Published in final edited form as:
Popul Environ. 2017 December ; 39(2): 147–172. doi:10.1007/s11111-016-0265-8.

Heterogeneous Climate Effects on Human Migration in Indonesia

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Keywords

migration; climate change; environment; displacement; Indonesia

Introduction

Motivated by concerns about the social costs of climate change, numerous empirical analyses of how climate shocks affect human migration have been published in recent years (Bohra-Mishra et al. 2014; Dillon et al. 2011; Feng et al. 2010; Gray and Mueller 2012a; Gray and Mueller 2012b; Hunter et al. 2015; Jennings and Gray 2015; Marchiori et al. 2012; Mueller et al. 2014). Scholars are now utilizing sophisticated methods for linking environmental and demographic data, and assessing the causal impact of climatic changes on migration (Fussell et al. 2014). Yet little consensus on the direction or magnitude of such effects has emerged from these findings. Arguably the most salient lesson from the body of existing evidence is that the effect of climatic change on migration operates through, and is moderated by social, economic, and political factors, with the implication that climate effects are contingent upon context and the livelihoods of affected populations (Black et al. 2011b; Morrissey 2013).

The observed complexity of these effects runs contrary to the predictions of scholars and policymakers who assume that out-migration is an automatic response to localized resource scarcity caused by climate shocks. It is also contrary to the assumption that social vulnerability to climate change translates directly into an elevated risk of displacement. In contrast, the nuanced findings of recent empirical research are more consistent with alternative conceptual frameworks for thinking about demographic responses to climate shocks and related resource constraints, such as the multiphasic response and livelihoods approach (Bilsborrow 1987; Davis 1963; Ellis 2000). These alternative perspectives suggest that migration is but one of many potential behavioral responses to environmental change, and that responses may be heterogeneous even within the same context. These conceptual frameworks, as well as recent empirical findings, motivate us to ask not simply if and how many persons will be displaced by environmental change, but also for whom and under what

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conditions would one expect migration to be part of a multi-pronged response. Specifically, we examine variation in migratory responses to climatic shocks across key demographic and geographic groups using a unique longitudinal survey dataset from Indonesia. By exploring the heterogeneity of these effects as well as parallel climate effects on origin-area livelihoods, we provide insight into the causal mechanisms linking climate and migration, and place the effects in context by measuring climatic effects on non-demographic behavioral responses. In addition to this primary objective, our paper also pays explicit attention to measurement and methodological decisions, which we argue have made it difficult to draw clear comparisons across existing studies.

The article proceeds as follows. In the next section, we briefly review previous research on environmentally-induced migration and outline a conceptual framework based on theories of population-environment interactions. We then describe our data and methods, and present the results of our analyses. We conclude by discussing the implications of our results.

Behavioral Responses to Environmental Change

Prior Research

Previous research on environmentally-induced migration has documented statistically significant climate effects, but the nature of these effects varies considerably from study to study. The result is a collection of studies that focus on different types of climatic changes, employ different measurement strategies, and study different types of migration. For example, studies have found that migration is driven by rainfall deficits (Gray and Mueller 2012a; Hunter et al. 2015) but not flooding (Gray and Mueller 2012b); while others show migration is largely a function of temperature shocks (Mueller et al. 2014) and temperature-related declines in crop production (Feng et al. 2010). Climate effects have also been found to be non-linear in some instances such that livelihoods and migration patterns are most affected after a critical climatic threshold is passed (Bohra-Mishra et al. 2014).

Despite some consensus regarding which livelihoods (e.g., smallholder agriculture) and geographic areas (e.g., coastal regions, areas without irrigation) are most vulnerable in general to climatic change, the implications for migration are not clear cut. Indeed, the direction of observed climate effects on migration also varies across studies. In some cases, climate shocks cause increased rates of out-migration from affected communities (Hunter et al. 2015; Mueller et al. 2014), but similar shocks have a migration-suppressing effect elsewhere (Black et al. 2011a; Gray and Mueller 2012a; Gray and Mueller 2012b; Warner et al. 2012). The diversity of climate effects across contexts is made particularly clear in a recent study by Gray and Wise (2016), who, using a common set of data and methods, find variation in the relationship between climate and migration across five countries in sub-Saharan Africa.

In addition to differences across contexts, climate effects may also be contingent upon the type of migration outcome examined. For example, local labor migration may increase in response to climate-related crises as households seek casual wage labor opportunities to cope with food insecurity. In contrast, rates of international migration may decrease as households lose the resources needed to fund long-distance moves (Henry et al. 2004).

Finally, certain social and demographic groups may be more or less likely than others to migrate in response to a climate shock. Between-group differences may reflect an unequal distribution of vulnerability to such events, but again we emphasize that vulnerability may either increase or decrease migration odds (Black et al. 2011a; Bohle et al. 1994; Gray and Mueller 2012a; Mueller et al. 2014). Between-group differences may also be a function of other factors, such as gender norms, that shape individuals' propensity or ability to use migration as part of a coping strategy net of a given climate shocks' impact (De Jong 2000)

Broadly, the body of existing research suggests two fundamental lessons. First, the context in which climate-migration relationships are being evaluated matters. The ecological context may affect which types of climatic change are substantively most important (e.g., cold versus hot temperature shocks; rainfall versus temperature). As well, context-specific social and economic conditions shape whether and among whom migration is likely to be used as part of a coping strategy. This conclusion underlines the need to evaluate environment-migration links through a broader lens that accounts for the links between migration and other responses, and that accounts for social structure. Second, the divergent results across existing studies also underline the importance of understanding the particularities of climate and migration measures used in this field (Auffhammer et al. 2013; Fussell et al. 2014). Many existing studies have made creative use of existing demographic and climate data. These approaches are novel—and in fact essential given existing data constraints—yet are not always ideal. Such data limitations, and disagreement among social and climate scientists about measurement, have resulted in inconsistencies across studies in how both climatic changes and migration are measured. The diversity of approaches also complicates comparisons across studies.

These issues motivate us to examine the effect of climate deviations on within- and between-province migration in Indonesia, and assess whether these effects vary across subpopulations. Through doing so, we attempt to identify social and geographic differences with respect to the use of short- and long-distance migration as a part of strategies for coping with environmental change. Our analyses also make a methodological contribution through the extension of a previously published study of environmentally-induced migration in Indonesia (Bohra-Mishra et al. 2014) by using higher-resolution measures of climate, a more inclusive definition of migration, and by simultaneously examining non-migratory climate responses. By conducting a distinct analysis with the same survey dataset and in the same context, we overcome a primary barrier to cross-study comparison that has limited this field.

Theoretical Perspectives

The complexity of results from previous studies was unanticipated by many early scholars of environmentally-induced migration, and also runs contrary to more contemporary perspectives that conflate vulnerability with the likelihood of displacement. While this complexity makes it difficult to develop a 'grand theory' of climate-migration linkages, it nonetheless places a clear focus on the respective linkages between the environment and social structure, and between migration and other behavioral responses.

