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Temperature shocks, rice production, and migration in Vietnamese households

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ABSTRACT

This paper analyses the relationship between temperature shocks and migration in rural households in Viet Nam. To control for the potential endogeneity between crop production and migration we use monthly minimum temperatures in the growing season as an instrument of rice production. In this way, we exploit a relationship uncovered in the natural science. Results show that the rise in minimum temperature during the core month of the growing season (i.e. June) does cause a reduction in rice production which, in turn, has a positive impact on people's propensity to migrate. This finding, which is robust to the use of different estimators and plausible violations of the exogeneity of the instrument, supports the 'agricultural channel' between climate shocks and migration by highlighting a specific feature at work in a rice-producing country.

1. Introduction

In South Asia, climate-induced migration has become an issue: recent estimates suggest that "internal climate migrants" could number over 40 million, 1.8% of the region's total population (Rigaud et al., 2018). This paper delves into this issue by investigating the relationship between climate-related shocks and migration in rural households in Viet Nam.

According to Dasgupta et al. (2007), Viet Nam is one of the countries highly affected by climate variations and shocks. Given a 1-m sea-level rise, Viet Nam would be the most affected developing country in terms of population (10.8%), GDP (a 10% reduction), and wetlands inundated (28%). Many Vietnamese households have climate-sensitive livelihoods: the share of employment in agriculture out of total employment was around 44% in 2015 and agriculture still accounted for a significant part of GDP, about 20%, in the same year (World Development Indicators).[1] According to UNESCO (2018), 13.6% of the Vietnamese population are internal migrants. This proportion is higher for the urban (19.7%) than the rural population (13.4%). This significantly outstrips international migration in the country, with total inflows and outflows of international migrants amounting to only 2.9% of the population. The International Organization for Migration (2017) reported that in 2016, approximately 6 million people left and nearly 6 million people entered the country.

The stream of literature relating migration and climate change is quite lively: the main hypothesis is that climate variations may dramatically affect the livelihood of individuals, thus, leaving them with no other choice but to migrate. Evidence for this hypothesis has been provided in many studies (Dell et al., 2014; Bohra-Mishra et al., 2014; Mueller et al., 2014; Gray and Mueller, 2012). The results, however, involve a number of difficulties and contingencies (Thiede et al., 2016). The main challenge in this field is the identification of the causal mechanism by which climate variations impact on an individual's decision to leave.

In this paper we bring evidence in favor of the "agricultural channel"

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[1] https://data.worldbank.org/products/wdi

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(Feng et al., 2010; Cattaneo and Peri, 2016; Cai et al., 2016; Falco et al., 2019).[2] Within this literature, our contribution, instead of using a generic measure of climate variation such as the mean temperature (Burke et al., 2009; Feng et al., 2010), claims that the relevant measure for a rice-producing country is the minimum temperature, an assertion based on the natural science literature (Caruso et al, 2016). In our opinion, what is lost in terms of generality (by analyzing a single country), is offset in terms of uncovering the specific channel in place, which may also be relevant for policy recommendations and interventions.

The instrumental variable approach has been adopted in the literature (Feng et al., 2010; Kubik and Maurel, 2016; Falco et al., 2019) both to solve the endogeneity between crop production and migration and to estimate the effect of climate variations on migration through the causal mechanism of agricultural productivity. In our work, we use exogenous deviations in monthly minimum temperatures in the growing season as an instrument of rice production. Our analysis also includes some controls for specific socio-economic household conditions. We find that the rise in the minimum temperature during the core month of the growing season (i.e. June) does cause a reduction in rice production which, in turn, has a positive impact on people's propensity to migrate.[3] This finding is robust to the use of different estimators.

The paper is organized as follows. Section 2 sets out some background data on rice production in Viet Nam, while section 3 is devoted to three short literature reviews, the first concerning climate change and migration, the second on the effect of climate change on rice production and the third on climate change and migration in Viet Nam. Section 4 explains the empirical strategy used to analyze the impact of temperature shocks on migration and introduces the data, while section 5 provides the results. Section 6 concludes.

