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SUPPLEMENTARY INFORMATION

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Heat stress increases long-term human migration in rural Pakistan

Our sample includes the households surveyed by the International Food Policy Research Institute (IFPRI) during its July 1986 – October 1991 Pakistan Panel Survey (*14*). We track members of households present in Round 14—the final, 1991 round. This survey selected the poorest district in each province by applying the district ranking methods of Pasha and Hassan (1982) to current information and district boundaries. The districts were: Attock in Punjab; Badin in Sindh; Dir in the North West Frontier Province (NWFP); and Kalat in Baluchistan (subsequently dropped for security reasons). Additionally, Faisalabad—a relatively prosperous district in Punjab—was selected as a comparison district. Within each district, two markets (mandis) were selected randomly. For each mandi, three lists of villages were prepared: those within 5 km, 5-10 km, and 10-20 km away. Villages were chosen randomly from these lists, and households were chosen randomly from a complete listing of the households in each village. We combine the 1991 data with data from tracking studies conducted in 2001 and 2012 to build an individual-level panel of migrating and non-migrating household members over a twenty-one-year period (1991-2012). The survey lacks sampling weights as it was not intended to be representative of the country or any province.

The Pakistan Institute of Development Economics (PIDE) conducted the 2001 tracking survey, collecting information on the timing of moves, destinations, and motivations for departure of each migrating, original member of the 1991 PRHS. IFPRI, in collaboration with Innovative Development Strategies (a survey firm based in Pakistan), followed suit by conducting a methodologically similar tracking study in 2012, using the same 1991 roster as a basis for tracking. During each tracking study, enumerators visited the same household surveyed in 1991 and tried to interview its head. If the head had died, the household containing his/her spouse was surveyed. If both were deceased, then the household containing the older son (or, if there was not one or he could not be found, the oldest unmarried daughter) was surveyed. If the entire household had migrated from the village since 1991, the enumerators asked relatives or neighbors to obtain the household's migration information.

It is important to note that few of the migrants who had left the household by 2001 were found in the household in 2012; 88.7% were still not present, while 11.3% had returned. Thus, most out-migrants appear to be truly long-term movers. Further, among those migrating to somewhere else in the same village as of 2001, only 2.9% migrated to somewhere outside of the village as of 2012.

We use the tracking information to develop a panel of migration patterns at the individual level over 1991-2012. The records of 689 households (of the 726 total PRHS households) were used as a basis for tracking, originating from 41 different villages in the Punjab, Sindh, and the NWFP. We lacked any information on 37 of the original PRHS households as the rosters from three full villages (one from Punjab, two from Sindh) were inadvertently destroyed before the tracking exercises. Thus, our sample includes only the 41 villages whose records were not destroyed. Of these 689 households, only some were found during each tracking exercise. In 2001, tracking of 672 households was attempted, and 638 households were successfully tracked and migration years recorded.[1] By 2012, security concerns made it more difficult to visit some

[1] Tracking of 17 households was not attempted due to random loss of selected records; thus, tracking of 672 households was attempted rather than tracking of all 689. Of these 672, 2 households refused to be interviewed, 22

areas and households often refused to be interviewed. 586 households were visited, though 37 households refused to be interviewed, 24 dwellings could not be found, and 3 dwellings were found but not currently occupied, leading to the successful tracking of only 522 households.

We restrict the panel to individuals at most risk of mobility to create a person-year dataset following previous work (*5-6, 15-18*). As migration rates in Pakistan are very low for individuals younger than 15 or older than 39, we consider these individuals as being at low risk of mobility and thus exclude them from the sample. Specifically, individuals are included in the dataset starting from baseline or when they reach age 15. They are excluded from the dataset after migrating or when they turn 40. Overall, the sample consists of 44,791 person-years, where 4,428 individuals are represented from 583 households.

Using the GPS coordinates collected in the 2012 tracking study, we link the person-year dataset to various secondary weather station and climate event data sources. From these secondary data sources, we construct numerous natural disaster variables at the village and province level. First, we extract daily precipitation and temperature data from the NASA-POWER data product, which were obtained from the NASA Langley Research Center POWER Project funded through the NASA Earth Science Directorate Applied Science Program. The NASA-POWER data are used to construct village-level weather variables: cumulative precipitation over the monsoon period (June-September), and the average temperature during the Rabi season (November-April). We include the average of the current and lagged values (*t* and *t-1*) of each weather variable in the regressions. Second, we create a province level variable which defines the severity of floods experienced in a given year according to the number of people reported as dead. The variable is based on global flood incidences reported from various sources and compiled by the Dartmouth Flood Observatory (*26*).