For one, variation in the effect of climate shocks on migration is a reflection that geographic mobility is but one of many possible behavioral responses. This point has been made, albeit sometimes implicitly, in much previous research, but is sometimes obscured by environmental determinists' claims. The multiplicity of possible behavioral responses was made earliest, and arguably most clearly, by research on the multi-phasic response. Building on Davis's (1963) original theory of the multi-phasic response to population pressure and environmental stress, Bilsborrow (1987) argued that rural households in developing countries respond to environmental pressure through a diverse set of demographic and economic changes. Potential changes range from shifts in nuptiality and contraceptive use ("demographic") to extensive or intensive shifts in agricultural practices ("economic") and out-migration to frontier regions or urban areas ("demographic-economic"). This framework and subsequent analyses underscore that responses to environmental stress often involve multiple behavioral changes, and that the exact set and sequence of changes is contingent upon household and contextual factors (Ezra 2001; Kalipeni 1996; de Sherbinin et al. 2008).

This observation is supported by a broader literature on livelihoods and livelihood diversification in the developing world, which demonstrates the ways in which multiple behaviors are strategically combined to navigate constraints and cope with risk (both *ex ante* and *ex post*) (Barrett et al. 2001; Ellis 2000). These insights have direct relevance for our purposes given that prior research has identified climatic variation as an important source of risk, and therefore also a determinant of poverty and economic status, in the developing world (Dercon and Krishnan 2000; Dercon et al. 2005; Gaurav 2015; Skoufias and Vinha 2013).The literature on risk and livelihoods also recognizes that migration is commonly used as a livelihood diversification (i.e., risk reducing) strategy. However, the literature on livelihoods has argued that the odds of migration versus alternative livelihood options are determined by the interaction of multiple types of capital, specifically human, financial, physical, social, and natural (Hunter et al. 2014; Scoones 1998). With respect to the current study, a key insight of this framework is that the environment is only one driver of livelihood-related decisions, and it does not operate independent of other sources of capital. The effect of environmental change on migration is therefore in part a function of the ability of affected persons to engage in other (possibly less disruptive) livelihood diversification strategies. In some cases, alternative *in situ* strategies may be available and effective, thus reducing the likelihood of using migration as a means of reducing risk. Such a scenario may be particularly likely with respect to costly longer-distance or permanent moves.

A parallel discussion has focused on the differential vulnerability of particular populations to environmental shocks, with concern centered on the involuntary displacement of marginalized and exposed groups such as women, agricultural households, and the poor (Adger 2006). This discussion complements the conceptual approaches described above, since it identifies groups that have particularly vulnerable livelihoods and face unique pressures and constraints with respect to their risk reduction strategies. The common assumption that the most vulnerable are also the most likely to migrate in response to environmental shocks is not fully supported by previous demographic research on the selectivity of migration (Gray 2009), but this literature nonetheless suggests a simple testable hypothesis: that individual and household characteristics will modify climatic influences on migration. Building on previous research on contextual influences on migration (Bilsborrow 1987), this hypothesis can also be expanded to include the institutional and agro-ecological context in which populations are embedded. In rural areas, for example, land quality and access to certain agricultural technologies (e.g., irrigation, improved seeds) partially determines the viability of on-farm adaptation strategies; while the structure of local labor markets shapes the possibility of securing alternative income-generating activities within an individuals' place of residence (Codjoe and Bilsborrow 2011). These examples and other constraints structure the set of possible responses available to affected persons.

Overall, these theoretical perspectives situate migration as one outcome among multiple potential behavioral responses to climatic shocks. In contrast to prior frameworks that assumed migration to be the primary response to local environmental changes, this approach does not lend itself to straightforward or universal expectations regarding environmentally-induced migration. It instead links the likelihood of migration outcomes to that of other possible responses to environmental change, many of which are unobserved in the empirical data used to study migration. As such, this perspective has utility in anticipating and explaining the divergence of existing findings across and even within contexts.

Current Study

The current study examines variability in the effects of climate deviations on human migration within the Indonesian context by addressing four main objectives. First, we address a fundamental measurement issue by examining whether results are sensitive to (1) modeling alternative migration outcomes and (2) analyzing climate data measured at different scales. Specifically, we assess whether previously observed non-linear effects of temperature and precipitation on the probability of whole-household migration in Indonesia (Bohra-Mishra et al. 2014) are also evident when using higher-resolution climate data to model effects on both within- and between-province migration of individuals. Our focus on individual migration across different spatial scales is informed by previous research showing that long-distance, whole-household migration represents a small fraction of population movements, and that local and non-permanent mobility is a common response to weather shocks. Temporary migration has also been a longstanding feature of population mobility in Indonesia (Hugo 1982), making it important to understand whether and how such patterns are affected by climate shocks in this particular context.

Our second motivation for building upon Bohra-Mishra et al. (2014) is to estimate the effect of climate variability on migration using higher-resolution climate data. By providing some insight into the consequences of measuring climate shocks at alternative scales, this exercise makes a broader contribution to the field in which such scalar differences are common. With respect to our analysis specifically, climate indicators in the previous study were based on area-weighted monthly temperature and precipitation means calculated for each province in the IFLS. These provinces are diverse in size, and many are large and climatically heterogeneous. In contrast, we use daily temperature and precipitation estimates generated for individual 0.5°-by-0.5° cells. By linking geo-coordinates of each community in the sample with these climate data, we are able to develop nearly community-specific measures of climate trends and deviations. We therefore reduce the risk that outlier locations (e.g., uninhabited, high-altitude zones) and other sources of within-province variation affect our climate measures. The implications of our approach versus the prior study are apparent in summary statistics for the climate variables of interest. For example, the four-year average temperature across our analytic sample is 27.3°C (SD=1.6°C), a full 2°C greater than the 25.3°C (SD=1.5°C) inter-survey average annual temperature reported in the prior study.

As a second main objective, we assess whether the effect of total annual rainfall differs from the effect of rainfall timing—specifically the timing of monsoon onset. Previous research in the Indonesian context supports conflicting expectations about rainfall effects. Bohra-Mishra et al. (2014), described above, found a significant non-linear effect of rainfall levels on migration. This is consistent with at least one other study from Indonesia that documented the effects of early-life rainfall levels on later-life health outcomes (Maccini and Yang 2009). However, other research suggests that delays in monsoon onset have a particularly strong and significant impact on rice and maize production, which plays a key role in the Indonesian economy (Naylor et al. 2002; Naylor et al. 2007) and has important consequences for household economic status (Skoufias et al. 2012). These findings suggest that the timing of rainfall has effects on rice production and local economies that are independent of total monsoon rainfall. Delays in monsoon onset force rice farmers to delay planting of the main rice crop, which extends the hungry season prior to harvest. This change also potentially disrupts the smaller, dry season rice crop that usually follows the main harvest—with clear implications for rice yields and economic conditions in the following year(s) (Naylor et al. 2007).

Our third main objective is to examine whether and how the effect of climate shocks on migration varies across sub-populations. Evidence of between-group heterogeneity can support causal claims about climate effects if group differences are consistent with expected mechanisms linking climate and migration. In the case of Indonesia, we expect that climate shocks are likely to shape migration through impacts on rice and maize production, and subsequent effects on the labor market, food prices, and economic conditions within households. Both theory and the divergent findings of prior research (e.g., Gray and Wise 2016) provide little basis for forming *a priori* hypotheses about the direction of climate effects on migration. However, if our expectation that climate effects on agriculture are the primary mechanism behind environmentally-induced migration is correct, one would expect variation in climate effects across at least four factors: membership in a farm household, gender, household wealth, and residence in Java relative to other parts of the country.