2. Rice production in Viet Nam[4]

Viet Nam is the world's fifth-largest rice-producing country, with a production that increased from 25 million tons in 1995 to 43.6 million tons in 2016. This increase is due both to the expansion of the rice-growing area and to a higher yield. Specifically, the yield increased from 3.7 t/ha in 1995 to 5.6 t/ha in 2010. The yield has increased because of modern varieties put into production, the more intensive use of fertilizers and improvements in irrigation. The rice production area expanded from 6.8 million ha in 1995 to 7.7 million ha in 2016, but annual growth was only 0.2% from 2005 to 2016. Viet Nam is the world's fourth-largest rice exporter. The country's rice exports reached 5.3 million tons in 2005 and 6.5 million tons in 2015, generating US$1.4 billion and contributing to 10.3% of total global rice exports.

Rice is still the staple food, with average annual per capita consumption rising from 138.8 kg in 1995 to 141.2 kg in 2009, but the share of total calories per person obtained from rice decreased from 66.6% (1407 kcal) per day in 1995 to 51.7% (1390 kcal) per day in 2009. A similar trend is in place for per capita protein intake, which now amounts to about 40% of daily consumption.

The Mekong River Delta produces most of Viet Nam's rice, which is also cultivated in the Red River Delta, northeast, and along the north-central coastline. The Mekong Delta has three cropping seasons: spring or the early season; autumn or the midseason; and winter, the long-duration wet-season crop.

3. Literature

This section illustrates the three streams of literature to which this paper contributes. First, we review the literature on climate change and migration, second, we focus on the natural science literature concerning the effect of climate variations on rice production and then we look at the relationship between climate change and migration in Viet Nam.

3.1. Climate change and migration

The standard migration literature distinguishes between network, pull, and push forces (e.g., Borjas, 1994; Martin and Widgren, 2002). Economic push forces include high unemployment and underdevelopment, while the opposites are pull forces. Sociopolitical push forces include war and persecution, whereas pull forces include peace and family unification. Reuveny (2007) argues that people cope with environmental problems in one of three ways: stay in place and do nothing; stay in place and mitigate the consequences, or leave affected areas. The choice between these options depends on the perceived net benefits and mitigation capabilities.[5] In developed countries, mitigation occurs through technological innovation, whereas less developed countries find mitigation more problematic because they lack both wealth and expertise. In this sense, migration is an extreme form of adaptation.

In the last ten years, this stream of literature has grown substantially; interested readers can go to Millock (2015) and Berlemann and Steinhardt (2017) for detailed surveys, while here we consider some issues that have emerged in the scholarship that are relevant for our work.

There are two approaches, one macro, based on international datasets including (often) dyadic data on migration, which tend to employ gravity-like models. The second approach is micro in nature and uses survey data. The empirical literature has addressed international and internal migration, yielding similar results. Most of the studies find that rising temperatures have a significant impact on both types of migration. This is particularly true in agriculture-dependent countries, via a reduction in wages and agricultural productivity. A partial difference involves excess precipitations, which are more relevant for internal migration, although weaker, when jointly controlled for, than the effect of temperature. However, these effects are small compared with other causes of migration, and, likely, mainly concern migration between and within African countries.

Estimations involve a number of covariates. The main group of right-hand side variables considers the labor market channel one of the reasons to decide to migrate: climate change affects job opportunities, and people may react by leaving their current place. Income and wages are usually included in the regressions to capture this effect. However, they may be so badly affected by climate-related shocks that individuals become credit-constrained and therefore unable to collect money to migrate. Ignoring these direct and indirect effects risks drawing

[2] In our case, a temperature shock affects rice production, the main crop in Viet Nam, and in turn, this modifies the individual's set of economic opportunities. A reduction in the supply of rice brings about an increase in the cost of rice for consumers (therefore reducing their real income), a reduction in the output of small landowners who suffer a fall in their income and possibly higher expenditure for fertilizers and irrigation to cope with the reduced output; in addition the demand for workers involved in rice production may fall causing lower wages and unemployment. All these events may lead to migration. Black et al. (2011) provide a framework in which, besides income and the environment, other factors such as politics, demography and society, affect migration. These factors are accounted for as covariates.