We further compute a moisture index using data from the NASA-POWER product, the Standardized Precipitation Evapotranspiration Index—SPEI (*19*). The SPEI uses monthly precipitation and temperature data to generate a continuous index over various time scales. We develop an index which measures the availability of water on the land surface over a twelve-month running period beginning in April—one of the hottest months of the year. The possible values of the index range from negative to positive, where negative values indicate dryness and positive values indicate wetness.

Descriptive statistics are shown (Supplementary Table 1). The sample is equally split between men and women, and people have an average age of 25 years. These individuals come from households with large numbers of dependents (seven children, on average), limited land and asset ownership, and low levels of education (the head has 3 years, on average). About 63% of households in the dataset own land, while about 43% own land with some form of irrigation (mostly from canals or wells). This suggests that more than two-thirds of landowners (68%) own some irrigated land, which reduces risks posed by low rainfall levels. Results for landowners, such as those in table 3, are therefore driven largely by irrigated land owners.

Migration rates are also rather low. Only 2.85 percent of men and 4.39 percent of women moved out of the household over twenty-one years. Movement is equally split between in-village and out-of village moves. For example, 1.51 percent and 2.13 percent of men and women,

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had moved but no tracking information of any kind could be obtained, 6 were temporarily away, and 4 had shifted nearby, limiting full tracking details to 638 households.

respectively, moved within the village compared to 1.34 percent and 2.25 percent of men and women who moved out of the village. The destinations of internal migrants (for those who reported specific addresses) are provided (Supplementary Figure 2). The map shows a strong inclination for migrants to stay within their district of origin or districts adjacent to their district of origin.