First, membership in a household in which at least one member is involved in a farm business is indicative of strong (or at least differential) ties to agricultural production relative to those only involved as wage laborers, or households entirely detached from agriculture. Farm ownership constitutes an important dimension of exposure to the effects of climatic changes, which prior research suggests is a determinant of vulnerability (Adger 2006; Gallopín 2006).

Second, if environmentally-induced migration can be explained by climate effects on agriculture and subsequent changes in the household economy, then one would expect labor-related migration to be most-affected. Prior research in the Indonesian context has demonstrated clear gender divisions in the labor market and labor migration (Antecol 2000; Hugo 1992). A main implication is that if women are systematically less involved in the agriculture-related labor market, they may be less exposed to climate effects. Likewise, gender barriers to accessing wage labor opportunities in the agricultural sector may prevent women from using casual wage labor as a response strategy. Assuming climate-induced migration is driven by opportunities in the labor market, this dynamic would correspond to smaller climate effects on migration among women. Differences in climate effects on migration by gender would be consistent with prior evidence of gender-mediated effects of environmental shocks in this context (e.g., on educational investments, Cameron and Warswick, 2001) and in the climate impacts literature more broadly (Denton 2002; Demetriades and Esplen 2008; Gray and Mueller 2012a, 2012b; Findley 1994; Perez et al. 2015).

Third, household wealth represents an indicator of the extent to which environmental change translates into material deprivation. Assets can provide a buffer to adverse conditions: households with large stocks of assets may be able to liquidate portions of their wealth to maintain adequate levels of consumption and avoid major changes in livelihood during periods of stress (Carter and Lybbert 2012; Frankenberg et al. 2003). In contrast, those without assets to draw on are more likely to be forced to make substantial behavioral changes (e.g., employing alternative livelihood strategies) to cope with the effects of environmental changes. Here, however, it is also important to note that assets may provide a stock of resources that are necessary to fund migration. Individuals from asset-poor households may be unable to migrate—particularly over significant distances—due to lack of resources (Black et al. 2011a). The result is that in some cases, those who are worst-affected by climatic changes are least able to move.

Finally, we expect systematic variation in climate effects according to whether individuals' beginning-of-period residence was on the island of Java or elsewhere in Indonesia. More than half of Indonesia's population lives on this single island, which represents a unique locus of economic activity in the country. With respect to our research question in particular, prior studies have identified fundamental differences in the ecological and economic structures across the Indonesian archipelago, with the most salient distinction between Java and the other islands. These observations date back to at least the writings of Geertz (1963) who argued that differences in ecology and governance between Java and the other islands created fundamental differences in the forms and intensity of agriculture (e.g., wetland rice vs. swidden; extensive vs. intensive expansion). While the conditions and historical processes that explain these disparities are complex, and indeed contested, evidence of differences is nonetheless quite clear: Throughout the decades covered by the IFLS, Java has been the agricultural heartland of Indonesia, with the highest rice yields of any region in the country and over half of the entire country's rice and maize production coming from the island (Makarim 2000; Naylor et al. 2002; Naylor et al. 2007). For this and related reasons, prior research has drawn distinctions between Java and the rest of the country (Frankenberg et al. 2002; Hugo 2000; Naylor et al. 2001; OECD 2012), a binary we also compare in this study.

As a fourth and final main objective, we examine the effect of climate shocks on sources of household livelihood as indicated by changes in household income by source. These supplementary analyses help us to assess whether and to what extent observed climate effects on migration correspond with indicators of non-demographic impacts and response. In this case, we consider changes in farm revenue, non-farm business revenue, and income from wage labor in (1) agricultural and (2) non-agricultural occupations. The emphasis on the multiplicity of potential behavioral responses to climate shocks in our conceptual framework suggests such attention to changes in the household economy more broadly can be helpful in developing a more comprehensive understanding environment-migration dynamics. As well, prior research (e.g., Bohra-Mishra et al. 2014; Mueller et al. 2014) has demonstrated the utility of such parallel analyses for interpreting climate effects on migration.

Data and Methods

Data

To meet these goals, we draw upon four rounds of data from the Indonesian Family Life Survey (IFLS) (Frankenberg and Karoly 1995; Frankenberg and Thomas 2000; Strauss et al. 2004; Strauss et al. 2009). These data have previously been used to examine the demographic effects of economic crises (Frankenberg et al. 2003) and forest fires (Frankenberg et al. 2005), among many other topics. The surveys were conducted in 1993–94, 1997, 2000 and 2007–08. In our migration analyses here, we consider only the first 4 years of the inter-survey period between 2000 and 2007–08 in order to maintain consistent inter-survey time periods. IFLS respondents were originally selected as a representative sample of the population living in 13 of 27 provinces in Indonesia, representing approximately 83% of the country's population. The IFLS tracks individuals between rounds for re-interview and has a remarkably low rate of attrition (Thomas et al. 2012).

Our analysis focuses on migration behavior among 12,773 individuals aged 15 to 49 years.[1] We link individuals observed in the IFLS to historical rainfall and temperature estimates produced by NASA's Modern-Era Retrospective-Analysis for Research and Applications (MERRA) (Rienecker et al. 2011) according to each individual's location at baseline of each inter-survey period. Geo-coordinates are only available for the 303 communities from which respondents were selected during the first round of the IFLS. In order to link baseline covariates with inter-survey migration outcomes, we restrict our analytic sample to persons that were observed in at least two consecutive surveys and who were located in one of the georeferenced communities at the beginning of an inter-survey interval. After these exclusions and limiting our analysis to persons aged 15 to 49 years old at each period baseline, our analytic sample includes a total of 27,194 person-period observations.

Our supplemental analyses of household livelihoods use the household as the unit of analysis and measure income during the final year of each inter-survey period. Detailed information on income was not collected for other years of the study. We follow identical procedures for linking IFLS and MERRA data, and impose the same restrictions regarding number of consecutive observations and location in a georeferenced community at period baseline. After imposing these conditions, our analytic sample includes a total of 18,237 household-period observations.

[1]We exclude individuals at older ages in which age-specific migration rates are extremely low.

Migration

We classify individuals as migrants if they reported moving across a community boundary (*desa*, equivalent to a rural village or urban neighborhood) and staying in that destination for six months or more during a given inter-survey period. Our analyses differentiate migrants by the type of boundary crossed during their move, which we take as a proxy for distance. Distance is known to be positively associated with the economic and psychic costs of migration (Sjaastad 1962), but we also note that local migration may not be an effective response if climatic changes have widespread effects (Rosenzweig and Stark 1989). The first category of migrants includes those who moved across a community boundary but remained within their province of origin (within-province migrants). The second category of migrant includes those that moved out of their province of origin (between-province migrants). Within-province migration is most common in Indonesia (see descriptive statistics below), but for context, note that supplementary analyses show that work- and family-related issues (e.g., marriage) are the most common motivation for both types of moves considered in our analysis.