[3] The exploitation of this specific channel goes in the direction of the methodological innovations advanced by Hsiang (2016).

[4] Data for this section are drawn from Global Rice Science Partnership (2013) and the General Statistics Office of Viet Nam (2017).

[5] The International Organization for Migration (2009) defines environmental migrants as 'persons or groups of persons who, for compelling reasons of sudden or progressive change in the environment that adversely affects their lives or living conditions, are obliged to leave their habitual homes, or choose to do so, either temporarily or permanently, and who move either within their country or abroad'.

mistaken conclusions about the relationship between climate shocks and migration (Beine and Parsons, 2017).[6] Other controlling groups include institutions (in international analyses) and conflict.

A key issue in the study of the relationship between climate variations and migration is that the specific channel by which climate affects migration is identified only in a few countries. Some of these studies focus on the impact that climate-induced variation has on agricultural productivity. Cai et al. (2016) find a positive and statistically significant relationship between temperature and international outmigration only in the most agriculture-dependent countries, consistent with the adverse impact of temperature on agricultural productivity. Falco et al. (2019) find that negative shocks to agricultural productivity caused by climate fluctuations significantly increase emigration from developing countries, with a strong impact in poor countries but less so in middle-income countries. To provide a causal interpretation they use a 2SLS approach in which climate variables are firstly regressed on agricultural output, then the predicted agricultural outcomes from this first stage regression are used as instruments in the second stage migration equation. At the micro level, Kubik and Maurel (2016) use an IV approach to analyze migration in Tanzanian households. They find that a 1% reduction in agricultural income induced by weather shock increases the probability of migration by 13% in the following year, an effect holding only for middle-income households.

3.2. Rice and climate change

Even without an increasing trend, temperature variability reduces crop production (Wheeler et al., 2000). The natural science literature suggests that variations in minimum temperature negatively affect cereal production because they increase the maintenance respiration requirement of the crops and shorten the time to maturity, thus reducing net growth and productivity.[7] Peng et al. (2004) analyzed weather data from 1979 to 2003 to examine temperature trends and the relationship between rice yield and temperature by using data from irrigated field experiments at the International Rice Research Institute Farm. They report that mean annual maximum and minimum temperatures have increased by 0.35 °C and 1.13 °C, respectively, and that grain yield declined by 10% for each 1 °C increase in growing-season minimum temperature in the dry season, whereas the effect of maximum temperature on crop yield was insignificant. Welch et al. (2010) studied 277 farm-managed rice fields in six major producer countries finding that temperature and radiation had statistically significant impacts during both the vegetative and ripening phases of the rice plant. Higher minimum temperatures reduced yield, whereas higher maximum temperatures raised it. Overall, this would result in a net negative impact on yield from moderate warming because prior research indicates that the impact of maximum temperature becomes negative at higher levels.

However, studies focusing on China (Huang et al., 2013; Deng et al., 2010; Zhang et al., 2010) find that an increase in temperatures increases rice yields. This contradiction exists since global warming may raise yields in cooler climates and lower them in warmer ones (Grant et al., 2011). The aggregate world effect in the period 1961–2002, as estimated by Lobell and Field (2007), is negative but close to zero, given the different impacts across countries.[8] Extending the dataset until 2008, Lobell et al. (2011) claim that global warming slightly reduces rice yields in Viet Nam. Finally, there is evidence that minimum temperature has increased approximately three times as much as the corresponding maximum temperature from 1951 to 1990 over much of the Earth's surface (Karl et al., 1991), which puts more weight on this indicator.

Overall, these pieces of evidence point towards a major role for a minimum temperature in determining rice production, and a negligible role for maximum temperature. In the remainder of the paper, therefore, we will employ the former in our specifications, whereas the latter will be used in a robustness check.

3.3. Climate change and migration in Viet Nam

A small stream of literature has addressed climate change and natural disasters in Viet Nam. As far as migration is concerned, there is some support for the relationship between climate change and the decision to migrate.

