of the problem to begin with (Koubi, Stoll, and Spilker 2016). Some studies find no migration response at all (Entwisle et al. 2016; Loebach 2016). This could happen because climate change operates on existing migration patterns that already incorporate adaptations to adverse conditions, with new changes to climate exerting little additional pressure, especially if they are incremental rather than catastrophic. However, all of this work, as with nearly all research on climate change and migration, focuses exclusively on those who leave, with little attention to the migration systems in which they are embedded. In this article, we contribute to this growing literature by looking at migration through a different lens by asking about potential effects of climate change on all parts of the process, including return migration. In doing so, we consider new ways to connect the literature on climate change and migration to migration theory.

Climate change is disruptive (Call et al. 2017). It disrupts processes that are already dynamic inasmuch as migration is related to life course transitions, evolving household strategies, and endogenous changes in social networks at and between places of origin and destination. Typically, studies of climate change impact focus on push-inspired out-migration in response to a single event or series of events (Hugo 1996; Massey, Axinn, and Ghimire 2010). This is only one possible outcome, however. Also of interest is the possibility of otherwise expected migration that does not occur, whether it be among those who might leave an origin or among those who may return, and indeed, the balance of return migration and out-migration in the overall system. By incorporating a life course perspective, including a focus on out-migration and return migration associated with the transition to adulthood, and embedding these in a systems approach, we identify a type of climate change impact that heretofore has not been considered: disruptions to established and expected streams of return migration. To our knowledge, we are the first to examine climate change impacts of this nature.

To investigate how climate change may affect migration *systems*, we study the interrelationships between climate change and the linked processes of out-migration and return migration through application of an agent-based model (ABM). Our ABM incorporates land use, social networks, and household dynamics in a specific setting: rural villages in Northeast Thailand where rainfed agriculture is the dominant livelihood strategy.

The ABM is grounded in decades of empirical survey and ethnographic data from the Nang Rong Projects and includes detail on demographic behaviors—including out-migration and return migration—and spatial-environmental processes relating to agriculture, land use, and weather patterns. That said, our intent is neither to reproduce the past nor to predict the future, but rather to use the model to explore the implications of the theories embodied within it.

The ABM explicitly models the dynamic and interactive pathways through which a climate-migration relationship might operate. All behaviors and processes occur in an interdependent system, linked by social networks and constrained by available land. Rather than assuming a direct "climate effect" on migration, we specify mechanisms of influence on migration through climate effects on crop yields, and thus livelihoods, in these agrarian communities. Importantly, we experiment on this social system in a counterfactual framework, comparing ceteris paribus migration responses in situations with and without the types of extreme weather events posited to grow in frequency in tandem with ongoing climatic change. Results from our simulations of extreme floods and droughts suggest minimal impacts on out-migration, but marked negative effects on return—that is, migrants otherwise expected to return do not. Our results also point to the important influence of social networks for both out-migration and return migration, and they demonstrate the need for greater attention to migration theory in models of climate-migration relationships.

APPROACHES TO MIGRATION RESEARCH

The focus of this article is rural-urban migration in Northeast Thailand. Typically, research on rural-urban migration in lower- and middle-income countries draws from economically focused theories, mostly about labor migration (Massey et al. 1993). Other common theories that are often interwoven in migration studies focus on noneconomic aspects such as social networks. While the literature on internal migration and residential mobility in high-income countries increasingly views migration in terms of life course transitions (e.g., Falkingham et al. 2016; Warner and Sharp 2016), these ideas are not often consulted in studies of migration in lower- and middle-income countries. We integrate these approaches to migration research in our agent-based model. We review each briefly, indicating the potential impact climate change might have in each.

Economic Perspectives on Migration

Economically focused theories of migration generally fall into one of two broad categories: the neoclassical model and the new economics of labor migration (NELM) model. According to the neoclassical model, the decision to move is made by individuals and is based on a comparison of economic opportunity at the place of origin and potential destinations (Harris and Todaro 1970). If opportunity is greater elsewhere, such that that the benefits of migrating outweigh the costs of doing so, the neoclassical migrant will move to that place. To the extent that climate change impacts at the origin tip the balance of opportunity in favor of one or more destinations, the neoclassical perspective predicts that it will stimulate out-migration. Migration in the neoclassical model is considered permanent, until circumstances necessitate another permanent move. Return migrants in this model are those who fail in the destination in terms of employment or earnings (Cassirino 2004).

Whereas individual profit maximization motivates migration in the neoclassical model, risk minimization guides decision making in the NELM perspective, which specifically emphasizes joint decision making in small and socially relevant groups, such as families and households. In this approach, rural households facing uncertain prospects due to the risks of agricultural production in conjunction with underdeveloped capital, credit, and insurance markets may reduce risks by diversifying their economic portfolios (Stark and Bloom 1985; Massey et al. 1993; Taylor 1999). One strategy rural households may use is to diversify spatially, sending one or more household members to another area, subject to a different set of risks than at the origin. For a variety of hotly debated reasons—ranging from altruism, exchange, insurance, investment, and normative behaviors within social networks (see Rapoport and Docquier [2006], Carling [2008], and Garip, Eskici, and Snyder [2015] for reviews)—these migrants may remit earnings back to the household and may return to that household when they have reached a target amount (Tong and Piotrowski 2010; Garip 2012*a*, 2012*b*). In this theoretical model, migration is intended to be temporary. To the extent that climate change increases risks in places of origin, absent changes in costs, it will motivate out-migration, although only if other diversification strategies are unattractive, unavailable, or not sufficiently successful. The impact of climate change on return migration in this model has not been well considered. If climate change does not also affect the place of destination, the return behavior of target migrants may be likewise unaffected; the benefits of spatial diversification are not changed. Alternatively, if strategies to reduce risks of agricultural production in the face of climate change impacts in the place of origin become more costly or the risks at places of origin are increased, return migration could be delayed. Assumed but unstudied in this theoretical tradition is that conditions on the ground in places of destination or origin are known; how such information is transferred is the subject of many social perspectives on migration.

Social Perspectives on Migration

Theories of the social forces that influence migration are common (Massey et al. 1993) but rarely consulted in the climate change and migration literature. We argue that these theories can help to better understand both out-migration and return migration processes in the face of climate change. We seek theoretical guidance from them here and incorporate them in our ABM as described below.

Whether migration is motivated by profit maximization or risk minimization, it is a costly endeavor. Decreases in the costs of migration will increase migrant flows, and vice versa. This issue is where social networks and associated theories of cumulative causation enter the discussion. By providing information or real help with finding a job or a place to live, social network ties to prior migrants reduce migration costs (Massey et al. 1993). As more and more migrants move to a destination, and ties between origin and destination densify, migration costs decrease and it becomes easier for those who follow, at least up to a point (Garip 2008; DiMaggio and Garip 2011). Migration becomes less selective as this process unfolds (Garip and Curran 2010). This is the cumulative causation theory of migration (Massey 1990; Massey et al. 1993).

Social networks within places of origin may also be relevant, in ways not usually considered in the migration literature. Social networks within places of origin comprise the sets of ties linking members of origin communities to one another, directly and indirectly, through kinship, acquaintance, exchange, and information sharing. Social networks can be important, for instance, because they condition information flows about migrants' activities in the destination, enabling access to knowledge about migration opportunities among those not directly connected to migrants. Such information flows can affect migration above and beyond a community's ties to the destination. Evidence of this can be seen in tests of survey researchers' ability to prospectively find and locate migrants in destinations, a capacity constrained by flows of information and knowledge. Such work finds that the success of survey follow-up in migrant destinations is enhanced when social networks in the village of origin are cohesive, even net of the number of direct ties between the origin and the destination (Entwisle et al. 2007; also see Wantanabe, Olson, and Falci 2017). Further, origin-based social networks may augment material motivations to leave by acting as the locus within which motivations stemming from feelings of relative deprivation and cultural valuations of migrants become salient (Mouw et al. 2014). Additionally, social networks transfer and enforce obligations to kin at origin, enhancing motivations to remain or return. Just like ties to destination, ties to origin are also directly affected by prior migration patterns from that place (Entwisle 2007). We further address dimensions of these processes below.

Another social perspective on migration—the life course perspective—is almost completely absent from the literature on migration in poorer countries. Yet, migration is part and parcel of the transition to adulthood in almost any country (Rindfuss 1991). In industrial and industrializing economies, young people often move as they complete school, enter the labor market, change jobs, enter marital or other unions, and begin to have children (Bernard, Bell, and Charles-Edwards 2014*b*; Warner and Sharp 2016). The transition may be crisp and well sequenced, predictable as a unidirectional pathway, but frequently it is not. The life course structures the extent, timing, and interconnectedness of moves (Clark and Withers 2008; Geist and McManus 2008; Findlay et al. 2015) as well as linkages with behaviors of others in the household and family. Migration is linked to other status transitions, such as family formation, that occur during the early adult years. It also reflects obligations to kin and others in places of origin and destination. In many rural areas, key times in the agricultural cycle—planting, the harvest—are occasions where such obligations are negotiated as migrants return, or do not, and decide to remain, or embark, at the nexus of individual and household decision making.

Out-migration and Return Migration as an Interactive System

Although most research focuses on out-migration, it is not a singular independent process. Return migration is also common, although interestingly, its interpretation varies depending on theoretical approach (Cassarino 2004). In the neoclassical model, returning migrants are perceived to be those who have failed to prosper in places of destination. In NELM, returning migrants are thought to have achieved their earnings target; they were only temporary migrants to begin with. In the life course approach, young people who return are coming and going as part of the transition to adulthood. They are neither failures nor successes, just "in process" (Coulter, van Hamm, and Findlay 2016). They also respond to kin obligations in places of origin, possibly delaying their departure or hastening their return, while they assemble the resources needed to redefine these obligations as they enter a fully adult status, possibly in the destination but possibly not. The life course approach is focused on status changes through the young adult years, in the context of kin obligations as well as opportunities in origin and destination.

As typically conceptualized, climate change affects conditions in places of origin (McLeman 2014). Climate change may occur broadly, at a global scale, but it can also act within as well as between regions and countries; further, there can be variability in its consequences for local environments (e.g., degree of flooding dependent on local topography). Accordingly, research has focused on the potential for climate change to increase out-migration. Indeed, frameworks for conceptualizing the environment-migration relationship view migration in terms of a decision to stay or go (Massey et al. 2010; Black et al. 2011; Hunter et al. 2015;). Even when migration is viewed in terms of connections between sending and receiving areas, the emphasis is on a single direction of movement: out (e.g., Morrisey 2013).