Climate Measures

To account for climatic conditions during the four-year inter-survey periods in our migration analyses and for historical climate conditions, we extracted climate data at an annual time scale and then defined our analytical measures as the average deviation of the annual means over each four-year period of interest from the overall local historical mean from 1984–2011. Thus positive values reflect four-year periods that are warmer, wetter or with later monsoon onset than the historical climate for that community. Negative values reflect periods that are cooler, dryer or with earlier monsoon onset. We apply this approach to mean temperature, total rainfall and monsoon onset delay. Building on previous studies of Indonesia, monsoon onset is defined as the number of days after August 1 that pass until cumulative rainfall reaches 20cm (Naylor et al. 2007; Skoufias et al. 2012). Our analyses of household income utilize similar measures of temperature and monsoon onset delay, but only over the one-year periods for which income was measured (see below).

Income Measures

To place our findings regarding climate effects on migration in the context of changes in households' economic conditions more broadly, we also examine climate effects on household income by source. Income data were collected for the 12 months prior to each survey, thus these analyses focus on end-of-period income. We consider four types of income. Two capture revenues from businesses owned by the household: (1) farm business revenue and (2) non-farm business revenue. The other two measures account for household members' earnings by sector of employment. Here, we simply distinguish between income earned from labor in the (1) agricultural sector and (2) all other non-agricultural occupations. The expectation is that climate effects on agriculture are likely to also manifest in shifts in activity between the farm and non-farm sectors. The occupational categories used to define the latter groups were defined in the IFLS data prior to our analysis (Frankenberg and Karoly 1995). For each measure, we summed reported income across all household members and transformed these sums to the natural log of 1+income to reduce skewness.

Statistical Models

Our primary analyses examine the effects of temperature, rainfall, and timing of monsoon onset, defined as the average deviation of these measures from the historical mean over the four-year inter-survey period. To identify the effect of climate conditions on migration behavior, we estimate a series of multinomial discrete-time event-history models. These models demonstrate whether and how climate conditions respectively affect the probability of in-province and out-of-province migration during each inter-survey period. For each of the specifications described below, we estimate a multinomial logit model that takes the general form:

$$\log\left(\frac{\pi_{mit}}{\pi_{nit}}\right) = \alpha_{mt} + \alpha_{mc} + \beta_m X_{it}$$

where π_{mit} is the odds of migration outcome m for individual i in period t, π_{nit} is the odds of no migration during that period, α_{mt} is the baseline likelihood of migration outcome m during period t, α_{mc} is the baseline likelihood of migration outcome m in community c, X_{it} is a vector of independent variables for individual i in period t, and β_m is a vector of parameters for the effects of those independent variables on the odds of migration outcome m.

Each model controls for a series of covariates known to affect migration, measured in the baseline survey of each inter-survey period prior to the period of migration and climate exposure (summarized in Table 1). Controls include sex, education, marital status, household wealth (natural log), an indicator variable denoting whether anyone in the individual's household worked in a non-farm business during the past 12 months, an indicator variable denoting whether anyone in the individual's household worked in a farm business during the past 12 months, and rural (vs. urban) location.[2] We also account for migration history (and corresponding social networks) by controlling for the number of migrations (as defined above) the individual experienced between age 12 and period baseline, and including an indicator of whether an individuals' province of residence at period baseline was the same as at age 12. We include community and period fixed effects to account for all effects of the time-varying national context and the time-invariant community context as long as these effects are linear. Finally, we adjust all standard errors for clustering within the 0.5°-by-0.5° cells that correspond to our climate measures.

In addition to the initial model describe above, we also test for differences in climate effects according to gender, membership in a farm household, household wealth, and baseline residence in Java, which correspond to the expectations of heterogeneous effects outlined above. For each of these factors separately, we test for climate vulnerability by allowing the variable to interact with both climate variables simultaneously. We present these results for a single reference category (e.g., female) in tables, but for the purposes of interpretation also

[2]2 In preliminary analyses, we estimated our overall model (Table 2, Specification A) with age and household wealth modeled as quadratic functions, since prior research suggests a non-linear relationship between migration odds and these variables exists in some contexts. We did not find evidence of a non-linear relationship in either case, so we proceed with the more parsimonious model.

estimate the net effects for the alternative reference category (e.g., male) and report these throughout the text.

Finally, our analyses of how climate shocks affect household income by sector utilize a similar approach but using linear models. Specifically, we estimate a series of OLS regressions that take the form:

$$Y_{sht} = \alpha_{st} + \alpha_{sc} + \beta_s X_{ht}$$

where Y_{sht} is the log-transformed income from source s for household h in the final year of period t, α_{st} is the intercept of source s income during period t, α_{sc} is the intercept of source s income in community c, X_{ht} is a vector of independent variables for household h measured in period t, and β_s is a vector of parameters for the effects of those independent variables on income from source s. We modify our climate measures to correspond to the 12 months for which income data were collected. Control variables analogous to those described above were extracted from the previous survey round and are also included. For this household-level analysis, we use the characteristics of the household head.[3] Finally, standard errors are clustered at the pixel as described above.

Results

Climate and Migration

We estimate a total of eight specifications of the main model, each of which corresponds to one or more of the objectives outlined above. In the first two specifications, which we present in the Appendix for brevity (Specifications AA and AB, Table A1), we assess whether the non-linear temperature and rainfall effects on permanent, whole-household migration observed in prior research (Bohra-Mishra et al. 2014) are also present when examining individual-level migration using finer-grained environmental data. In Specification AA (Table A1), we follow this prior study by including a quadratic function of temperature and rainfall. Our results reveal effects on within-province migration that are jointly significant for temperature (χ^2=9.84, p=0.007) and non-significant for rainfall (χ^2=1.32, p=0.518). Temperature effects are jointly non-significant with respect to between-province migration (χ^2=0.05, p=0.974), as are the effects of rainfall (χ^2=2.63, p=0.269). We find no evidence of non-linear climate effects on individual, non-permanent migration when measuring climatic variation at 0.5°-by-0.5° resolution.

Since the timing of rainfall may be more important than the total amount, in the second specification we replace the indicator of precipitation levels with a measure of monsoon onset delay (Specification AB, Table A1). We again model this as a quadratic function for purposes of comparison with Specification AA. Estimates of Specification AB show no evidence of non-linear temperature or precipitation effects. However, the negative effect of temperature deviations on within-province migration is robust to using this alternative measure of precipitation.

[3]3 If data for the household head were not present, the characteristics of the oldest present adult were used.

We remove the squared terms for both temperature and precipitation in the remaining analyses since we found no evidence of non-linear effects in the prior two models. We retain the temperature and monsoon onset delay variables since they were significant in prior models, and the results are not sensitive to simultaneously controlling for precipitation levels (see Specification AC, Table A1). We begin by estimating our main model, without any interactions (Specification A, Table 2). Both temperature and monsoon onset remain significant predictors of within-province migration in this more parsimonious model. Our estimates show that above-average temperatures are associated with reduced probability of within-province migration (Odds Ratio, OR=0.047); and delays in monsoon onset are associated with increased probability of within-province migration (OR=1.031). We find no significant climate effects on between-province migration. To put the regression estimates into perspective, we use the results of Specification A (Table 2) to calculate the predicted probabilities of within-province migration across a range of climate conditions (Figure 1). The plate on the left shows declining probabilities of within-province migration as temperature deviations increase; while the right-hand plate illustrates increasing within-province migration probabilities as the delay in monsoon onset increases.