Gröger and Zylberberg (2016) use high-precision satellite data to identify variations in the flooding caused by a catastrophic typhoon and match them to household panel data before and after the shock. The resulting drop in income causes rural households to migrate to urban areas. Non-migrant households react by sending new members away to provide remittances. Koubi et al. (2016a, 2016b) stress the role of perceptions. They find that sudden-onset environmental events, such as floods or typhoons, increase the likelihood that individuals opt to move whereas longer-term environmental problems, such as drought or salinity, reduce the likelihood of migration. They interpret this finding as adaptation to long-term environmental events, since individuals are socially and economically bound to their location. Berlemann and Tran (2020) employ commune-level data from Viet Nam and find that episodic droughts and flood events tend to cause emigration from the affected communes. While droughts cause primarily temporary migration, flood events tend to induce permanent moves out of the affected regions. The perception that drought or flood events have become more severe leads to systematically higher emigration. Episodic typhoons or worsening typhoon trends have no significant effect in either the short- or long-run. Dun (2011) shows that unusually large flooding events in the Mekong Delta region, adversely impacting the lives and livelihoods of local communities, can trigger household or individual migration and are a cause for government-initiated resettlement of households.

4. Data and empirical specification

4.1. Method and estimation

We adopt a two-stage least square (2SLS) approach. The motivation behind its use is threefold. First, it addresses the endogeneity between migration and rice production due to reverse causality between the two variables. Variations in migration may affect agricultural production and vice versa. By instrumenting rice production appropriately in the first stage, however, a causal link can be established from rice production to migration. Second, the adoption of 2SLS formally models our assumption that climate-induced changes have an indirect effect on migration through their negative impact on agriculture output. In the second stage, the predicted values of rice production from the first stage are used to regress migration on only the part of rice production that is explained by climate variations. This procedure identifies the specific channel by which climate-induced migration occurs in Viet Nam. Third, omitted variables (such as irrigation) and measurement errors (possibly in the quantities of some of the covariates) may play a role in our model, making our estimates biased. For example, omission of a relevant variable is likely to inflate the effect of some others: if we omit irrigation, other variables positively related to production (such as the use of fertilizers and pesticides) can be expected to be biased upwards.

In the first stage, we use the deviation of minimum temperature during the rice-growing season as an instrument for rice production. This variable indicates by how much a particular month was warmer or

[6] In the macro-economic growth literature, this problem is known as the ‘over controlling problem’ (Dell et al., 2014), while the micro-economic literature refers to ‘bad controls’ (Angrist and Pischke, 2009).

[7] On this point and for a more general survey of the agronomic aspects of rice production and climate change, see Hatfield et al. (2011) and Wassmann et al. (2009).

[8] It is interesting to note that the effects of the increase in minimum temperature may have a positive effect on wheat production (Nicholls, 1997); therefore it is important to focus on the correct climate indicator/crop bundle.

colder than the average monthly temperature. The use of this instrument is in line with what is described in the scientific literature about rice and climate change which claims, as stated in section 3.2, that shocks at this stage of the process affect future crops harshly. The core of the growing period is from May to July. In particular, we use deviations recorded in June because in Viet Nam it is in the middle of the growing phase, when rice is more vulnerable to shocks. Stunted growth during this phase typically results in further delays in the following seasons, and in some cases leads to the outright failure of the harvest. Formally, our 2SLS model is illustrated in Eqs. (1) and (2) below:

$$Rice_{it-2} = \beta_0 + \beta_1 Dev\ min\ temperature\ June_{jt-2} + \beta_2 X_{it-2} + a_r + y_t + u_{it} \quad (1)$$

$$Migration_{it} = \beta_0 + \beta_1\ Rice_{it-2} + \beta_2\ X_{it-2} + a_r + y_t + \varepsilon_{it} \quad (2)$$

Here, $Rice_{it-2}$ is the quantity of rice produced by households (the subscript i indicates the household). *Dev min temperature June*$_{jt-2}$ is the deviation in minimum June temperature in the grid where the household is located (the subscript j indicates the grid cell for which we have climate data). Migration is a dummy variable indicating with 1 if the household has at least one component who has left for work, and 0 otherwise. Both the first stage and the second stage include a vector of controls X_{it-2} as well as time and regional fixed effects respectively y_t and a_r, u_{it} and ε_{it} are the error terms. Time fixed effects control for those factors that could impact both agriculture and migration trends. Regional fixed effects capture unobservable time-invariant regional specific factors that could influence productivity in the rice fields such as other climatic factors, the use of different technologies and geography.