Until now, the literature has overlooked the possibility that climate change may affect return migration. However, migration theory clearly articulates mechanisms by which this would occur, whether it be by altering labor shortage–remittance trade-offs in the new economics of labor migration framework (Rozelle, Taylor, and deBrauw 1999) or by disrupting the role of out-migration and return migration as they relate to the transition to adulthood in the life course framework. To be clear, our interest is in comparisons of migration patterns given more and less climate change. This is quite separate from recovery migration—that is, who comes back among migrants who left specifically because of a discrete catastrophic climate event (e.g., Hurricane Katrina; Fussell, Curtis, and DeWaard 2014).

In addition to directing attention to return migration as a potential outcome, we also draw on the idea that out-migration and return migration are not just singular behaviors; instead they are interconnected steps in a migration system. Life course, demographic, and social networks perspectives describe ways in which these behaviors are integrally connected into a system, as we now explain.

Out-migration and return migration are integral to the transition to adulthood (Rindfuss 1991). There may be movements back and forth as young people fulfill their obligations to their natal family and accumulate the resources necessary to establish themselves as independent adults. There may be movements back and forth as ties to the natal family are redefined through the transition. Indeed, it is not unusual as part of this process for young people to return home before they leave again (Coulter et al. 2016); a growing literature on "boomerang kids" in wealthier countries shows the prevalence of this phenomenon (Sandberg-Thoma, Snyder, and Jang 2015; South and Lei 2015). There is a tendency in the migration literature to view movements as planned, but this is not always so (De Jong et al. 1985; De Jong 2000; Coulter et al. 2011). Movements back and forth from places of origin occur within a larger system, but from the perspective of lived lives, the timing and duration of these moves is not always as planned or predicted. For example, migration initially intended to be temporary, part of a household strategy in the place of origin, can extend indefinitely as migrants stay longer and build ties to others in the destination (Korinek, Entwisle, and Jampaklay 2005). It is not unusual for migrants to marry earlier than nonmigrants (Jampaklay 2006); potential partners are much more available in urban areas, especially when young migrants are housed together. Contingency is an essential element of the transition to adulthood as each pathway is structured by changing opportunities and constraints in multiple contexts in origin and destination.

The demographic concept of exposure to risk is another key. Out-migration creates migrants, and it is these migrants who are exposed to the risk of return migration. Thus, increases in out-migration will increase the stock of people exposed to the risk of return and at the same time decrease the stock of people exposed to the risk of out-migration. The same is true for return migration: it drains the stock of migrants and increases the stock of residents of an origin area who are then exposed to the risk of out-migration. Most out-migrations followed by return migrations (especially, but not exclusively, those emanating from poorer countries) are undertaken by young adults (Rogers, Raquillet, and Castro 1978; Bernard et al. 2014*a*). Older adults are much less likely to migrate for any reason and thus should not always be considered to be part of the stock of people who could be potential migrants during periods of climate stability or change. At the same time, older adults in origin areas serve as conduits of information or key connecting nodes in social networks. Depending on their needs, they may also represent sources of obligation for potential out-migrants and return migrants.

The social networks perspective also explains a dynamic link between migrants, nonmigrants, and return migrants. When out-migration increases, the stock of people who can provide information about migration increases and more information and other kinds of help become available. However, if the prevalence of migration becomes too high, this can disrupt the connectivity of a network, breaking the ties along which information flows. Likewise, if return migration is high, then this might create higher connectivity in a network, but decrease the number of people who possess active information about a destination.

Because out-migration and return migration are so intimately connected, if we want to understand the influence of climate change on out-migration, looking only at out-migration provides only half the story. The influence of exposure to risk predicts a fairly linear and inverse connection between out-migration and return migration. The life course perspective also predicts a relationship between patterns of departure and return but suggests that the relationship might be more fluid and less planned and can change over time. The influence of social networks, with concern for linkages, nodes, and connectivity, predicts a relationship, but not in a linear or easily quantified manner. In any case, we expect that a model that can connect out-migration and return migration at the population level will provide new and different insights than a traditional regression model of individual migration behaviors during periods of climate change. We also anticipate that social networks will play a role in creating these new and different results by changing knowledge of on-the-ground conditions, among other things. In the remainder of this article, we explore these ideas using an agent-based model.

CASE STUDY: CLIMATE CHANGE AND MIGRATION IN NORTHEAST THAILAND

Consistent with much of the literature on climate change and migration, we take a case study approach. Our research draws on a multidecade set of transdisciplinary research endeavors based in Nang Rong District, Thailand, undertaken by a large team of sociologists, demographers, geographers, economists, and others from the University of North Carolina at Chapel Hill and Mahidol University in Bangkok (http://www.cpc.unc.edu/projects/nangrong/). On the social side, the Nang Rong Projects consist of a series of community surveys and household censuses conducted in villages of Nang Rong District in 1984, 1994, and 2000, with additional follow-up surveys of migrants living in destination areas that were identified by origin households in the 1994 and 2000 survey rounds. Additional qualitative work spanning the 1980s to the 2010s was also conducted. The environmental side of the Nang Rong Projects is informed by detailed land use mapping surveys, remote sensing, and extensive geographic information systems (GIS) integration.[3] The location of Nang Rong is shown in figure 1. We focus on migration connecting rural villages in Nang Rong District, in Northeast Thailand to Bangkok, the Eastern Seaboard, and other urban areas in Thailand. We begin by setting the scene.

Nang Rong is about the size of a small county in the United States, occupying 1,300 square kilometers. Historically, it was a settlement area for migrants from other parts of Thailand, with few established villages prior to World War II (Entwisle et al. 2008). After the 1960s, as natural increases from the region's demographic transition took off, net migration flows reversed and out-migration became a dominant feature of village life. Migration, both permanent and temporary, is common in Nang Rong (Fuller, Lightfoot, and Kamnuansilpa 1985; Fuller, Kamnuansilpa, and Lightfoot 1990; Korinek, Entwisle, and Jampaklay 2005). At the time of this study, migration streams to Bangkok and the Eastern Seaboard were well established. Prospective empirical research on Nang Rong shows that, of villagers ages 10–19 in 1994, almost half (43%) were migrants six years later, in 2000; of those ages 20–29 in 1994, the comparable figure was one-third (30%). Among former residents of Nang Rong villages in 1994, the same prospective studies show that 23% of those ages 10–19 and 19% of those ages 20–29 were no longer migrants in 2000. As cohorts age, those remaining in origin

[3] Data from the projects are available from the University of Michigan's Data Sharing for Demographic Research website: http://www.icpsr.umich.edu/icpsrweb/DSDR/studies/4402.

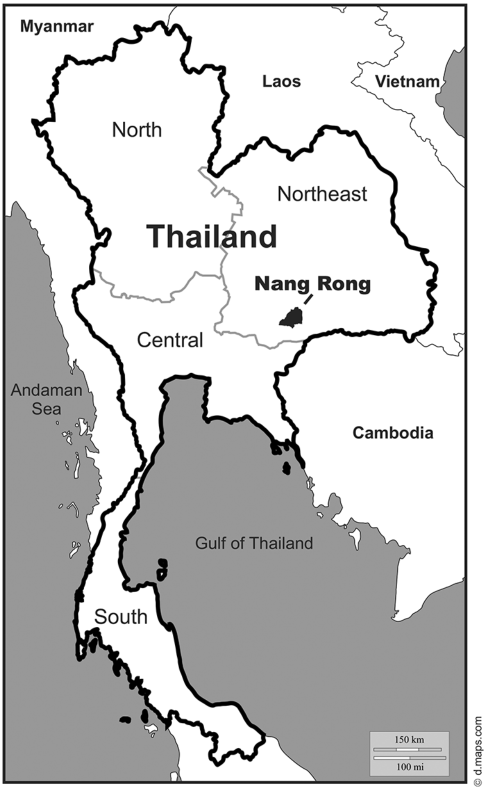

FIG. 1.—Location of study site

and destination are increasingly differentiated by the selectivity of the migration process, a phenomenon that has long been recognized in the literature (e.g., Lee 1966).

The economy in Nang Rong is largely agricultural, based on wet rice cultivation as well as upland crops such as cassava and other lowland crops such as sugar. Irrigation is rain fed, dependent on the annual monsoon. Rains arrive in the late spring to early summer, but precipitation is unpredictable in both timing and amount. Livelihoods depend on these features of the rain's arrival. This is a challenging environment in which to succeed economically (Bardsley and Hugo 2010) and most farmers live "on the edge." Figures 2 and 3 superimpose the locations of villages (fig. 2) and dwellings (fig. 3) on a rare satellite image of Nang Rong while flooded during the annual monsoon (rare because clouds obscure images during these months). Villages line up along the rivers; dwellings likewise hug the borders of the flooded areas, with arrows pointing to their inundated fields. There is a delicate balance between too much water, and too little, confirmed in interviews

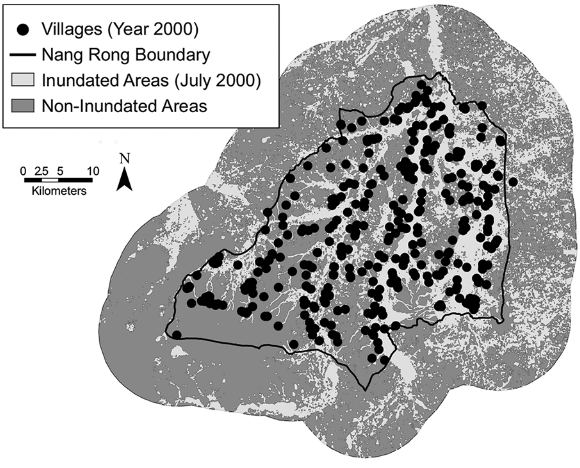

FIG. 2.—Location of villages relative to area inundated by monsoon, July 2000

with farmers on multiple occasions. Different rice varietals require different amounts of water, whose availability can be difficult to predict (traditional irrigation systems dominate in the region). The anticipation of water availability also influences the choice to grow crops other than rice: with more water, sugarcane is preferable; with less, cassava. Farmers report having "tried many things just to survive" (village interviews in 2010). Because of the marginal environmental setting, combined with the frequency of inundation and droughts, Nang Rong households have likely adapted already to extreme weather events, at least to some extent. For instance, empirical work finds

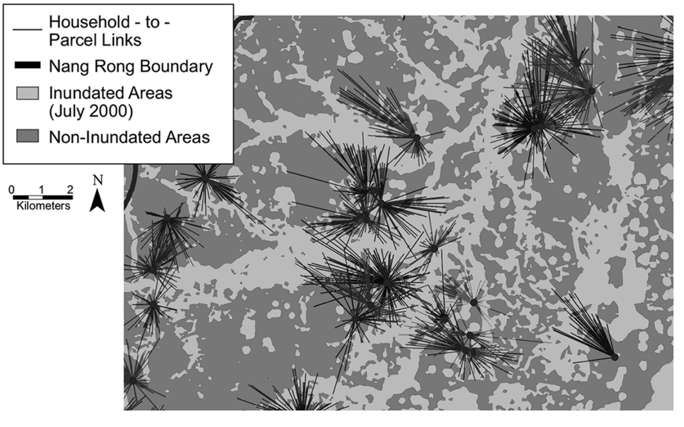

FIG. 3.—Location of parcels relative to village centers on inundated landscape, July 2000.

no relationship between village water shortages and migration or remittance behaviors at the household level (Garip 2014; Garip et al. 2015), although other work at the individual level shows a small negative relationship between village water shortage and out-migration (Garip 2008).