With respect to our first objective, results from the first three model specifications that we estimated suggest that the non-linear climate effects observed in previous research may be specific to the migration outcome measured, or to the province-level climate data and measures used as independent variables in that study. Prior results may have also been influenced by the particular model specifications used in that research, which included controls for exposure to other natural disasters. Regarding the second objective, our results indicate that precipitation effects on within-province migration occur through the timing of monsoon onset rather than the total level of rainfall.

To address our third objective—assessing variation in climate effects across subpopulations—we estimate additional specifications of the model that test for between-group differences in climate effects (Specifications B-E, Table 3). Each specification includes a different pair of interactions between both temperature deviation and monsoon onset delay and factors expected to potentially mediate climate effects on migration probabilities. We begin by assessing gender differences in climate effects (Specification B, Table 3), which research suggests are common in migration outcomes across many contexts (Pedraza 1991) and has been shown to be an axis of differentiation with respect to climate impacts and responses (Denton 2002; Demetriades and Esplen 2008; Gray and Mueller 2012a, 2012b; Findley 1994; Perez et al. 2015). The effect of temperature on the odds of within-province migration is statistically significant and negative for both men and women. However, within-province migration among women is significantly less sensitive to temperature deviations (OR=0.109) than migration by men (OR=0.019). The effect of monsoon onset delay is significant and positive among men (OR=1.038), but only marginally significant among women (OR=1.025, p=0.093). All climate and climate-sex interaction effects on out-of-province migration are non-significant. To demonstrate how the interaction between gender and climate produces differences in within-province migration across a range of climate conditions, we again calculate and plot predicted probabilities of within-province migration (Figure 2). Relative to women, the steeper negative slope of men's within-province migration as temperature increases is clearly visible. Similar patterns exist for the relationship between the probability of migration and monsoon onset delay, where the slope is positive for men but not statistically different from zero for women.

Specification C interacts the pair of climate variables with an indicator for membership in households that own a farm business (which excludes landless farm laborers). Membership in farm households may be associated with disproportionate exposure to climate-sensitive sources of livelihood if non-farm households are entirely removed from the agricultural sector. However, members of non-farm households may still work in the agricultural sector as casual laborers, demand for which may be quite sensitive to climate shocks. Our estimates show that temperature has a significant negative effect on the probability of within-province migration among non-farm households (OR=0.033) and farm households (OR=0.107). The effect of monsoon onset delay on within-province migration is significant and positive only among individuals with membership in non-farm households (OR=1.042). Among members of households that own farms, the net effect of monsoon onset delay on within-province migration is non-significant. We put the estimated climate effects on within-province migration in perspective by plotting the probability of these within-province moves across a range of temperature deviations (Figure 3). There is a clear distinction between within-province migration from non-farm households, which increases steeply with temperature, versus farm households, which is flat. Estimates of Specification C indicate no statistically significant climate effects on between-province migration.

As a third test of heterogeneity in climate effects, we examine variation by household wealth (Specification D, Table 3). We find no variation by wealth in the effects of monsoon onset delay or temperature on within- or between-province moves. In the final model (Specification E, Table 3), we interact the climate variables with an indicator for residence on the island of Java (East, Central, and West Java provinces) at period baseline. We focus on these provinces because the majority of Indonesia's rice and maize output is produced on Java and production has been shown to be tied to seasonal climate patterns (Naylor et al. 2002; Naylor et al. 2007). While the overall levels of engagement in agriculture may not be disproportionately high in Java, the type of involvement in the agricultural sector and intensiveness of production likely vary between regions. For example, agriculture in Java is more intensive, as indicated by high rice yields[4] (Makarim 2000) and much smaller farm sizes than the rest of the country (0.36 hectares (ha) versus 1.35 ha[5]) (OECD 2012). As well, the composition of our sample suggests that residents of the island are somewhat more likely to work as laborers than those elsewhere, who are more likely to own their own farm enterprises. 41.8% of our observations from outside of Java were from households that owned a farm, more than five percentage points more than on Java (36.4%). In contrast, a greater share of observations from Java (18.3%) received wage income from the agricultural sector, compared to 11.4% of observations from outside of Java. Given these qualitative differences in the type of agriculture on and off Java, evidence that effects vary between Java

[4]4 According to Makarim (2000), the rice yield in 1996, near the time IFLS2 was fielded, was 5.36 tones per hectare (t/ha) on Java. This figure is more than 0.6 t/ha higher than the yield across Indonesia (4.7 t/ha). For reference, also note that with the exception of Bali (5.36 t/ha), the highest rice yield among the provinces outside of Java was 4.77 t/ha (South Sulawesi); and the lowest was 2.63 t/ha (Central Kalimantan).

[5]5 This figure compares irrigated farmland in 2007. On Java, the average size of dry land farms is 0.30 ha. In contrast, off Java the average dry land farm size is 0.99 ha for farms engaged in food/horticultural production and 1.20 ha for farms growing perennial crops (OECD 2012).

and other regions would lend some support to the hypothesized agricultural mechanisms linking climate and migration.

Our estimated model of within-province migration suggests that temperature effects are statistically significant across the country and do not vary significantly between Java and other parts of Indonesia included in the sample. However, the effect of monsoon onset delay is only significant at conventional levels outside of Java (OR=1.032). Neither temperature nor monsoon onset have statistically significant effects on between-province migration.

Climate and Income by Source

As a supplementary analysis, we place our estimates of climate effects on migration in the context of climate-induced changes in other aspects of households' livelihood. Specifically, we examine climate effects on end-of-period household income by source (described in Table 4). Our analyses focus on the effects of temperature and monsoon onset deviations in order to correspond with our main non-interaction specification of the migration model (Table 2, Specification A).

A number of important results emerge from this analysis (Table 5). For one, we find a positive association between temperature deviations and farm business revenue. This result suggests that the temperate deviations that occurred during the period of observation were associated with improved agricultural conditions. Wage labor in agriculture and related sectors is not significantly affected by climate deviations, which suggests that the average impacts on the agricultural wage labor market were generally not substantial. We find that temperature deviations have a positive effect on income from non-agricultural wage labor. If, based on the first result, we assume that positive temperature deviations are associated with improved agricultural conditions, this finding suggests that the relationship between the agricultural and non-agricultural sectors is complementary in nature. For example, improved agricultural output may increase opportunities for the processing and sale of agricultural goods.

With respect to rainfall, we find that delays in monsoon onset are associated with increased non-farm business revenue. In light of prior research that has shown monsoon onset delays to have a negative effect on agricultural production (Naylor et al. 2002, Naylor et al. 2007), this finding would seem to support the conclusion that climate deviations are associated with declines in on-farm production and shifts into business activities outside of agriculture. Although we do not find a corresponding negative effect on farm revenue, it is possible that declining production is offset by increases in prices or shifts in revenue sources (e.g., from rice to livestock). Still, demand for labor within the household is likely to decline as a result of such shocks, allowing corresponding shifts into activities that increase revenue for non-farm enterprises.