Rice production (and consequently the deviations), and the covariates are lagged. Specifically, to describe migration in 2016, we use variables from 2014; for migration in 2014 we use factors from 2012, and so on. This choice is due to the retrospective nature of our dependent variable. When questioned about migration, the interviewee is asked if the household has a member who left in the last two years. In this case, the migration occurred before the interview was carried out. Therefore, migration should be explained by factors that occurred years before the interview.

Since our dependent variable is binary, using a TSLS estimator corresponds to estimating a linear probability model (LPM) with instrumental variables. This model is commonly applied in economics (Wooldridge, 2002). As suggested by Angrist and Pischke (2009), it provides good approximations for marginal effects which are similar to estimates resulting from a non-linear model. The use of LPM, however, is subject to many criticisms and alternative estimators are usually adopted (Lewbel et al., 2012). In section A.1 in the appendix, we delve into this issue and adopt different approaches to check the robustness of our results.

4.2. Data

Our dataset uses a balanced version of the VARHS household dataset,[9] which includes only the families continuously interviewed over the period 2010–16. The year 2008 was dropped since data on migration were collected from 2012; as regressors lagged variables at 2010 are used. The resulting dataset contains 2088 households living in 459 communes. Fig. 1 maps the communes involved in our analysis. Table 1 reports the summary statistics.[10]

4.2.1. The dependent variable: migration

Our dependent variable is a dummy variable equal to 1 when at least one member of the household left for work in the two years preceding the interview, and 0 otherwise. Data reporting the reasons for migration are collected in Q11 ancillary files of the VARHS household dataset. Here, each migrant is listed with the household she belongs to as well as information about marital status, education and so on. Work is the main driver of migration in the VARHS sample of Vietnamese households: 45.29% of people migrated in order to work over the period considered (plus 1.07% who migrated to look for a job) while 34.44% left to study. Other drivers like marriage (9.74%), army service (3.82%), family unification (1.68%) are far less important.[11] In the end, 2088 households, about 8% per year, reported at least one migrant leaving for work. This number slightly increased over the period considered.[12]

4.2.2. The independent variable: rice production

Data about rice production are drawn from the VARHS household dataset. As mentioned before, the agricultural sector is still prominent in the Vietnamese economy and rice is the main crop grown in Viet Nam. The households in our sample are no exception: 82.33% claim that they earn an income from agriculture with rice accounting for much the largest crop.

4.2.3. Climate data: the minimum temperature

Climate data are drawn from the CRU TS4.01 dataset of the Climatic Research Unit at the University of East Anglia.[13] This dataset includes monthly time series of rainfall, the minimum, mean and maximum temperature from 1901 to 2016 on a 0.5 × 0.5-degree grid. Our dataset combines data from the VARHS household dataset with climate data. This process involved many steps. First, we imputed the latitude and longitude of 459 VARHS communes using data from GADM (Global Administrative Areas),[14] a database that provides the location of the world's administrative areas. Then, we placed the communes into 0.5 × 0.5-degree cells to which we attributed minimum temperature and rainfall values as shown in the CRU TS4.01 dataset. Finally, we computed the monthly deviations of observed minimum temperature and rainfall from their monthly averages. As suggested by the literature in the field (Beine and Parsons, 2015; Beine and Parsons, 2017), monthly deviations (both in temperature and precipitation) are calculated as:

$$clim\ dev_{jt} = clim\ level_{jt} - clim\ avg_j \quad (3)$$

where *clim level*$_{jt}$ denotes the monthly level of rainfall or temperature of each grid j in year t, and *clim avg*$_j$ denotes the monthly average rainfall or temperature of each grid.[15]

Figs. 2 and 3 provide climate patterns resulting from plotting these two variables. Fig. 2 shows that there is a tendency towards an increase in minimum temperatures since 2010. Conversely, the patterns in Fig. 3 do not show any increase in rainfall.