Supplementary Figures and Tables

Figure 1: Migration and Climate Trends

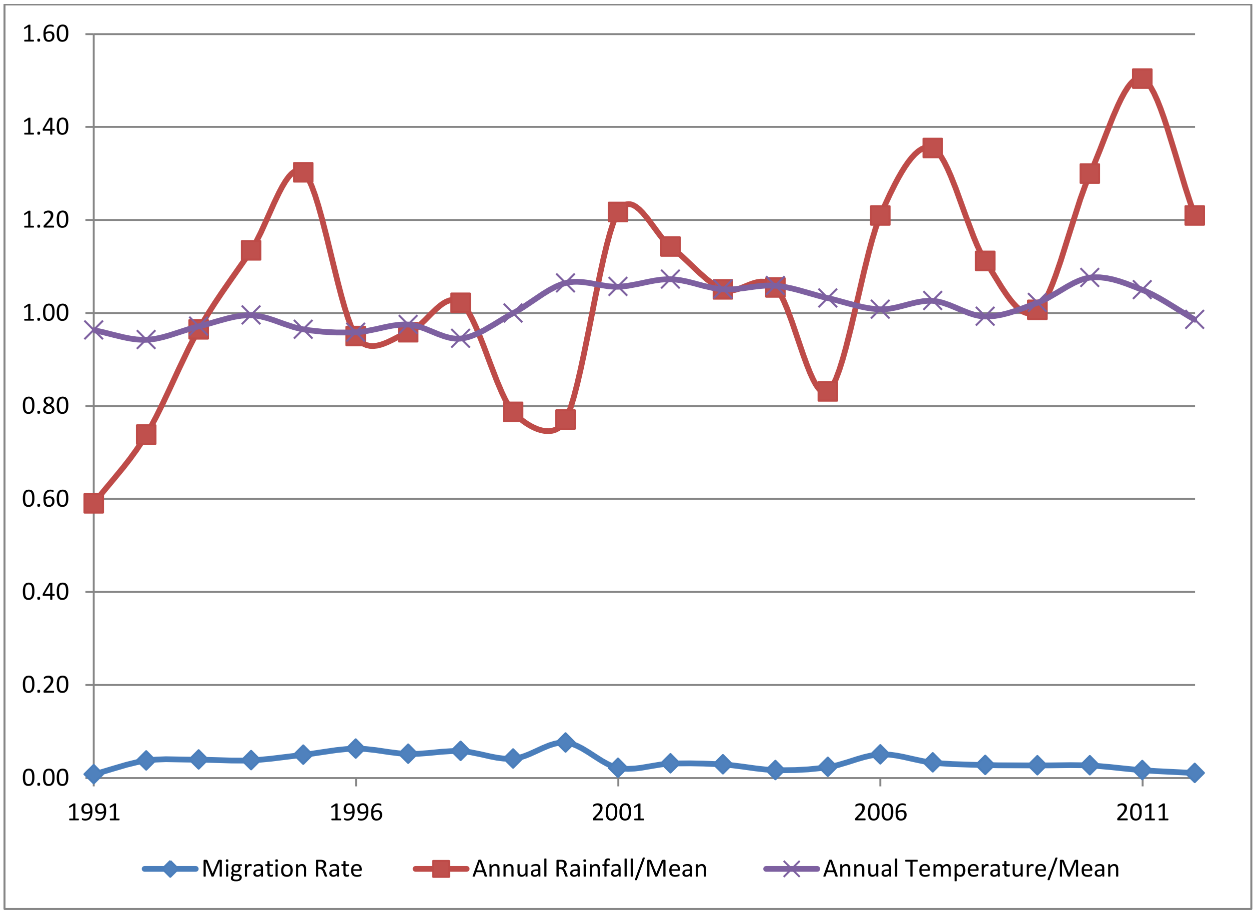
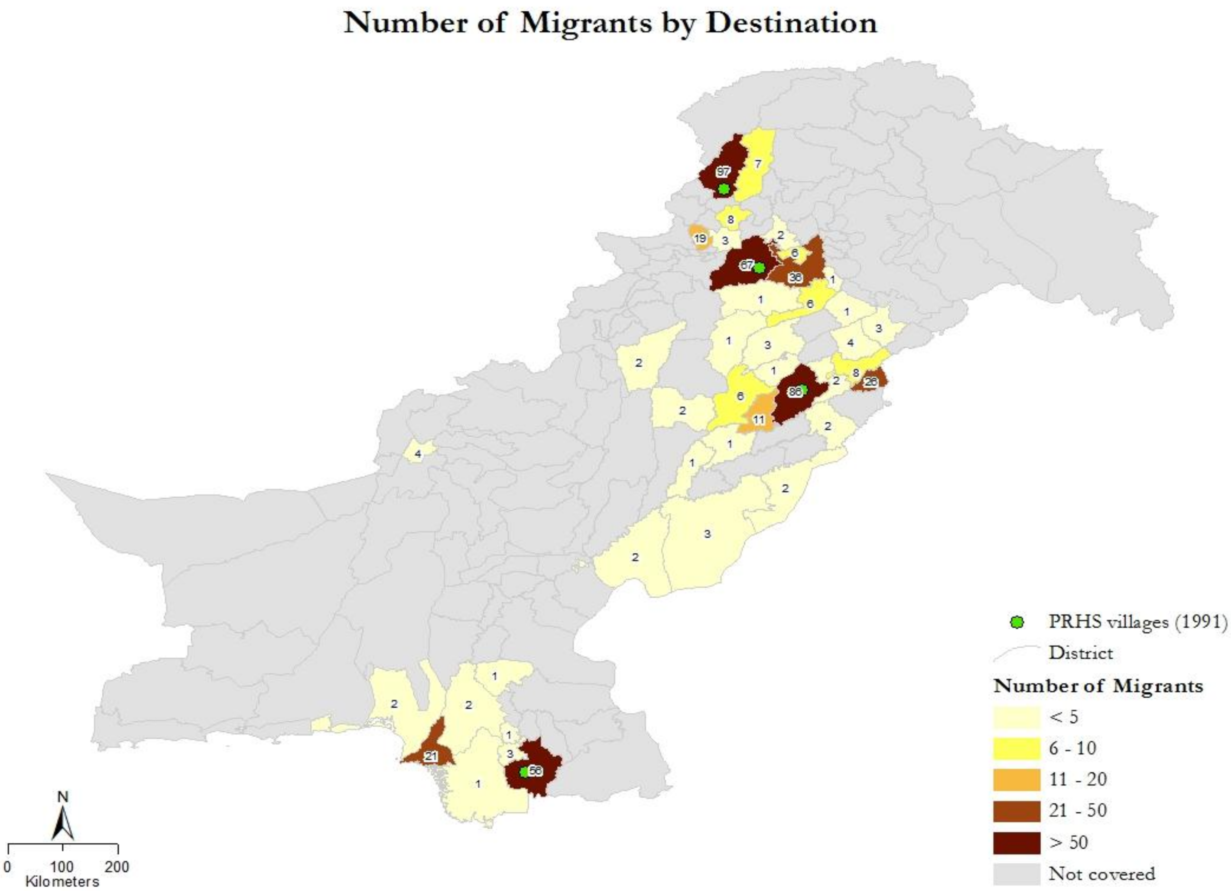