Discussion and Conclusion

Our analysis of climate-migration relationships in Indonesia—using higher-resolution climate data than a prior study, modeling multiple migration outcomes, and considered in relation to changes in household income composition—reveals findings that are consistent neither with common assumptions about this process nor with a previous analysis of these data. Firstly, consistent with previous studies (Gray and Mueller 2012b; Jennings and Gray 2015) but not with common assumptions outside of the social science literature, we show that climate variability is more important for short-distance population movements than long-distance moves. This finding is theoretically consistent with a view of climate adaption in which households adopt the least disruptive, often *in situ* responses to environmental variability (Bilsborrow 1987). This finding is also consistent with the high social and financial costs of long-distance migration in the Indonesian setting.

Secondly, we show that climate impacts on migration are multidimensional and that the directions of these effects do not always conform to expectations. Delays in monsoon onset increase migration. This relationship is consistent with prior research showing monsoon delays to undermine agricultural production (Naylor et al. 2002; Naylor et al. 2007). This interpretation is also in part supported by our supplementary analyses of household income. The results of that analysis showed that monsoon onset delay corresponded to increases in non-farm business revenue, a possible indication of shifts to non-agricultural livelihood activities. Compared to observed rainfall effects, increases in temperature have the opposite effect and decrease migration. Our analyses of household income demonstrate that temperature deviations are positively associated with farm business revenue, an indicator of own-farm production. This suggests that the declines in migration during warmer periods reflect positive economic conditions for agriculture and relatively high demand for household labor during such periods. This finding directly challenges the common assumption that migration will increase globally under a future, warmer climate. It instead underlines the need to understand context-specific nuances with respect to how climatic changes may support or undermine agricultural production.

Thirdly, we show that climate effects on migration vary across subpopulations and regions in ways that are only partially consistent with hypothesized mechanisms for this relationship. Specifically, (1) temperature and monsoon onset effects on within-province moves are greater for men than women; (2) monsoon onset effects on within-provinces moves are concentrated among members of non-farm households; and (3) monsoon onset delays increase within-province moves outside of Java. The first finding suggests that households respond to improved on-farm agricultural production during periods of high temperatures and good conditions by retaining men for on-farm labor. In contrast, under cooler and less favorable conditions, men are more likely to migrate. These results are consistent with the disproportionate involvement of men in agriculture and the wage labor market in this context, as well as the gendered dimensions of climate-induced migration observed by previous studies (Dillon et al. 2011; Gray and Mueller 2012; Henry et al. 2004; Jennings and Gray 2015).

The second finding may indicate a dynamic whereby members of farm households are tied to their place of residence due to intra-household labor demands. In contrast, those who do not own farms but may nonetheless be involved in the agricultural sector (e.g., wage laborers) are more mobile, and may respond to the effects of delayed monsoon onset by seeking opportunities elsewhere. The third finding suggests that demographic responses to adverse conditions vary between Java and the outer Islands. Monsoon delays increase within-province mobility among residents of other islands, but do not have a statistically significant effect on such short-distance moves on Java. Although we are unable to identify the particular factors that underlie this regional difference in migration responses to monsoon delays, we speculate that regional differences in agriculture may explain apparent differences in the sensitivity to monsoon delays. Specifically, recall that rice production is concentrated on Java, and that it is also disproportionately irrigated. According to analysis of community-level data, nearly 60% of the rural IFLS communities on Java have technical irrigation, compared with just over one-third in rural IFLS communities outside of Java. A possible implication is that this region may be less sensitive to changes in rainfall timing relative to other parts of the country—and relative to the effects of temperature shocks, which cannot be regulated through technology.

Taken together, these results support a growing number of studies that identify climate effects on migration as multidimensional, heterogeneous, and inconsistent with simple narratives of increased migration under future climate change (Bohra-Mishra et al. 2014; Gray and Mueller 2012a; Gray and Mueller 2012b; Hunter et al. 2015; Jennings and Gray 2015; Mueller et al. 2014). Scholars and policymakers should eschew the assumption that poor households are passive victims of climate shocks who will readily give up their livelihoods to adopt long-distance migration. They must instead recognize these households to be strategic actors who have many options for *in situ* and local adaption and must navigate high barriers to long-distance, permanent migration. Future climate change will undoubtedly contribute to global population movements over coming decades, but the significance, direction and magnitude of these effects are unlikely to be consistent across the globe.

Appendix

Table A1

Coefficient estimates from multinomial logistic regression predicting out-migration, by destination

Independent variable	Specification AA		Specification AB		Specification AC	
	In-province	Out-province	In-province	Out-province	In-province	Out-province
Temperature[a]	−1.5457	−0.6883	−2.1877 +	−1.7086	−2.9360 **	−0.5509
Temperature[a] squared	−4.8919	1.9582	−4.7808	3.2029		
Precipitation[b]	−0.0012	0.0009			0.0010	0.0052
Precipitation[b] squared	−0.0001	−0.0002				
Monsoon onset delay[c]			0.0293 +	0.0198	0.0343 **	0.0346
Monsoon onset delay[c] squared			0.0016	0.0009		
N (person-periods)	27,194		27,914		27,194	
Joint test of climate vars. (Chi^2)	12.72 **	3.11	13.46 **	1.26	10.25 **	1.83
Psuedo R^2	0.1871		0.1873		0.1873	
Log pseudolikelihood	−9086.6417		−9084.5087		−9084.8202	

*** p<0.001,

** p<0.05,

[+] $p<0.1$

Values are coefficient estimates from a multinomial logistic regression

[a] Deviation of annual mean temperature from long-term mean (°C), 4 year mean

[b] Deviation of annual rainfall from long-term mean (cm), 4 year mean

[c] Monsoon onset delay (days), 4 year mean

All models also include community fixed effects and control variables listed in Tables 1 and 2

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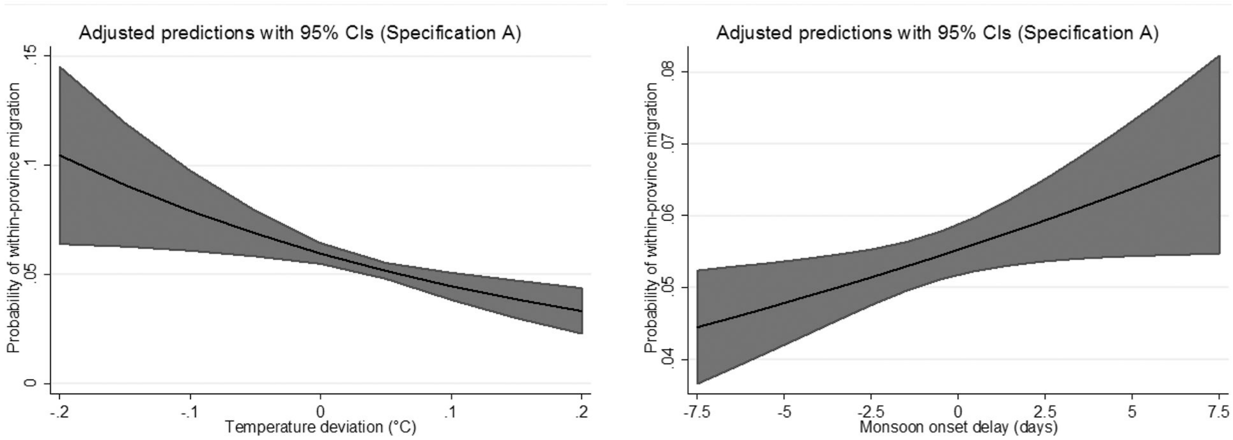