Rainfall is not a viable instrument since it affects both rice production and migration (Findlay, 1994; Rain et al., 2011; Hermans and Garbe, 2019). However, deviations in rainfall may affect the amount of

[9] For a detailed description of the VARHS dataset, see Brandt and Tarp (2017).

[10] Other reasons account for 3.96%.

[11] Because of how the question is asked in the survey, we cannot ascertain either whether migration was internal or international, or whether it was short- or long-term.

[12] Data source: http://wps-web1.ceda.ac.uk/submit/form?proc_id=Subsetter

[13] Data source: https://gadm.org/

[14] To reduce the influence of outliers, we extend the reference period from 2004 to 2016, following a common practice in the literature (e.g. Hendrix and Salehyan, 2012; Benjaminsen et al., 2012).

[15] We also included rainfall as an instrument in addition to the minimum temperature. Results are rubust to our main results. However, the statistic for the Hasen J test shows that the null hypothesis maintaining that both the instruments are exogenous is rejected at 1% in columns 2–5. Thus, this figure indicates that at least one of the two instruments is endogenous. The sensitivity analysis presented in section 5.3 of our paper, however, suggests that the minimum temperature is plausibly exogenous. We replicate this sensitivity analysis for rainfall. Results indicate that rainfall may not be exougenous. Thus, we include only the minimum temperature as an instrument in our analysis. Results are available upon request.