Figure 2: Number of Migrants of Original 1991 Pakistan Rural Household Survey Household Members, by Location of Move



Source: Pakistan Tracking Surveys 2001, 2012

Table 1: Descriptive Statistics of Individual, Household, and Climate Variables

	Unit	Level	Time-varying?	Mean	SD
Male	0/1	Individual	No	0.51	0.50
Age	#	Individual	Yes	24.78	6.83
Head or Spouse	0/1	Household	No	0.05	0.21
Female head	0/1	Household	No	0.01	0.11
Age of head	#	Household	No	48.05	13.62
Education of head	#	Household	No	3.01	4.11
Children	#	Household	No	6.86	4.10
Males ages 16 to 55	#	Household	No	2.65	1.69
Females ages 16 to 55	#	Household	No	2.61	1.54
Males ages > 55	#	Household	No	0.38	0.54
Females ages> 55	#	Household	No	0.32	0.54
Owned land	10 ha	Household	No	1.04	2.44
Total assets	10,000 rupees	Household	No	16.47	27.67
Percent of owned land irrigated	#	Household	No	0.38	0.45
Annual monsoon rainfall	100 mm	Village	Yes	2.98	1.00
Rainfall in 1Q	0/1	Village	Yes	0.19	0.40
Rainfall in 4Q	0/1	Village	Yes	0.27	0.44
Average temperature (Nov-Apr)	degrees Celsius	Village	Yes	17.47	6.18
Temperature in 1Q	0/1	Village	Yes	0.25	0.43
Temperature in 4Q	0/1	Village	Yes	0.30	0.46
Moisture index	Positive values indicate wet, negative values indicate dry	Village	Yes	-0.00	0.65
Flood intensity	100s of deaths	Province	Yes	2.81	5.09
Person-years	44,791				

Table 2: Complete Regression Results for Specification C

	Men						Women					
	Logit Move		Multinomial logit Distance of move				Logit Move		Multinomial logit Distance of move			
			In-village		Out-of-village				In-village		Out- of-village	
Age	1.05	***	1.07	***	1.03	***	1.00		1.00		1.00	
Head or Spouse	0.29	***	0.12	***	0.40	**	0.19	***	0.11	***	0.28	
Female head	0.42	***	0.63	*	5.44E-07	***	0.82		0.61		1.35	
Age of head	0.99		1.00		0.99		0.99		1.00		1.00	
Education of head	0.95	**	0.94	**	0.97		0.99		0.98		1.00	
Children	1.06	***	1.04	*	1.09	**	1.07	***	1.08	***	1.06	**
Males ages 16 to 55	1.07		1.07		1.06		0.95		1.02		0.87	**
Females ages 16 to55	1.03		1.15	**	0.88		1.05		1.03		1.06	
Males ages > 55	1.16		0.92		1.57	**	0.99		1.04		0.97	
Females ages> 55	0.72	***	0.92		0.48	***	0.91		0.98		0.82	
Owned land	0.98		0.96		0.99		0.95	**	0.99		0.90	
Total assets	1.00		1.00		1.00		1.00		1.00		1.00	
Percent of owned land irrigated	0.74	**	0.72	**	0.79		0.86		0.93		0.78	
Rainfall in 1Q	1.47		1.51		1.57		1.13		0.99		1.36	
Rainfall in 4Q	0.82		0.84		0.81		1.20		1.20		1.30	
Temperature 1Q	0.84		1.02		0.68		0.83		0.80		0.84	
Temperature 4Q	5.09	***	2.83	***	11.16	***	1.85	***	1.82	***	2.19	**
Joint tests												
Village fixed effects	9.8E+07	***	5.9E+04	***			2.8E+07	***	7.6E+05	***		
Time fixed effects	777	***	1.8E+04				264	***	2.9E+08	***		
Individuals	2,125		2,147				2,303		2,303			

Inverse probability weights constructed from model in S7. *** p<0.01, ** p<0.05, * p<0.1. Odds ratios and statistical significance reported. Village and time fixed effects included.