Figure 1.
Predicted probabilities of within-province migration

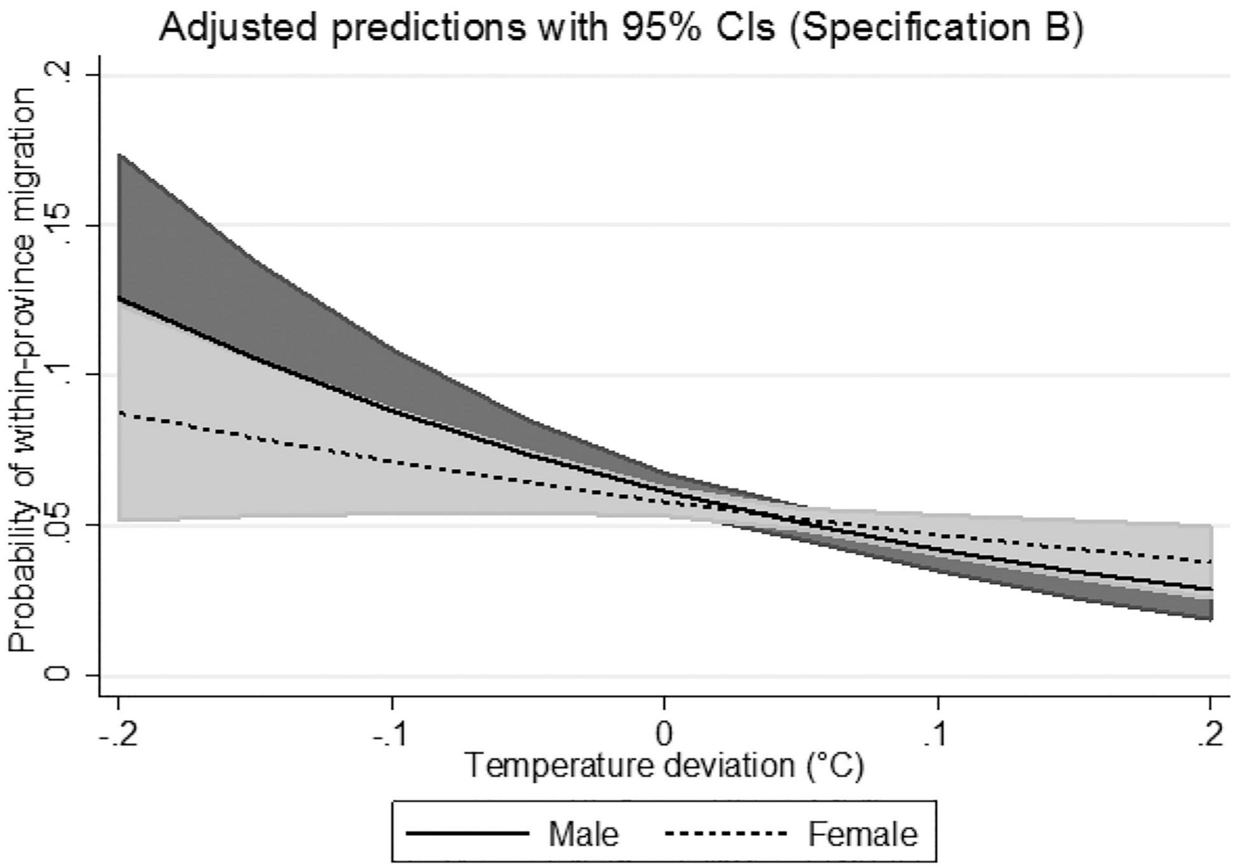

Figure 2.
Predicted probabilities of within-province migration, climate-gender interaction

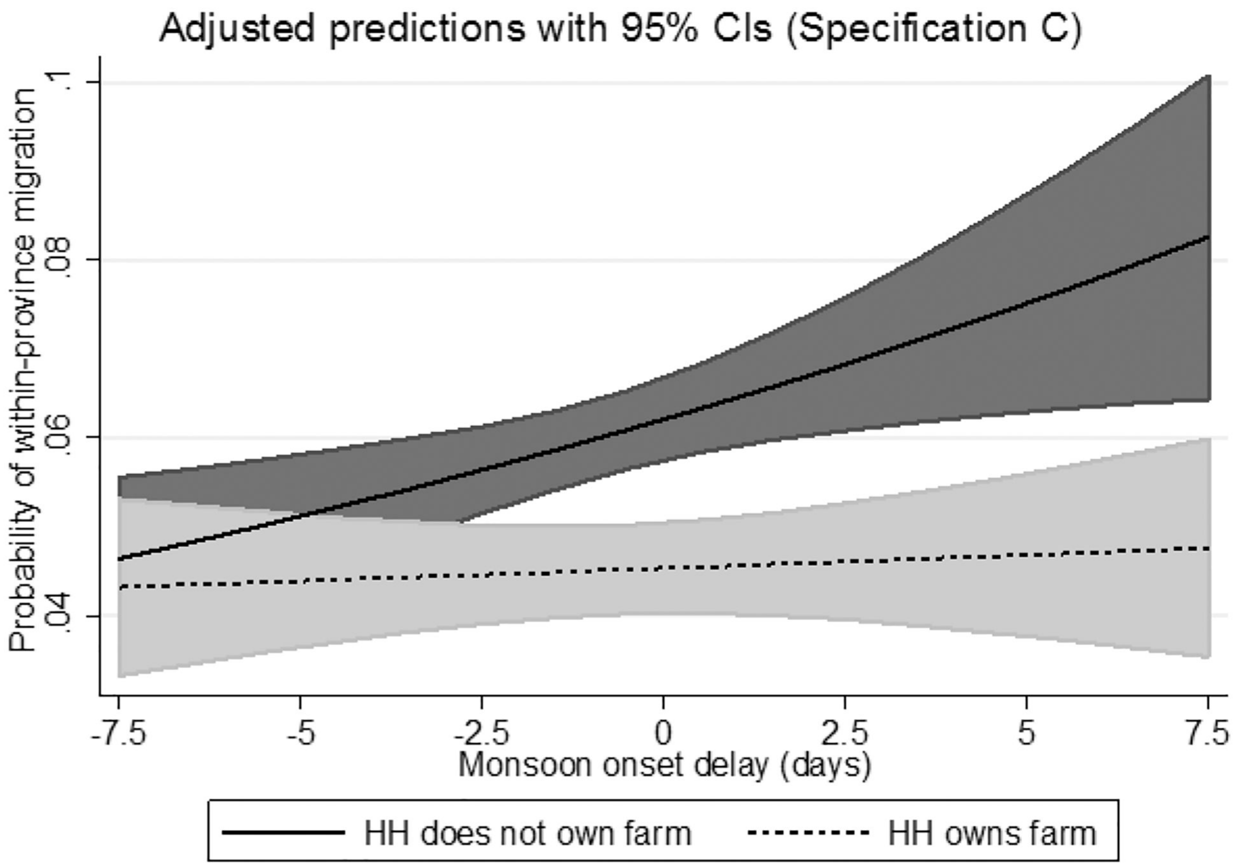

Figure 3.
Predicted probabilities of within-province migration, climate-livelihood interaction