We are interested in the consequences of floods and droughts for migration processes in this setting. Rice is the region's major crop, for subsistence and sale, and rice cultivation is a key component of our model. With rice, the timing of planting and harvest are organized around the beginning and end of the monsoon season, typically June and December (Naylor et al. 2007). If the monsoon comes early and is heavy, farmers may have to replace their crop, replanting, possibly more than once. They report: "If you fail twice, you would not try again for rice" (village interviews in 2010). If the flooding is less extensive, they may lose part of the crop. If the monsoon comes late and is light, fields are less productive. It is in this way that monsoonal variation, and, in particular, the pattern of floods and droughts, connects directly to the livelihoods of Nang Rong farmers. This was described to us again and again in fieldwork based in the district. Other crops, too, depend on the monsoon for irrigation, although these other crops are typically planted in plots less suited for rice cultivation. Our model includes cassava and sugar as alternate crops.

Consistent with expectations based on climate change (Nickl et al. 2010), average rainfall amounts in Nang Rong have declined over the 20th century; equally important, annual variance in rainfall has increased (Bardsley and Hugo 2010; see also fig. 4). What if these extremes were to increase in magnitude and duration, as anticipated by climate models? What would

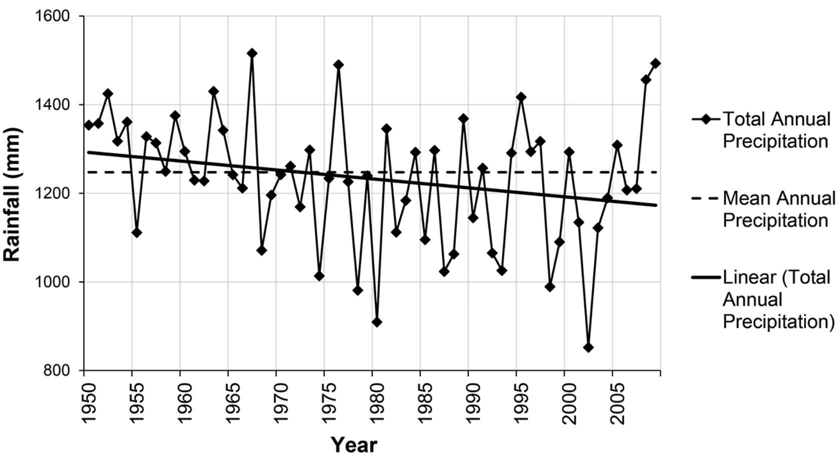

Fig. 4.—Trends in annual precipitation: Nang Rong

be the impact on migration processes? To answer these questions, we ran experiments on an ABM of land use and household dynamics developed for the Nang Rong setting. The focus is on a magnification of trends already underway, not catastrophic climate events that make entire regions uninhabitable (e.g., sea level rise or devastating hurricanes). The ABM is grounded in the wealth of quantitative, qualitative, social, spatial, and environmental data available from the Nang Rong Projects (Walsh et al. 2013), and code and documentation for it are available from the Carolina Population Center.[4]

AGENT-BASED MODEL

An ABM simulates a population of autonomous, heterogeneous agents that interact with each other and their environment according to a set of prescribed rules (Bruch and Atwell 2015; Macy and Willer 2002). The dynamic actions of agents at the microlevel and their responses to the behaviors of other agents and characteristics of their environment result in regularities or emergent patterns at the macrolevel. In the literature, ABMs range in complexity from highly simplified "toy models" such as Schelling's (1971) account of residential segregation to models attempting to replicate many of the features of real landscapes (Bruch and Atwell 2015; Manson et al. 2020). In some cases, the purpose is to elaborate a theory or theories (e.g., Centola, Willer, and Macy 2005; Centola and Macy 2007), whereas in others, the purpose is to plan for alternative futures (e.g., Naivinit, Trebuil, and Gajaseni 2010). Although we start out with highly detailed information about individuals and households situated in a real landscape, our aim is to explore theories. We do not seek to replicate reality or predict any future. Rather, we use our ABM to test the implications of the theories described above in a variety of local ecologies.

ABMs allow for the direct incorporation of feedbacks that are fundamental to the dynamism of human and ecological systems. In our model, these feedbacks are of two types. One involves endogenous relations among key variables: for example, the risk of migration depends on household assets, which in turn depend on loss of household labor through prior migration as well as remittances. The other type of feedback involves interaction among agents, that is, the influences that neighbors have upon each other. In our ABM, the behavior of individuals and households depends on the behavior of other individuals and households, structured through social networks. The emphasis is on process rather than individual events. With feedbacks, ABMs provide the ability to analyze the dynamics of an interconnected system over time, making it possible to find emergent and unexpected

[4] http://www.cpc.unc.edu/research/tools/abm/nangrong.

patterns in trajectories that would not be possible with a statistical regression approach.[5]

Our ABM capitalized on extensive data and research already conducted in Nang Rong. It built on longitudinal panel survey data that followed all individuals in 51 villages, including out- and in-migrants and return migrants; collected complete social network data (kin and exchange) in villages of origin; georeferenced villages, households, and the locations and attributes of plots farmed by each household; and collected information about what households grew on each of their plots. It drew on a ground-truthed time series of satellite images classified for land cover/land use, a digital elevation model constructed from topographic maps, soil depth and drainage maps, and observations in the field. It was also informed by qualitative interviews with village heads, farmers, and other residents in the district conducted over multiple field visits. Spatially explicit ABMs that fully incorporate explicit geography are rare in sociological applications (Bruch and Atwell 2015; Manson et al. 2020); also rare are ABMs that use empirical measures of networks (Smith and Burow 2018).

The agent-based simulation includes multiple types of agents: individuals, land parcels, and households. Households are a point of integration for the model: individuals form households, 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 direct and indirect kin ties among members within and between those households, including former members (i.e., migrants). Villages are modeled separately, one at a time.[6] Complete descriptions of the model can be found in Walsh et al. (2013) and Entwisle et al. (2016). Appendix A presents a detailed overview of the components of the model most relevant to out-migration and return migration. Here, we focus on aspects key to our arguments in this article.

Each individual agent has attributes such as age, gender, marital status, and place of residence and can experience demographic, social, and/or economic processes including giving birth (married women of reproductive age, or MWRA, only), death, out-migration, marriage, and establishing a new residence locally. When not residing in the community, these agents can return, remit to the origin household (influencing that household's assets), marry, or die. Couples can rent and own land and accumulate assets and can pass them on to their kin when they die or reach old age. Subfamilies

[5] Simulating the effect on out-migration of resource declines due to climate shocks based on a snapshot, as done in a standard regression analysis, presumes that the population at risk is continually replenished, which is not necessarily the case.

[6] Distance is not a consideration in the ABM. Because households are clustered within villages, they do not differ in distance to Bangkok and other urban destinations. There are differences between villages, but they are quite small, especially in relation to distance to Bangkok.

are groups of individuals (such as a married daughter, her husband, and children) who live within households and can split off to form a new household. The modeling of household formation and dissolution, and the distribution of land and other assets when households split or otherwise dissolve, is based on extensive fieldwork.

Land parcels also have attributes, such as size, distance from the village, flooding potential and topographic setting, land use type, and soil suitability for various agricultural uses. The impact of floods and droughts varies within and between villages depending on these attributes. Land parcels are explicitly located on Nang Rong's landscape as measured in the geographic and environmental survey data described above. Depending on parcel characteristics, household resources, and environmental factors such as the timing and amount of rainfall, each household makes a choice about whether to farm or not (and where, among their available options), whether to rent additional parcels, what crop to grow (rice, sugar, or cassava), and whether to use inputs such as chemical fertilizer, herbicides, and pesticides. Climate change in the form of floods and droughts affects land use decisions, that is, what to grow on each parcel. Those parcels in turn experience levels of productivity, specific to the crop in question, that are based on household choices, parcel attributes such as soil suitability and flooding potential, and the timing and amount of rainfall. In terms of the model, the timing and amount of the monsoon each year is one of the factors affecting the yield on each plot cultivated by the household in that year. In this way, climate change affects yield, which in turn affects household assets. These components of the model, described by Walsh et al. (2013) in detail, are based on agricultural and environmental science (Jones et al. 2003; Heumann, Walsh, and McDaniel 2011; Heumann et al. 2013; Malanson et al. 2014) and extensive fieldwork in the region in 2004 and 2010.[7]

Importantly, we do not build a direct effect of climate change on outmigration or return migration into our ABM. Our interest is not in catastrophic floods and droughts, which might occasion mass migration out of an area, but in extensions of weather trends already well underway (Nickl et al. 2017; see fig. 4). Accordingly, we operationalize the effects of climate change on migration through a linked set of mechanisms centering on livelihoods. This is illustrated in figure 5, which abstracts from the ABM shown in appendix A to illustrate specific feedbacks in the model.

The primary pathway through which extreme climate events can influence migration patterns in this ABM is the following: the timing and

[7] In the ABM's landscape module (described in Walsh et al. [2013]), land use decisions and outcomes are informed by household characteristics, land suitability (calculated within a maximum entropy model), inputs (three fertilizer amounts), anticipated yield (based on the decision-support system for agro-technology transfer, or DSSAT cropping model), and a prespecified climate scenario.