Table 3: Predicted Probabilities for Temperature and Rainfall Scenarios, Specification C

Exposure to temperature	All moves (%)		Within-village moves (%)		Out-of-village moves (%)	
Men						
Temperature IQR, Rainfall IQR (reference)	0.02	***	0.01	***	0.01	***
Temperature IQR, Rainfall Q1	0.03	***	0.02	***	0.02	***
Temperature IQR, Rainfall Q4	0.02	***	0.01	***	0.01	**
Temperature Q1, Rainfall IQR	0.02	***	0.01	***	0.01	***
Temperature Q4, Rainfall IQR	0.09	***	0.03	***	0.09	**
Temperature Q1, Rainfall Q1	0.03	***	0.02	***	0.01	***
Temperature Q1, Rainfall Q4	0.02	***	0.01	***	0.01	**
Temperature Q4, Rainfall Q1	0.13	***	0.04	**	0.12	*
Temperature Q4, Rainfall Q4	0.08	***	0.02	***	0.07	*
Women						
Temperature IQR, Rainfall IQR (reference)	0.04	***	0.02	***	0.02	***
Temperature IQR, Rainfall Q1	0.04	***	0.02	***	0.02	***
Temperature IQR, Rainfall Q4	0.05	***	0.02	***	0.02	***
Temperature Q1, Rainfall IQR	0.03	***	0.02	***	0.02	***
Temperature Q4, Rainfall IQR	0.07	***	0.03	***	0.04	***
Temperature Q1, Rainfall Q1	0.04	***	0.02	***	0.02	***
Temperature Q1, Rainfall Q4	0.04	***	0.02	***	0.02	***
Temperature Q4, Rainfall Q1	0.08	***	0.03	***	0.05	***
Temperature Q4, Rainfall Q4	0.08	***	0.04	***	0.05	***

*** p<0.01, ** p<0.05, * p<0.1.

Table 4: Probability of an individual remaining in the sample from 1991 to 2012

	Coefficient	Standard Error	P value
Respondent characteristics (in 1991)			
Male	0.028	0.035	0.425
Born in 1972-1981	-0.347	0.072	0.000
Born in 1962-1971	-0.515	0.061	0.000
Born in 1952-1961	-0.453	0.076	0.000
Household characteristics (in 1991)			
Household head's education	0.006	0.006	0.338
Value of assets (10,000 Rupees)	0.002	0.001	0.073
Household size	-0.025	0.007	0.000
Resident in Northwest Frontier Province	0.153	0.053	0.004
Survey variables			
Village attrition excluding respondent	-2.884	0.128	0.000
Interviewer 2	0.327	0.274	0.233
Interviewer 3	-0.072	0.297	0.808
Interviewer 4	0.185	0.289	0.521
Interviewer 5	0.037	0.286	0.897
Interviewer 6	0.110	0.268	0.680
Interviewer 7	0.608	0.308	0.049
Interviewer 8	-0.772	0.285	0.007
Interviewer 9	0.083	0.299	0.782
Interviewer 10	0.384	0.315	0.223
Interviewer 11	0.283	0.310	0.361
Observations	8,376		

Standard errors are clustered at the village level.

Village attrition is calculated using the attrition dummy values for all of the individuals sampled from a given village excluding the individual *i* for whom we are calculating the attrition variable value. This assures that the variable is exogenous to the individual.

Table 5: Specifications in Table 1 substituting Five-Year for One-Year Time Fixed Effects

	Men						Women					
	Logit		Multinomial logit				Logit		Multinomial logit			
	Move		Distance of move				Move		Distance of move			
			In village		Out of village				In village		Out of village	
Specification A												
Rainfall	1.03		1.03		1.04		1.10		1.10		1.10	
Temperature	1.63	**	1.61	**	1.65	*	1.48	***	1.59	***	1.39	**
Joint test of variables	6.78	**	7.99	*			13.06	***	13.61	***		
Specification B												
Rainfall	0.82		1.73		0.28	**	1.04		1.34		0.73	
Temperature	1.60	**	1.67	***	1.44		1.48	***	1.61	***	1.33	*
Rainfall × Temperature	1.01		0.97	*	1.08	**	1.00		0.99		1.02	
Joint test of variables	7.10	*	16.79	**			13.89	***	17.38	***		
Specification C												
Rainfall in 1Q	1.54	*	1.39		1.81	**	1.00		0.95		1.09	
Rainfall in 4Q	1.17		1.22		1.15		1.09		1.08		1.13	
Temperature 1Q	0.97		1.04		0.91		0.95		0.95		0.96	
Temperature 4Q	3.49	***	2.14	***	7.85	***	2.01	***	1.76	***	2.50	***
Joint test of variables	29.39	***	40.18	***			44.80	***	49.80	***		
Specification D												
Flood	1.00		0.99		0.99		1.00		0.98		1.02	
Temperature	1.65		1.64	***	1.67	*	1.48	***	1.62	***	1.33	*
Joint test of variables	6.57	**	7.53				11.31	***	13.17	**		
Specification E												
Moisture index	0.66	***	0.64	***	0.70		0.77	***	0.69	***	0.87	
Individuals	2,125		2,147				2,303		2,303			

Inverse probability weights used. *** p<0.01, ** p<0.05, * p<0.1.