Table 1

Summary of variables

Variable	Mean	SD	Min	Max
Migration				
No migration	0.884	-	0	1
Within-provinc e	0.096	-	0	1
Between-province	0.020	-	0	1
Temperature[b]	0.022	0.094	−0.204	0.321
Precipitation[c]	−2.256	23.743	−64.222	63.810
Monsoon onset delay[d]	−0.5	3.9	−12.2	7.5
Sex				
Female	0.563	-	0	1
Male	0.437	-	0	1
Age (years)	32.2	9.8	15	49
Education (years)				
0–6	0.569	-	0	1
7–11	0.229	-	0	1
12+	0.202	-	0	1
Marital status				
Unmarried or estranged	0.269	-	0	1
Married	0.731	-	0	1
Number of moves since age 12	0.7	1.4	0	17
Resides in same province as age 12				
Yes	0.902	-	0	1
No	0.098	-	0	1
Value of household assets[a] (1,000 rupiah)	26,633	77,730	0	2,243,000
Household owns non-farm business				
Yes	0.431	-	0	1
No	0.569	-	0	1
Household owns farm business				
Yes	0.394	-	0	1
No	0.606	-	0	1
Rural status				
Urban	0.473	-	0	1
Rural	0.528	-	0	1
Period				
1993/4–1997/8	0.266	-	0	1
1997/8–2000	0.370	-	0	1
2000–2004	0.365	-	0	1
Region				
East, Central, and West Java	0.441	-	0	1

Variable	Mean	SD	Min	Max
Other	0.559	-	0	1
Valid N (person-periods)			27,194	

[a]The natural log of the value of household assets (rupiah) is used in the regression analyses

[b]Deviation of annual mean temperature from long-term mean (°C), 4 year mean; mean (SD) 4 year mean temperature = 27.3°C (1.6°C)

[c]Deviation of annual rainfall from long-term mean (cm), 4 year mean; mean (SD) 4 year rainfall = 267.6 cm (57.3 cm)

[d]Monsoon onset delay (days), 4 year mean

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Table 2

Coefficient estimates from multinomial logistic regression predicting out-migration, by destination

Independent variable	Specification A	
	In-province	Out-province
Temperature[a]	−3.0477 **	−1.1712
Monsoon onset delay[c]	0.0304 **	0.0145
Sex		
Male		
Female	0.0076	-0.6047 ***
Age	-0.0693 ***	-0.0847 ***
Education (years)		
0–6		
7–11	0.4055 ***	0.1910
12+	0.6674 ***	0.4354 **
Marital status		
Unmarried or estranged		
Married	−0.5937 ***	−0.2774
Number of moves since age 12	0.2058 ***	0.2011 ***
Resides in same province as age 12		
Yes		
No	0.2267 **	1.2325 ***
Value of household assets (ln)	−0.0170	−0.0015
Household owns non-farm business		
No		
Yes	−0.1162 +	−0.3307 **
Household owns farm business		
No		
Yes	−0.2881 ***	−0.3833 **
Rural status		
Urban		
Rural	0.1646	−0.6681
Period		
1993/4–1997/8		
1997/8–2000	0.6867 ***	0.2094
2000–2004	0.8129 ***	0.7699 **
Constant	0.0555	1.8230
N (person-periods)	27,914	
Joint test of climate vars. (Chi^2)	10.35 **	1.14
Psuedo R^2	0.1872	

Independent variable	Specification A
Log pseudolikelihood	−9085.4487

*** p<0.001,

** p<0.05,

+ p<0.1

Values are coefficient estimates from a multinomial logistic regression

[a] Deviation of annual mean temperature from long-term mean (°C), 4 year mean

[b] Deviation of annual rainfall from long-term mean (cm), 4 year mean

[c] Monsoon onset delay (days), 4 year mean

All models also include community fixed effects

Table 3

Coefficient estimates from multinomial logistic regression predicting out-migration, summary of interaction models by destination

Independent variable	Specification B		Specification C		Specification D		Specification E	
	In-province	Out-province	In-province	Out-province	In-province	Out-province	In-province	Out-province
Temperature[a]	−3 9494 ***	−0.8301	−3.4171 ***	−1.4881	−4.5603 **	0.9958	−2.7774 **	−1.2624
Monsoon onset delay[b]	0.0369 **	0.0008	0.0409 **	0.0325	0.0813 **	0.1107	0.0313 **	0.0333
Female × temperature[a]	1.7301 ***	−0.7896						
Female × monsoon onset delay[b]	−0.0125	0.0314						
Household owns farm × temperature[a]			1.1812	0.5822				
Household owns farm × monsoon onset delay[b]			−0.0341 **	−0.0527				
Household wealth × temperature[a]					0.1001	−0.1280		
Household wealth × monsoon onset delay[b]					−0.0033	−0.0062		
Java × temperature[a]							−0.8212	2.1843
Java × monsoon onset delay[b]							0.0015	−0.0879 **
Sex								
Male								
Female	−0.0657	−0.5530 ***						
Value of household assets (In)					−0.0192	0.0020		
Household owns farm business								
No								
Yes			−0.3709 ***	−0.4806 **				
N (person-periods)	27,194		27,194		27,194		27,194	
Joint test of climate and interaction vars. (Chi^2)	22.38 ***	4.34	14 92 **	3.48	12.44 **	2.76	12.55 **	6.94
Joint test of interaction vars. (Chi^2)	11.55 **	3.41	4.68 +	1.81	2.18 **	1.24	1.23	6.15 **
Psuedo R^2	0.1878		0.1877		0.1874		0.1877	
Log pseudolikelihood	−9079.2601		−9080.3738		−9083.495		−9079.8141	

*** p<0.001,

** $p<0.05$,

+ $p<0.1$

Values are coefficient estimates from a multinomial logistic regression

[a] Deviation of annual mean temperature from long-term mean (°C), 4 year meanValues

[b] Monsoon onset delay (days), 4 year mean

All models also include community fixed effects and control variables listed in Tables 1 and 2

Table 4

Summary of household income (1,000 rupiah) by source

Income source[a]	Mean	SD
Farm business revenue	13,766	52,524
Non-farm business revenue	5,819	64,510
Agricultural labor	315	1,510
Non-agricultural labor	3,599	10,530
N (household-periods)	18,237	

[a]The natural log of the value of household assets (rupiah) is used in the regression analyses

Table 5

Coefficient estimates of OLS regression predicting household income, by source

Independent variable	Farm business revenue	Non-farm business revenue	Agricultural labor	Non-agricultural labor
Temperature[a]	2.3566 **	−0.6445	−0.8119	1.5970 **
Monsoon onset delay[b]	−0.0083	0.0298 **	−0.0036	0.0011
R^2	0.4697	0.2427	0.1626	0.2648
N (household-periods)		18,237		

*** p<0.001,

** p<0.05,

+ p<0.1

Values are coefficient estimates from a linear regression

[a] Deviation of annual mean temperature from long-term mean (°C), final year of period

[b] Monsoon onset delay (days), final year of period

All models also include community fixed effects and control variables