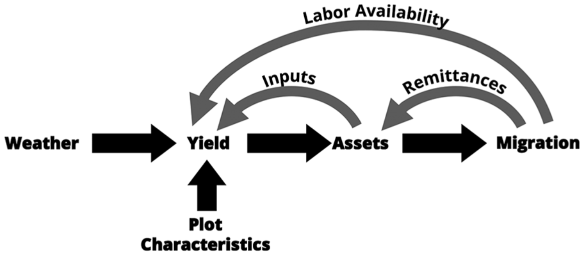

FIG. 5.—Major pathway in the ABM: weather affects migration through yield, assets, and feedbacks.

amount of rainfall affects crop yields (rice, cassava, and sugar are modeled separately), crop yields affect household assets, and household assets as well as the characteristics of current and prior household members affect out-migration and return migration (households with more assets are better able to finance migration and to afford the loss of labor associated with it). There are feedbacks from migration to household assets (remittances increase assets), migration to crop yields (through labor availability), and household assets to crop yields (through inputs such as fertilizer, which must be purchased). Rainfall is assumed to be exogenous, a reasonable assumption given the focus on the experiences of individual villages over annual time steps. Because the plots farmed by households vary in their vulnerability to floods and droughts (elevation, distance from rivers, soil suitability), the impact of climate shocks can vary within villages (see Walsh et al. [2013] for a complete description of this part of the model).

The rules for out-migration and return migration are based on a probabilistic approach and were derived from a statistical analysis of Nang Rong survey data as well as relevant substantive and theoretical literature (Entwisle et al. 2016). Reflecting our interest in the role of the life course in structuring migration patterns, individuals between the ages of 10 and 29 are eligible to out-migrate and return migrate. In the Nang Rong survey data, few individuals outside of these age ranges depart from or return to the village.[8] The coefficients from regression models are used in the agent-based simulation to determine individual specific probabilities of out-migration and return migration in each simulated year. Individuals are randomly selected to migrate with the chance of doing so proportional to probabilities defined by regression-based out-migration and return migration equations. These regression-based out-migration and return migration equations were designed specifically to incorporate some of the

[8] Among migrants in the 1994 Nang Rong Household Survey, only 11% initiated their most recent migration when they were outside of these age ranges. Among those in the 2000, the corresponding percentage was 15%.

key predictors of migration reflected in the theories mentioned above as well as characteristics that are important for the research questions herein, such as age, marital status, and childbearing (as life course status indicators), household assets, social networks (measured at multiple levels), and village characteristics. The equations used to determine probabilities of out-migration and return migration, operational definitions of the measures, and treatment of uncertainty are presented in appendix B. Consistent with a life course focus, we calculate migration probabilities for agents who are 10–19 years old and those who are 20–29 years old in two separate equations.

Social networks are both cause and consequence of migration in the model (Entwisle 2007; Klabunde and Willekens 2016). Potential out- and return migrants move (or not) depending on "pulls" in places of origin and destination. Social ties bear on these pulls as both sources of information and help and sources of obligation, as we have described earlier. Social ties are also changed as a result of migration. When a potential migrant moves out of the household and village of origin, a new tie to the destination is added, increasing the flow of information and other resources to other members of the household and village, perhaps encouraging additional migration in the future. At the same time, a tie within the origin is subtracted, which, depending on where in the village-based network the prior resident and his or her household was situated, may affect household centrality, links to well-off households (top 10%), and overall village cohesiveness—all relevant to migration. Return migration leads to analogous changes in the patterning of social ties. Logically, social networks are endogenous, part and parcel of dynamic interrelationships involving migration. With ABMs, it is possible to fully incorporate this endogeneity.

Multiple levels of social organization are potentially relevant to the operation of social network ties in relation to migration. The ABM includes network variables at three levels: individuals, households, and villages. Because of their significance for migration, we focus on kin networks. These are measured in terms of first- to fourth-degree kin ties, where degree is operationalized as steps involving birth or marriage (both of which are also processes in our ABM). An example of a fourth-degree tie is mother's mother's child's child—in other words, first cousin. At the individual level, we include the number of kin ties that potential migrants have to migrants from the village and that potential return migrants have to village residents. For individual village residents and migrants, we also construct a dependency ratio that measures the number of ties to potentially dependent kin (younger than 10, over 60) in the village divided by the number of kin ages 10–60 (the working ages in this context) in the village able to assist them. At the household level, we include a measure of household centrality and a count of ties to households in the top 10% of the wealth distribution. At the village level, we include a measure of network cohesion as well as a measure of migration prevalence (see app. B for further details).

While weather → crop yields → household assets → migration is the primary pathway through which extreme climate events can influence migration patterns, endogenous feedbacks in the model create additional pathways that may yield results that are less simple. Factors motivating migration change each year in the model due to prior migration behavior (e.g., migrant remittances increase household assets) as well as the behavior of other agents (e.g., social ties to destination reflect the migration of others in the household and village). A decrease in household assets may motivate migration; remittances may address the shortfall. Such effects are found in empirical regressions based on snapshots of either out-migration or return migration in Nang Rong villages (Tong and Piotrowski 2010; Garip 2014) and elsewhere (Garip 2012*a*), but their dynamics in a coupled system of out-migration and return migration, social networks, household assets, and land use have not been explored. Prior migrants from a household or village can make it easier for more prospective migrants to move to a destination and can influence what neoclassical models of migration deem "success"; that is, they help retain migrants who have already moved there (Korinek et al. 2005; Garip 2008). Social ties to the village, especially to potentially needy kin, may speed return or delay migration in the first place. Interrelationships between land use, household assets, social networks, and both out-migration and return migration are dynamic in the ABM. Macro-micro connections between migration, land use, and social organization are complex and multidirectional (Axinn and Ghmire 2011).

CLIMATE IMPACTS

In the ABM, we simulate 25 years of experience in Nang Rong villages in annual time steps, initialized with empirical social and land use data from the Nang Rong surveys conducted in 2000. The models are realistic in that they start with "real" data measuring the characteristics of "real" villagers in "real" villages. However, it was never our purpose to reproduce the past or predict the future. Rather, our goal is to use the ABM to explore the implications of the theories embodied within it, which for the purposes of this article, are those involving out-migration and return migration. Specifically, we use the ABM as a laboratory for a series of experimental studies of rainfall patterns and migration and then the role played by dynamic social networks in producing the observed effects. In each instance, we simulate population processes over a period of time, then make one change and resimulate, with everything else the same.

We study the impacts of extreme weather events by manipulating the climate in four scenarios, one of which serves as a benchmark. We created these scenarios based on monthly rainfall data for Nang Rong from 1900 to 2008, accessed from the University of Delaware Center for Climate and Land Surface Change.[9] Each scenario begins and ends with the same weather pattern, what we call "normal-normal" weather to reflect normal timing of the monsoon and normal amount of rainfall associated with it. Normal in this case is defined as average timing and amounts of monsoon rain based on the historical record. In all scenarios, normal-normal weather is present for simulation years 0–10, allowing the ABM to become fully established, and in simulation years 18–25, when there may be recovery. The scenarios differ in the middle years (simulation years 11–17). The first scenario focuses on droughts; its middle years are marked by a seven-year period of extremely dry weather. The second focuses on floods and contains a seven-year period of extremely wet weather in the middle years. In the third, we examine variability with a scenario whose middle years fluctuate between severe droughts and floods. Each is compared to a reference scenario, containing normal-normal weather during the middle years, which serves as a benchmark. Hereafter, we call these scenarios "drought," "flood," "variability," and "reference."

The drought, flood, and variability scenarios each include a single period of seven years (running from simulation years 11–17) that experiences extremely dry weather, extremely wet weather, or extremes alternating every two years. In the dry years, the monsoon is late and amounts lower; in the wet years, the monsoon is early and the amounts greater. The dry years are drier than experienced in the historical record, but there is still 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. By examining seven-year periods of extreme weather preceded by 10 years of normal-normal weather and followed by normal-normal weather in the remaining eight years, we can study the destabilizing effects of climate change as well as look at recovery. Further detail on creation of the scenarios is provided in Walsh et al. (2013).

Models were run separately for 41 Nang Rong villages. We selected these villages from the 51 Nang Rong Project villages for whom social and spatial survey data were available because they had the highest quality data, including cadastral maps or high-quality field measurement of which households use which plots of land. From the standpoint of the model, each village constitutes its own set of "initial conditions." Despite the fact that the villages are located in a relatively small area in Thailand's Northeast, they vary in their susceptibility to weather events. A lowland village close to one of Nang Rong's rivers will be less susceptible to drought, and more

[9] http://climate.geog.udel.edu/~climate/html_pages/archive.html#gcd.

susceptible to flooding, compared to an upland village with limited water supply but good drainage. Each village varies in its location, nature and quality of soils, access to water and susceptibility to flood, as well as population size, economic characteristics, migration patterns, social networks and the like (all initialized with real data). By considering all 41 villages, we accommodate the diversity found in the district. We also ensure that model results do not depend on the particulars of any specific village, as might occur if we relied exclusively on the experience of an exemplar village. To accommodate stochastic elements in the ABM and to gauge the prospects of outcome uncertainty, each climate scenario was run 40 times for each of the 41 villages (1,640 runs for each climate scenario). This aspect of potential variability in results yielded little additional information, so median results are reported for each village.

We show results in a series of graphs, one for each climate scenario. The x-axis shows model years, from 1 to 25. 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. The y-axis portrays out-migration or return migration as a proportion of those eligible, measured as deviations from the baseline rate for each of the villages, with the baseline defined according to the reference scenario of no extreme weather. In this case,

$$deviation_{y,s=focal} = 100 * \left(\frac{migration_{y,s=focal}}{migration_{y,s=reference}}\right) - 100,$$

where y indexes the year, and s indexes whether the scenario is a focal scenario (drought, flood, or variability) or the reference scenario. This presentation allows us to counterfactually assess migration dynamics in the village under extreme weather events consistent with climate change (drought, flood, or variability scenarios) compared to what would be observed in the absence of such events (reference scenario). As such, there are minimal differences in village means prior to the onset of the climate event (year 11), differences that are consistent with slight random variation in the stochastic processes we study. Our interest is the direction of the migration response, either positive or negative, during and after the climate event occurs, where each village serves as its own control. That is, we are comparing how the village looks in each extreme weather scenario to how it would look under the reference scenario. We are also interested in the durability of extreme weather impacts, the persistence of migration responses after the extreme weather subsides and the focal scenario resumes the weather pattern of the reference scenario (years 18–25). Further, our interest is in response across all of the villages, not trajectories of experience for individual villages. For each model year, the graphs show a box plot summarizing the distribution of results across the 41 villages for which the simulations were run.