Odds ratios and statistical significance reported in the table.

Table 6: Specifications in Table 1 Differentiating Current and Lagged Weather

	Men						Women					
	Logit Move		Multinomial logit Distance of move				Logit Move		Multinomial logit Distance of move			
			In village		Out of village				In village		Out of village	
Specification A												
Rainfall *t*	1.13		0.89		1.55	*	1.21	***	1.18		1.24	*
Rainfall *t-1*	1.14		1.07		1.24		0.96		1.01		0.90	
Temperature *t*	1.99	***	2.16	***	1.79		1.56	***	1.90	***	1.26	
Temperature *t-1*	1.38		1.15		1.63		1.23		1.12		1.35	
Joint test of variables	19.99	***	35.58	***			41.28	***	52.79	***		
Specification B												
Rainfall *t*	1.07		1.19		0.89		1.28		1.47	*	1.00	
Rainfall *t-1*	1.01		1.56		0.58		0.82		1.07		0.59	
Temperature *t*	1.95	***	2.30	***	1.53		1.54	***	1.91	***	1.16	
Temperature *t-1*	1.37		1.19		1.58		1.23		1.13		1.31	
Rainfall *t* × Temperature *t*	1.00		0.99		1.03		1.00		0.99		1.01	
Rainfall *t-1* × Temperature *t-1*	1.01		0.98		1.03	**	1.01		1.00		1.02	*
Joint test of variables	27.82	***	44.26	***			44.61	***	68.17	***		
Specification C												
Rainfall in 1Q *t*	0.90		0.74		1.22		0.75	*	0.58	***	1.06	
Rainfall in 1Q *t-1*	0.79		1.26		0.48	**	1.06		1.13		1.00	
Rainfall in 4Q *t*	0.54	***	0.59		0.51	**	1.14		1.23		1.07	
Rainfall in 4Q *t-1*	1.05		0.76		1.44		0.98		0.83		1.18	
Temperature 1Q *t*	0.63		1.08		0.34	***	0.95		0.93		0.97	
Temperature 1Q *t-1*	1.69		0.93		3.27	*	1.01		0.75		1.60	
Temperature 4Q *t*	2.53	***	1.87		3.34	**	1.52	*	1.64		1.39	
Temperature 4Q *t-1*	0.98		1.01		0.94		1.00		1.10		0.86	

	Men						Women					
	Logit		Multinomial logit				Logit		Multinomial logit			
	Move		Distance of move				Move		Distance of move			
			In village		Out of village				In village		Out of village	
Joint test of variables	34.93	***	50.24	***			15.71	**	44.50	***		
Specification D												
Flood *t*	0.99		0.99		0.98		0.98		0.99		0.98	
Flood *t-1*	0.98		0.97		0.98		0.99		0.97	**	1.01	
Temperature *t*	2.08	***	2.21	***	1.95		1.71	***	2.04	***	1.38	
Temperature *t-1*	1.46	**	1.25		1.73	**	1.21		1.12		1.28	
Joint test of variables	19.59	***	32.33	***			20.05	***	35.26	***		
Specification E												
Moisture index *t*	0.89		0.72	**	1.12		0.88	*	0.74	***	1.03	
Moisture index *t-1*	0.80	**	0.98		0.65	**	0.86		0.87		0.83	
Joint test of variables	4.00		10.81	**			5.95	*	12.93	**		
Individuals	2,125		2,147				2,303		2,303			

Inverse probability weights used. *** p<0.01, ** p<0.05, * p<0.1.

Odds ratios and statistical significance reported in the table.

Table 7: Specification C Logit Model with Grouped Bootstrapping Method

	Men		Women	
	Logit Move		Logit Move	
Rainfall in 1Q	0.22		0.10	
Rainfall in 4Q	-0.22		0.11	
Temperature 1Q	-0.18		-0.16	
Temperature 4Q	1.42	**	0.59	*
Person-years	22,860		21, 931	

Standard errors are taken from the grouped bootstrap method using 200 repetitions.

*** p<0.01, ** p<0.05, * p<0.1.