RESULTS

Figure 6 shows the impacts of flood, drought, and variability on out-migration rates, defined as the proportion leaving of those eligible to leave in each year of the model run compared to the reference scenario. The graph contains results from all 41 villages, plotted as a distribution of village-specific deviations averaged over the 40 runs of the model. Of interest is the mean and spread of experience each year and especially the discontinuities in years 11 and 18, the beginning and end of the simulated climate event. Since we focus on within-village deviations between the extreme weather scenarios and the reference scenario, positive numbers indicate a village's migration is greater in the focal scenario than it is in the reference scenario, negative numbers indicate the opposite, and zeros mean that migration does not differ between the extreme weather scenarios and the reference scenario. Because we obtain the results for each village by experimentally manipulating the climate scenarios in the ABM and explicitly benchmarking them against what would occur in that village under more normal climate conditions, it is helpful to think of these results as changes in out-migration rates that are induced by the different climatic scenarios.

Results are highly clustered until year 13. Even though extreme weather events begin in year 11, it takes a few years to provoke a response in the model, which suggests agents' adjustment in the face of short-term challenges. After that, the distribution of response expands substantially. In some villages, out-migration increases, but in others, it decreases. The impact depends

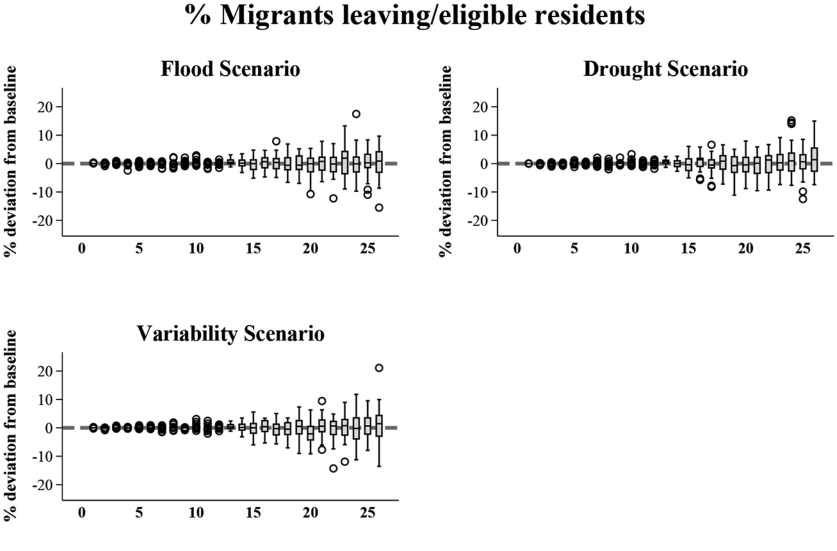

FIG. 6.—Deviations in proportion of eligible village residents who out-migrate in each climate shock scenario relative to reference climate scenario.

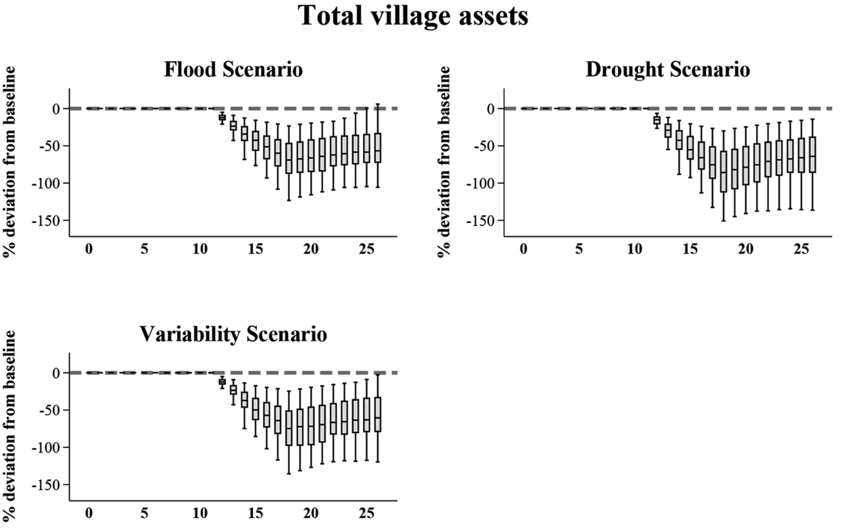

FIG. 7.—Deviations in total village assets in each climate shock scenario relative to baseline climate scenario.

on which village we select. Averages are little affected, however. Median response across villages hovers around zero. For every village showing climate shocks to have a positive effect on out-migration, there is another showing a reverse effect. There are few differences by scenario: the pattern is the same for droughts, floods, and variability between them.[10] The model results suggest no systematic effect of climate shocks on out-migration in this setting.

An immediate question is whether the weak effect on out-migration is due to relatively weak effects of rainfall patterns on yields and assets. As noted earlier, the effect of climate on migration is indirect in our ABM: the timing and amount of the monsoon affects yield, which affects assets, which affects migration. If there is only a weak effect on yields, or on assets, we would not be surprised to see a weak effect on out-migration. To demonstrate that the lack of an out-migration response is not due to some failure along this pathway, figure 7 shows the impact on total assets measured at the village level for each of the climate scenarios. The negative impact of floods and droughts is clearly visible in this figure: assets respond immediately to the beginning of the climate shock. In fact, although the situation improves

[10] Floods and droughts do affect land use decisions and productivity differently. For example, total sugar yields respond more dramatically to droughts than to floods (Entwisle et al. 2016).

after the end of the shock, except in a few rare instances, total village assets do not rebound to preshock levels by the end of the simulation.

What about return migration? Figure 8 shows the impacts of flood, drought, and variability on return migration, defined as the proportion returning among those eligible to return in each model year, in comparison with the reference scenario. As before, results for all 41 villages are shown. Again, results are tightly clustered around baseline until year 13 (i.e., slightly after the climate shock begins), but in the case of return migration, rates clearly fall after that, even as the distribution of results expands. Indeed, there are only one or two instances of villages where return migration is higher than baseline, and these are not sustained, appearing for no more than a year or two. Whether the climate shock is flood, drought, or variability, the effect is to retard and diminish return migration. This is a persistent effect, remaining beyond the end of the climate shock, throughout the simulated years for most villages.

What can we say about the magnitude of the effects shown in figures 6 and 8? Are they reasonable? There are several sources reporting broadly convergent results, although we note that interpretations are tricky because of differences in the timescale of migration, cohort versus period estimates, and eligibility criteria used. Across all years and climate scenarios, the ABM results for out-migration rates vary across villages from 12.7% to 51.5% (mean 33.1%). In prior work, Garip's (2008) study of predicted probabilities

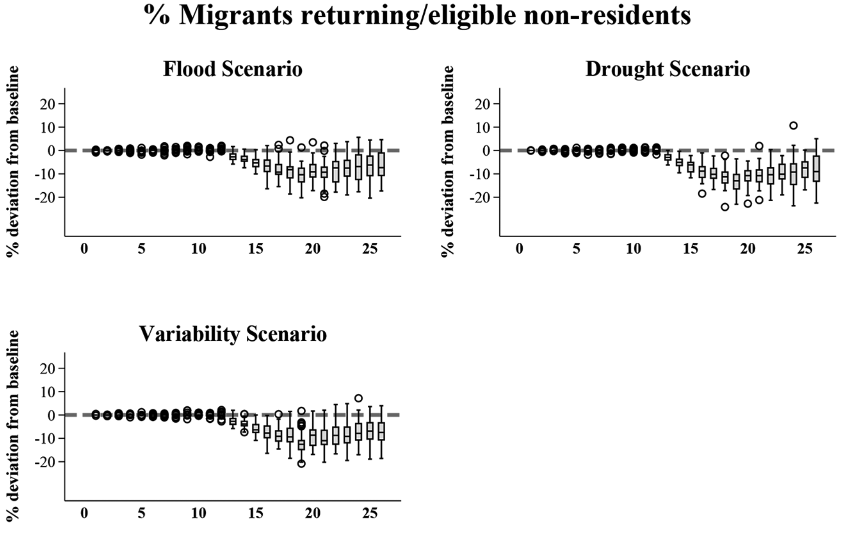

FIG. 8.—Deviations in proportion of eligible migrants who return to village in each climate shock scenario relative to reference climate scenario.

of migrating among Nang Rong residents shows a similar range to what is observed at the village level in the ABM data. In another of her papers (DiMaggio and Garip 2011), village-level percentages of migrants range from about 20% to about 50% (median approximately 33%). Curran and colleagues find migration prevalence rates in Nang Rong villages with a similar range to that reported here (Curran et al. 2005). Similarly, for return migration, the variation of ABM results across all years and climate scenarios (10.5% to 56.0%, with a mean of 28.4%) corresponds with figures reported in other studies (e.g., 26% in Tong and Piotrowski [2010]; 27.8% for males and 30.0% for females in Korinek et al. (2005)). The ABM broadly reproduces migration levels found in other studies, even though such reproduction was not an explicit aim given our theory-testing orientation, lending credibility to our efforts.

Now, to the more interesting question: Why does the model show impacts on return migration but not on out-migration? The two findings are likely connected. Nang Rong is a setting where repeat migration is common. In such a marginal economic setting, where out-migration is already well established, there is not much "room" for additional impact. This would be all the more true if the stock of potential migrants were decreasing due to reduced return migration, a feedback in the system. One variable in the migration model is the kin dependency ratio, which reflects the number of older and younger kin residing in the village relative to kin in the productive age ranges. Out-migration increases the ratios; return migration decreases them. If migrants do not return, then the stock of potential future out-migrants is reduced relative to competing needs in the village. Kin dependency ratios act as an equilibrating factor in the model.

How do these results reflect the role of endogenous social networks? As explained earlier, we measure kin and other social ties to both origin and destination in our model, with estimated effects based on regressions of out- and return migration using the longitudinal survey data (also see app. B). The relative number of migrants from the village already in the destination facilitates out-migration, as do specific ties to family members who are there. Ties to nonmigrants are also relevant, especially ties to potentially dependent family members relative to the number of working age adults (a person-specific kin dependency ratio). These ties encourage out-migration at the youngest adult ages but decrease in size and eventually reverse in effect as potential migrants grow older. They consistently encourage return migration. Note that all of these ties are updated in the model annually, in response to births, deaths, and migration in the previous year.

We can address the question of networks systematically. An advantage of the ABM approach is the ability to conduct experiments to test the importance and impact of specific mechanisms in the model (Bruch and Atwell 2015). We do this by "breaking" the links between different conceptual processes and migration by altering different sets of coefficients in the migration probability model. To break links involving social networks, we set all network coefficients to zero and re-run the ABM.

Figure 9 shows the consequences of breaking these links for modeling out-migration. No matter what scenario we choose, without the facilitating effects of social networks, climate stress *decreases* out-migration. How can we explain this? In the absence of social ties, migration becomes a profoundly individual decision, a simple cost-benefit decision. It is "neoclassical." In our scenarios, the benefits associated with migration are essentially held constant, but costs can vary. There are two sources of impact relevant to costs. One is the ability to afford the costs of a move. Floods and droughts reduce the assets available for this purpose. The other are the costs themselves. The relative numbers of villagers currently living in urban destinations as well as specific ties to former household members living there bear directly on these costs. The more contacts prospective migrants have, the more help they can expect in finding a job and a place to live. Without these contacts, costs of migration are high. In essence, in the absence of social ties, each migrant is a "pioneer." Breaking the links involving social networks thus increases the costs of migration as the resources needed to finance the trip are decreased as a result of climate events. The upshot is reduced out-migration.[11]

The implications for return migration may also appear surprising. As shown in figure 10, without social networks, return migration is not responsive to flood, drought, or variability in our model. The likelihood of return continues along as before. How do we explain this? A likely explanation is that without social ties linking migrants to their home villages, little news about hardships associated with floods and droughts at home reaches the migrants; hence, decisions to return or not are unaffected by these patterns. In addition, there would be no conduits through which home households could leverage social ties in places of destination to exert their influence. It is possible that return migration may still respond to household assets. However, there are two countervailing effects. Assets are greater if migrants do not return and instead remain away to remit. At the same time, greater assets hasten return. Qualitative work from Northeast Thailand recognizes these countervailing pathways. Potential returners note: "There are more

[11] There are few studies of climate change and migration that incorporate social networks, and therefore few studies with which to compare this result and its interpretation, but there is one. Nawrotski and colleagues (2015, 2016) report that social networks suppressed climate-induced international migration based on an analysis of data from the Mexican Migration Project. This is opposite of what we found. However, it is difficult to interpret this disparity given so many differences between the two studies in basic design (prospective vs. retrospective), the definition of migration (individual vs. household; internal vs. international), the measurement of social networks (direct vs. indirect), the measurement of remittances (explicit vs. presumed), and the measurement of climate variables (local vs. municipality level).

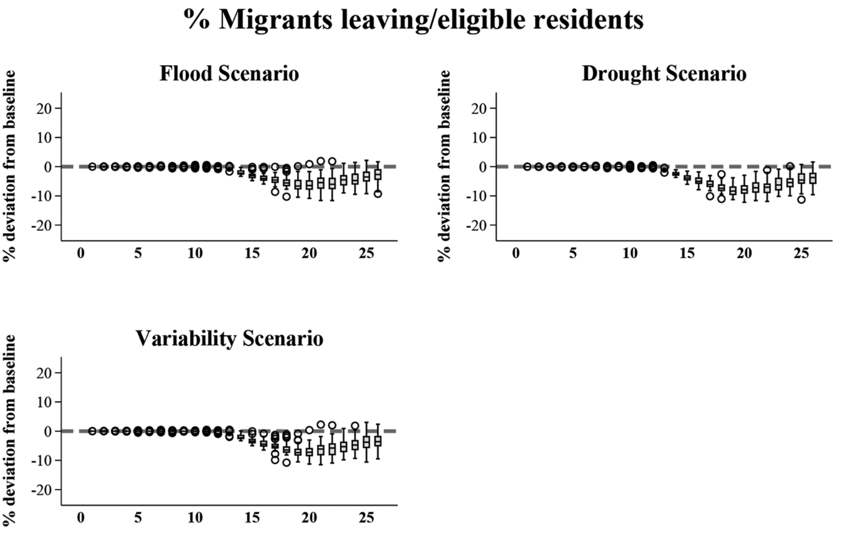

FIG. 9.—Deviations in proportion of eligible village residents who out-migrate in each climate shock scenario relative to reference climate scenario when social network effects are removed.

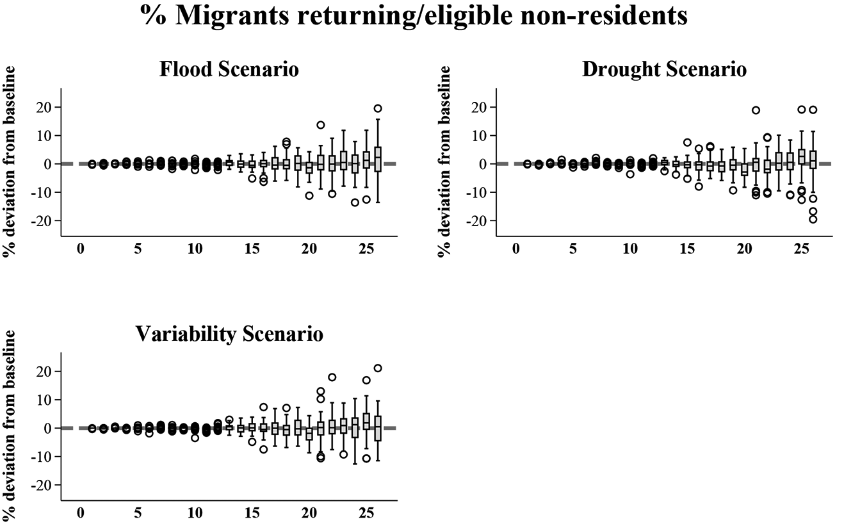

FIG. 10.—Deviations in proportion of eligible migrants who return to village in each climate shock scenario relative to reference climate scenario when social network effects are removed.

expenses if the children stay home. If we go away to work, there are less people home, and it [is] less expensive to feed the family" (quoted in Garip 2014, p. 677). Others who have returned commented, "It might have been better for me to stay in the village because we had land. When I migrated for work, no one took care of the land, so we had to rent it out" (quoted in Garip 2014, p. 677). Such response patterns differ by household wealth (Garip 2014), but both sentiments are predicated on feelings of obligation to kin and decision making that extends beyond the household. In the absence of influences from social ties, on average, the two cancel each other out. When social ties are included in the model, climate events clearly depress return migration relative to baseline.

DISCUSSION AND CONCLUSION

Climate change can occur slowly when measured in the scale of human lives. In areas such as Nang Rong, Thailand, where weather patterns are already quite variable, it can be difficult to detect a turning point in the extent or frequency of floods and droughts. In areas such as this, households likely have already adapted to periodic floods and droughts, even extreme ones. Transformations in the livelihoods once supported in a given locale take time, raising the possibility of adjustment in the interim. A migration response need not be immediate, unidirectional, or uniform, and indeed may not occur at all.

Migration processes evolve over the course of lives that are embedded in social networks and structured within migration systems. These insights are not always reflected in the climate change and migration literature. Accordingly, our ABM acknowledges the role of migration in the life course, especially the transition to adulthood, its role in the household economy, and its role in responding to as well as reforming social networks in origin as well as at destination. The system is dynamic, and climate change has the potential to disrupt any or all parts of it.

In contrast to a literature preoccupied with out-migration, we also studied return migration. From the standpoint of the life course, both out-migration and return migration are central to the transition to adulthood, with young people leaving and returning to their village of origin as they assemble the resources they need to meet obligations to family that are also are redefined at the same time. From the standpoint of the household economy, household members who migrate to urban areas for work often return after they achieve earnings targets. From both of these perspectives, out-migration and return migration are connected. Climate shocks may provoke out-migration, but equally, they may discourage return migration. Either can lead to depopulation over time.

Our empirical focus in this article is climate shocks related to the timing and amount of rainfall. Recent literature on climate change effects has considered temperature as well as precipitation (e.g., Mueller, Gray, and Kosec 2014; Bohra-Mishra, Oppenheimer, and Hsiang 2014; Thiede et al. 2016; Bohra-Mishra et al. 2017).[12] There is evidence to suggest warming in Thailand (Limsakul et al. 2011), with potential consequences for cropping patterns. However, in interviews with Nang Rong farmers undertaken over multiple field visits, temperature was never mentioned as a problem. We selected rainfall as a focus because of its centrality to rice cultivation (Naylor et al. 2007) and the livelihoods of Nang Rong households.[13]

We examined three extreme weather scenarios, which are beyond recent experience, but do not negate the possibility of adaptation and adjustment. Whether the climate shock involves flood, drought, or both, the result is the same in our models. This may at first seem puzzling, given that the scenarios move water conditions in opposing directions. However, it is important to emphasize that they are all extreme shocks, beyond the case where a little more water would improve yields in a too-dry village or a little less would improve them in a too-wet village. Further, the effects all operate through livelihoods, specifically the productivity of plots. Other possible consequences of extreme weather scenarios are outside our model.

Further, considering the set of villages as a whole, there is little effect on out-migration in the median of all villages. However, there is a pronounced reduction in the likelihood of return migration compared to baseline for each of the villages. Of course, the experience of specific villages may vary, depending on village characteristics such as wealth, the strength of social ties, migration history, the agricultural potential of the land farmed by village households, and vulnerability to floods and droughts. An exploration of village heterogeneity is beyond the scope of this article but would certainly be a worthwhile undertaking in the future.

To better understand these results, and to gain a better understanding of the ABM in general, we broke the links involving social networks. In the absence of social networks, climate shocks reduced out-migration relative to baseline, but with little consequence for patterns of return migration. Clearly, social networks are important to the maintenance of out-migration

[12] In their investigation of the effects of annual variability in precipitation, temperature, and typhoons on census-based measures of interprovincial outmigration in the Philippines, Bohra-Misha et al. (2017) find temperature effects but not precipitation effects (also see Bohra-Misha, Oppenheimer, and Hsiang 2014). That study is focused at the provincial level and examines migration over five-year intervals. Agricultural dependence also differs between the Philippines and our setting. We are looking at much more fine-grained processes.

[13] Further, within the realm of potential warming scenarios, increased temperatures are unlikely to impair the productivity of the crops we model (rice, cassava, and sugar); such crops are more susceptible to low than high temperatures (Matthews and Hunt 1994; Timsina and Humphreys 2006).

and return migration flows in this system. As clearly, patterns of out-migration and return migration are linked in important ways; after all, those who might return are those who left, and many of those who might leave are those who have previously returned.

Of course, our results and the inferences drawn from them are conditional on a particular ABM of household dynamics and land use change for the specific case of Nang Rong, Thailand. It drew on extensive social and spatial data collected over three decades in this setting, analyses of those data, and observations based on numerous field visits. It capitalized particularly on the prospective, longitudinal panel, the follow-up of out-migrants and return migrants, complete social network data, and links between households and georeferenced field plots, the last of which were characterized with extensive geospatial data on elevation, soil, and land use. Compared to some ABMs, ours involves considerable detail. The data used to initialize the model were also quite detailed, drawn from empirical social and spatial survey data, thus permitting us to accommodate a range of initial conditions over the 41 villages simulated. However, from the start, it emphatically was not our interest to make specific predictions, but rather to explore the implications of the theories embedded in the ABM.

What light does our model shed on economic theories of migration? Whether a neoclassical migrant or a temporary migrant moving as part of a household strategy, the likelihood of a move depends on costs and the ability to afford these costs. Ties to the destination embody resources such as help finding a job or place to live that diminish costs of migration. The importance of these ties was dramatically illustrated when out-migration plummeted as social network links in the model were broken. With no ties to destinations, potential out-migrants become pioneers, completely reliant on their own resources. This result points to the importance of social context even for the individuals who are the focus of neoclassical theory.

In NELM, households are the focus. Here, our concern is with household assets in relation to the behavior of individual members. Household assets are diminished by out-migration, at least in the short run, because of the loss of labor power as well as the resources needed to support migration. In the absence of remittances, the loss of labor power continues to depress household assets over time, other things equal. Remittances can restore assets and potentially even provide a return on the investment, but risks remain in this risk-minimization strategy. The longer household members reside in the destination, the more likely they are to acquire new obligations, for example, through marriage (Jampaklay 2006). By depressing the likelihood of return, climate shocks begin to undermine a central tenet of spatial diversification as a household strategy.

Economic theories of labor migration are central to the study of international as well as internal migration, which raises a question as to whether our results might shed any light on movements across as well as within national borders. Indeed, Donato and Massey (2016) argue that international migration is shifting from "moving to opportunity" during the 20th century to "evading threat" in the 21st, with one of the threats being climate change. As is true of the literature in general, studies of climate change and *international* migration focus on out-migration. What might we expect for return migration? Given the higher costs and greater difficulty of return for international than for internal migration, we might expect an even greater impact of climate change on return migration when international borders are involved. It will depend on the porosity of the borders, of course. An example of porous borders are those between Burkina Faso and Cote d'Ivoire, adjacent countries in West Africa with a long tradition of movement between them (OECD 2017). An example of a hardened border would be that between the United States and Mexico. In the latter case, return migration is already so substantially depressed as a result of U.S. policy (Massey, Durand, and Pren 2016) that there might not be much potential for further impact.

Social forces are also relevant. An innovative feature of our model is that it incorporated a life course approach. The literature on residential mobility, and to some extent internal migration in developed countries, is increasingly informed by life course concepts and approaches (Bernard et al. 2014*b*; Coulter et al. 2016; Warner and Sharp 2016). This is not yet true of the literature on rural-urban migration within developing countries or migration across international boundaries. The life course approach offers particular insight on out-migration and return migration through the transition to adulthood. These processes are linked to other status transitions occurring during the early adult years, including entry into the labor market, marriage, and childbearing. Young people who move to Bangkok may do so as part of a household strategy, but in the course of their stay may meet a future spouse from somewhere else. What started as a temporary move may evolve into a more permanent stay as a consequence of life course transitions. Decisions to leave and return in our model illustrate the life course principles of agency and timing as well as the contingent nature of the transition to adulthood. Our attention to the potential importance of initial conditions (simulating 41 separate villages with different migration histories, population compositions, social networks, and landscape features), and indeed to the particulars of Nang Rong as a setting, captures the principle of historical time and geographic place. The principle of linked lives is reflected in network dynamics. As demonstrated in our simulations, out-migration and return migration depend on the needs (as reflected in the number of dependents in the village) and prior migration behavior of kin.

Social networks are fundamental to the dynamics of our ABM. We focused on kin networks, which change as a result of migration but also other demographic processes such as fertility and marriage. Kin ties are conduits for information flow, within and between origin and destination. They are potential sources of help and assistance, for recent migrants particularly, as well as sources of obligation, especially in the home village, along with social pressure to meet these obligations. Networks are central to understanding the risks and costs of migration. They are also central to understanding migration in the context of linked lives. Of course, our focus on kin networks is a simplification. Friends, schoolmates, neighbors, employers, and other acquaintances may also have a role to play, but these alternate ties are beyond the scope of our model.

A major strength of the ABM approach is the ability to run experiments (Bruch and Atwell 2015). We conducted two types of experiments. In the first, we isolated and manipulated weather patterns, simulating the effects of flood, drought, and variability between the two. Everything other than weather patterns was held constant in these simulations, which is reasonable given that villages are small relative to national and international markets for agricultural products in Thailand. The second type of experiment manipulated key linkages in the model, specifically those involving social networks, shedding light on the dynamics of the ABM and the complex pathways producing the effects observed in the simulations. In these experiments, as in all true experiments, all else is equal. In the real world, of course, it is not.

While it is not possible to generalize beyond the model and the case, the results do suggest a new avenue for research on the impacts of climate change: return migration. To be sure, there is interest in recovery migration among the people who leave an area because of a catastrophic flood such as caused by Hurricane Katrina or the Indonesian Tsunami, and important research is based on these populations as well as on new migrants to affected areas (e.g., Fussell et al. 2014). The impact highlighted in our study is quite different, however. In ordinary times, many young people in the Nang Rong villages leave for Bangkok and other urban areas; roughly half of them return. Climate shocks have the potential to affect either direction of movement, and it is important to look at both. Definitional issues come into play here, revolving around migrant intent and length of absence. We believe that it is important to look at return separately rather than model the round trip as the outcome (Call et al. 2017). Whether migration is temporary or permanent is only known after the fact. In our model, climate shocks reduced the likelihood of return relative to baseline although it did not alter patterns of out-migration in any systematic way.

To be sure, it is more difficult to observe migrants who do not return than prospective migrants who leave. The *New York Times* will be challenged to find iconic photographs and related stories of this potential impact. Yet in terms of local populations, if young people leave and stop returning, the consequences for social and economic life are no less dramatic.

APPENDIX A

Figure A1 provides a graphic representation of our agent-based model (ABM). The paragraphs below provide additional description for each of the model's components. Appendix B provides further detail on how migration is modeled. As noted in the text, the ABM is run separately for each of 41 villages.

Initialization

Initial values are set for households, household members, and parcels in the selected village. For households: a household identifier (ID), a roster (identifying current and prior household members), a list of owned parcels, a list of managed parcels, assets and remittances as well as the identification of subfamilies, and a land split trigger. For individuals, these include a household ID, a person identifier, age, sex, marital status, status as resident or migrant, years gone (if migrant), and spouse, mother, and father identifiers (to identify kin ties). For parcels, these include a parcel ID, size, a list of LULC cells included in the parcel (raster), land use type, duration in that land use, suitability for rice, cassava, sugar cultivation, distance to road, distance to river, and household IDs (multiple in the case of shared management). For villages, a village ID and list of households, and aggregate or constructed measures based on individuals, households, and parcels. Initial values come from the 2000 household survey (and derivatives from prior surveys) and the associated identification and characterization of parcels (Rindfuss et al. 2004). All of these items are drawn from the empirical Nang Rong social and spatial data collected in the 2000 wave.

The model runs household by household within each time step, with values updated at the end of each time step. What follows is a description of procedures for households during a single time step.

Select First Household

Proceed to parcel module.—Within household, determine whether the household is engaged in agriculture. If not, owned land is rented and owning household receives one-third of the product and renting household receives remainder (based on field interviews).

If the household is engaged in agriculture, for each plot, based on land characteristics, choose crop; based on assets, choose inputs (or not); calculate the yield based on crop, inputs, and rainfall pattern.

Repeat these steps for all parcels.

The yield is valued based on market prices prevailing at the time. The total is added to household assets.

See Walsh et al. (2013) for further details on this component of the model.

Proceed to Household Member Module

Within household, select member.—Use survival schedule to calculate the likelihood of a death. If a death, adjust roster, subfamily tracker, and sociomatrices.

If female and in fertile ages, use fertility schedule to calculate the likelihood of a birth. If a birth, update the roster, the household subfamily tracker, and the sociomatrices.

If a current resident.—Migrate? See appendix B for details.

If a prior resident (i.e., migrant).—Return? See appendix B for details.

For all current residents who are single (including those who have just returned.—Calculate the risk of marriage. If there is a marriage, determine postnuptial residence (randomly: 40% chance of moving to and settling in an urban destination; 30% chance of moving to another village; 30% chance of staying in origin village, with equal chances of living with parents or establishing an independent household). If a marriage and postnuptial residence is with parents in origin village, update the subfamily tracker.

For all prior residents who are single (including those who have just migrated).—Calculate the risk of marriage. Update the rosters.

For all prior residents.—Calculate the risk of remittance based on gender, marital status.

Repeat these steps for all members of the household.

Consider the household as a unit.—Did the last parent die? If so, then allocate assets according to a set of rules based on fieldwork. If no, then are there one or more subfamilies? If so, is there a split? (Splits are based on the number of subfamilies, presence of children, and length of coresidence.) If so, create a new household and allocate the land.

Update wealth.—*Assess wealth* based on productivity of parcels as determined in the parcel module and remittances as determined in the household member module. Deductions for use of inputs, loss of labor due to migration, consumption of those remaining in the household, and land conversion (rice to upland crops, upland crops to rice).

Proceed to the next household.

After all households are complete, update the kinship network and other information for the next t(ime).

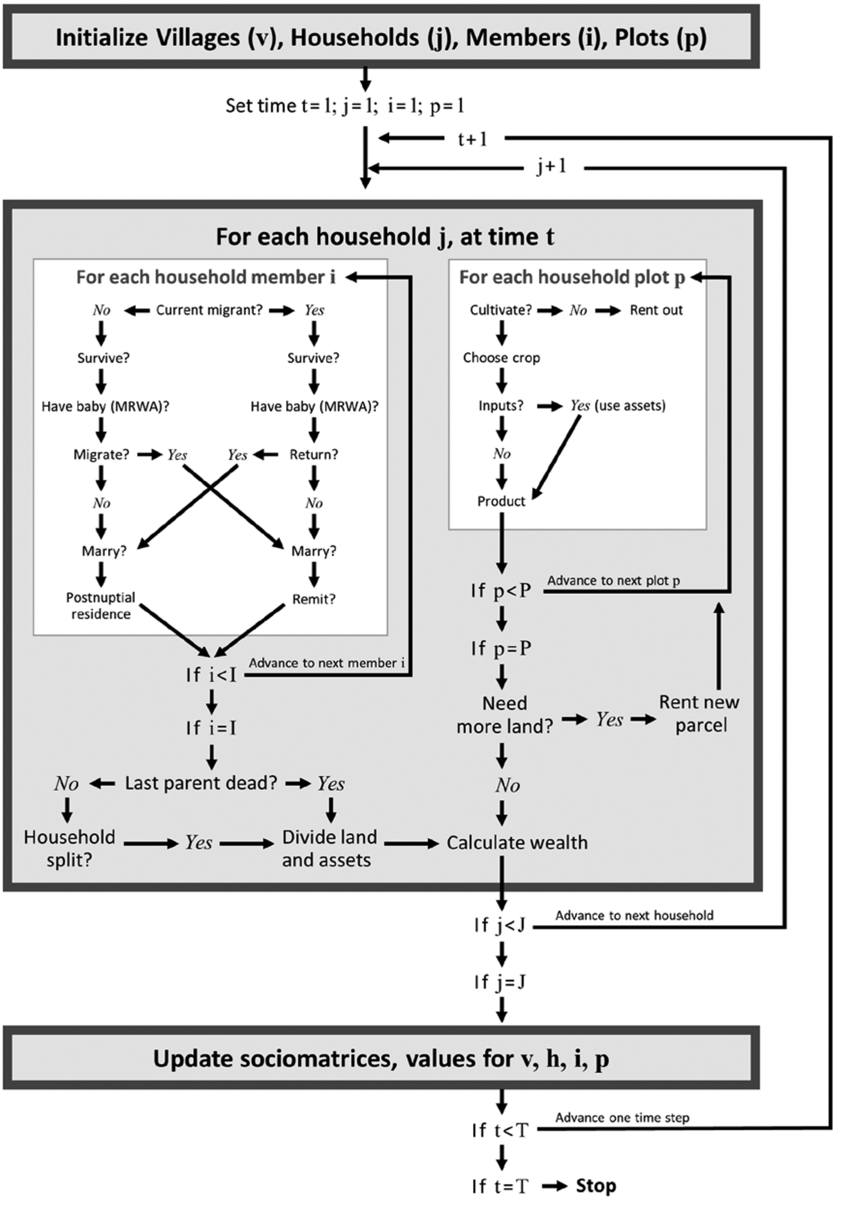

Fig. A1.—Graphic representation of Nang Rong ABM

APPENDIX B

Agent-Based Model Components Relevant to Social Networks and Migration

The social network and migration components of the agent-based model (ABM) draw on an analysis of out-migration and return migration between 1994 and 2000 based on data from the 1984, 1994 and 2000 Nang Rong surveys. The 1994 household survey collected data on complete networks in 51 villages of origin. Because of their significance for migration, we focus on kin networks.

A complete enumeration of current and previously counted (1984) household members was undertaken in the 1994 survey. Links to mother, father, and spouse were obtained for each person listed on the household roster. In addition, links to siblings were obtained for each person ages 18–35. We used these data to construct matrices of first-degree kin ties between current and former members of each village (i.e., everyone enumerated in 1984). We derived second-, third-, and fourth-degree kin ties through matrix multiplication. From the individual ties, we constructed measures of the extended kinship system for each village (see Verdery et al. 2012).

The model includes network variables at three levels: individuals, households, and villages.

At the individual level, we measure the number of kin ties (first to fourth degree) that potential migrants (village residents) have to migrants, and the number of kin ties that potential return migrants have to village residents. We also measure ties to dependent kin, both young and old. Dependency is typically measured at the household level. However, kin obligations in places of origin may extend beyond origin households to include other relatives living nearby. Further, demands may be felt differently depending on the availability of other kin to help, and these other kin may not be located in a single household. We therefore used the kin network data to create person-specific dependency ratios within three or fewer kinship degrees. Orthodox dependency ratios use ages 15 and 65 as thresholds; we adjusted these to reflect the agricultural nature of the setting, from 15 to 10 at the lower end and 65 to 60 at the upper end.

At the household level, we measure degree centrality within village-based household networks. We also measure whether or not there are kin ties to a wealthy household, defined as those in the top 10% of the village wealth distribution.

At the village level, we measured connectivity as the mean for the sum of households reachable in kin paths of three or fewer degrees, divided by the total number of households in the village, multiplied by 100. We measure migration prevalence as the proportion of 1984 village residents no longer living in the village in 1994.

We estimated logistic regressions of whether village residents in 1994 were no longer resident in 2000 (out-migration) and whether migrants in 1994 (those who were surveyed in the villages in 1984 but were reported as migrants in the 1994 surveys) had returned by 2000. We did this separately for two cohorts, persons ages 10–19 in 1994 and persons ages 20–29 in that year. In addition to assets and measures of kin ties, we included age (and age squared), sex, and marital status of individuals; assets and dependence on farming as a livelihood at the household level; and population size, the prevalence of cassava cultivation, and the percentage of households owning a pump, a television, and a vehicle. Results shown in table B1 below confirm that kin ties measured at multiple levels and in multiple ways affect out-migration and return migration.

TABLE B1
LOGISTIC REGRESSIONS FOR OUT-MIGRATION AND RETURN MIGRATION VARIABLES, NANG RONG, THAILAND,1994–2000

	At Risk of Out-migration		At Risk of Return Migration	
Variables	10–19	20–29	10–19	20–29
Village characteristics:				
Ln village population	−.243	−.032	−.346	−.307
	(.169)	(.230)	(.312)	(.222)
Migration prevalence	−.033*	.003	−.034***	−.020**
	(.018)	(.010)	(.013)	(.009)
%HH grow cassava	.002	−.003	.005	−.003
	(.002)	(.003)	(.004)	(.003)
%HH own pump	−.011**	−.015**	−.003	−.002
	(.005)	(.007)	(.010)	(.006)
%HH own TV	.010**	−.010	−.011	.005
	(.005)	(.006)	(.009)	(.006)
%HH own vehicle	−.003	.002	−.002	.006
	(.004)	(.005)	(.007)	(.005)
Connectivity	−.551***	−.017	.027	−.002
	(.192)	(.041)	(.055)	(.039)
Migr. Prev. *Connectivity	.010**	NA	NA	NA
	(.004)	NA	NA	NA
km to nearest village	.085**	−.001	−.013	.119**
	(.041)	(.058)	(.082)	(.060)
Individual characteristics:				
Ties to migrants/ residents	.046***	.028***	.034***	.019***
	(.008)	(.010)	(.011)	(.007)
Age	1.663***	−.108	.697**	−.177
	(.119)	(.254)	(.324)	(.256)
Age^2	−.052***	−.000	−.021**	.003
	(.004)	(.005)	(.010)	(.005)
Female	.087	−.731***	−.012	.485***
	(.055)	(.077)	(.109)	(.076)

TABLE B1 (*Continued*)

Variables	At Risk of Out-migration 10–19	At Risk of Out-migration 20–29	At Risk of Return Migration 10–19	At Risk of Return Migration 20–29
Ever/currently married	−.292*	−.569***	−.296	−.437***
	(.174)	(.086)	(.197)	(.082)
Dependency ratio	.177	−.552**	.888*	.250
	(.238)	(.264)	(.494)	(.302)
Household characteristics:				
Ties to wealthy HH	−.182**	.054	.007	−.060
	(.074)	(.102)	(.162)	(.112)
Total assets	−.038***	.010	.044*	.015
	(.011)	(.015)	(.023)	(.016)
HH centrality	−.007*	−.022***	−.024*	−.009
	(.004)	(.005)	(.012)	(.007)
Has to farm	−.108	−.077	−.005	.001
	(.075)	(.106)	(.144)	(.096)
Constant	−10.275***	3.850	−2.992	2.825
	(1.971)	(3.631)	(3.479)	(3.581)
Observations	6,059	3,822	2,037	4,714
Log pseudo likelihood	−3,841	−2,120	−1,058	−2,253

Note.—HH = household. Numbers in parentheses are estimated SEs.
* $P < .05$.
** $P < .01$.
*** $P < .001$.

The coefficient estimates in table B1 provided the starting point for modeling the effects of social network ties in the agent-based model. The next step involved converting the predicted probability of moving over the six-year period to a predicted annual probability. The six-year probabilities were rescaled assuming constant annual probabilities but allowing for the repeated nature of migration as an event.[14]

The equations predicting annual probabilities of out-migration and return migration were based on an analysis of all 51 villages in the dataset. The ABMs were run separately by village, initialized with actual data from each of 41 villages with the best spatial data in 2000, and subsequently updated based on predicted values at the end of that year. Values for all of the social network variables were recalculated for each village, household, and household member at each iteration of the model depending on whether that household member moved, whether other household members moved, whether other village residents moved, and whether migrants returned. The calculations also adjusted for births, marriages, and deaths during the year. Kin networks are thus fully endogenous in the agent-based model,

[14] We would like to thank Peter Mucha for contributing this method.

both cause and consequence of out-migration and return migration and other demographic events.

The ABM also includes a stochastic element for each prediction. This is both an acknowledgment of the incompleteness of the equations (i.e., not all relevant determinants of migration behavior are included, and indeed, it is not clear that this would even be possible) as well as potential imperfections in the coefficient estimates reported in table B1. In recognition of this stochasticity, each model was run 40 times to obtain a distribution of results for each village; we focus on village averages, which do not alter the story. In addition, in an early stage of model development, the sensitivity of the ABM results to the particular regression coefficients was tested by using the estimated standard errors to develop "strong" and "weak" versions of the expected network effects. Although the ABM results were not identically the same (and were not expected to be), trends were similar.

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