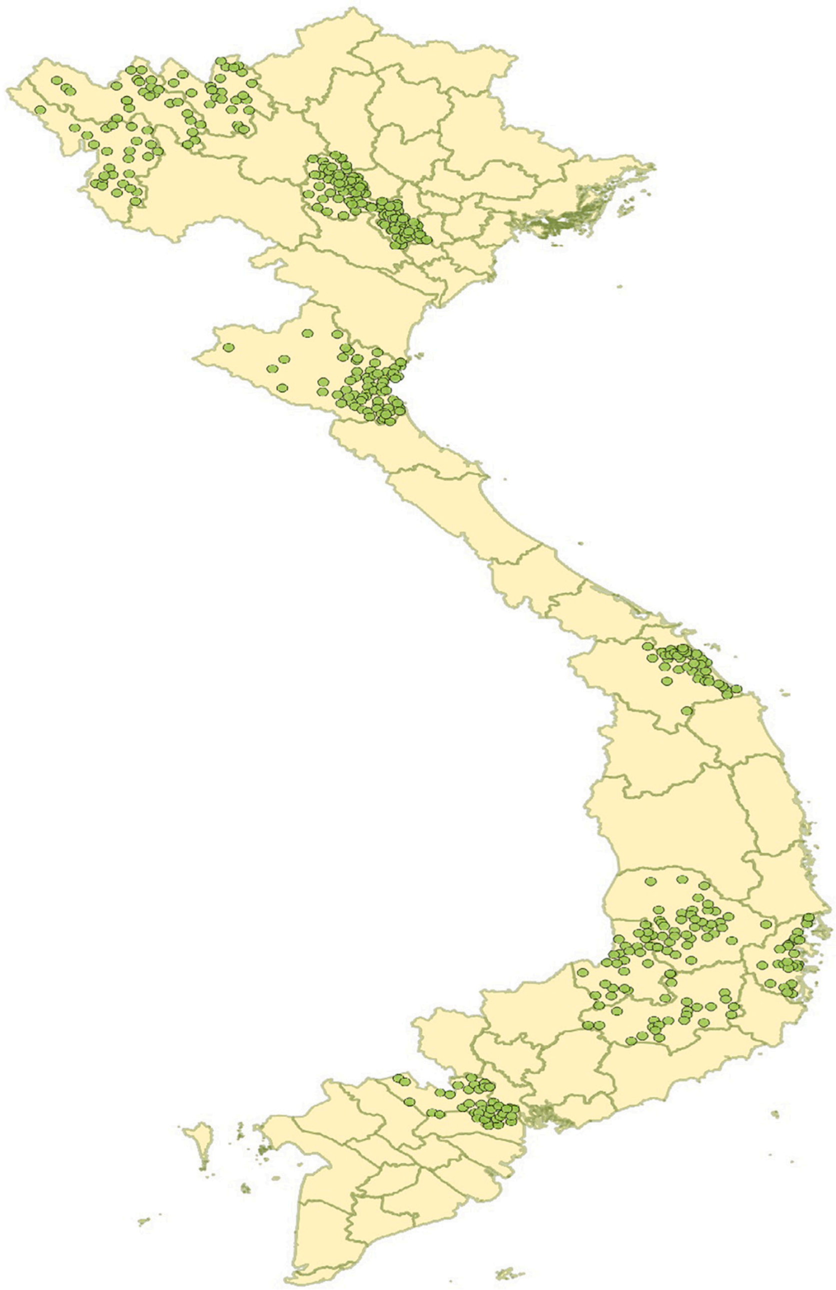

Fig. 1. The VARHS communes included in our sample.
Source: Authors' elaboration from VARHS data files.

water available, and therefore affect rice production. Hence, they are included as a covariate in our baseline model.[16]

4.2.4. *Other regressors*

The inclusion of specific controls depends on the established literature and available data. We use a set of covariates describing household economic and social conditions. As seen in section 3.2, the propensity of an individual to migrate can be affected by these factors. Therefore, we account for households' human capital and their demographic characteristics (Bohra-Mishra et al., 2014). Moreover, we include controls for rural household wealth such as the total area of land owned, the number of livestock owned and the value of savings.

Our model also introduces two measures describing the credit available to households. As mentioned in section 3.2, financially constrained individuals cannot afford the cost of migration, and, hence, the availability of money can positively impact on migration. Therefore, we include measures for both formal and informal loans. Furthermore, we also control for the quality of the social and institutional environment considered by migrants as a pull force, as previously mentioned. To do so, the number of household members joining local groups and organizations is used as a proxy. Finally, we include two variables indicating the ethnicity of the household and the gender of the household head, respectively. In doing so, we take into account the potentially different migration dynamics of the majority Kinh group with respect to disadvantaged groups (Narciso, 2017). Table 3 lists definitions of variables and descriptive statistics. Table A.1 in the Appendix reports the

[16] The dataset and the codes for our estimates have been uploaded to the journal website.

Table 1
Summary statistics.

Variable	Description	N	Mean	St. Dev.	min	max
Migration	If the hh has at least one component who has left for work	6264	0.08	0.271	0	1
Rice, t-2 (ln)	Total quantity of rice produced	5234	6.1	3.017	0	12.548
Dev of min temperature, t-2	June deviation of the minimum temperature from the average in the period 2004–2016	6264	0.234	0.185	−0.146	0.623
Deviation of rainfall, t-2	June deviation of precipitation from the average in the period 2004–2016	6264	−11.094	61.194	−146.077	162.462
Dev of max temperature, t-2	June deviation of the maximum temperature from the average in the period 2004–2016	6264	−0.117	0.509	−0.823	0.923
Dev of avg. temperature, t-2	June deviation of the average temperature from the average in the period 2004–2016	6264	0.059	0.311	−0.4	0.554
Livestock, t-2 (ln)	Number of all livestock currently owned	6264	1.975	1.769	0	12.429
Fertilizers, t-2 (ln)	Value in total production: Chemical fertilizers (urea, NPK, phosphate)	5436	5.611	3.347	0	12.742
Total area owned, t-2 (ln)	Total area owned	6264	7.892	1.572	0	12.175
Savings, t-2 (ln)	Money value of all savings	6264	7.483	4.16	0	15.299
Household size, t-2	Number of hh members	6264	4.25	1.766	1	14
Education, t-2	Education per capita	6264	8.499	2.78	0	13.5
Formal loans, t-2 (ln)	Total amount of formal loans	6264	3.023	4.669	0	15.447
Informal loans, t-2 (ln)	Total amount of informal loans	6264	1.354	3.355	0	15.01
Groups, t-2	Number of hh members in local groups, or associations	6264	2.055	1.395	0	10
Gender of household head, t-2	1 if the hh has a male head; 0 otherwise	6264	0.777	0.416	0	1
Kinh, t-2	1 if the hh is kinh; 0 otherwise	6264	0.802	0.399	0	1

Source: Authors' calculation from VARHS dataset.

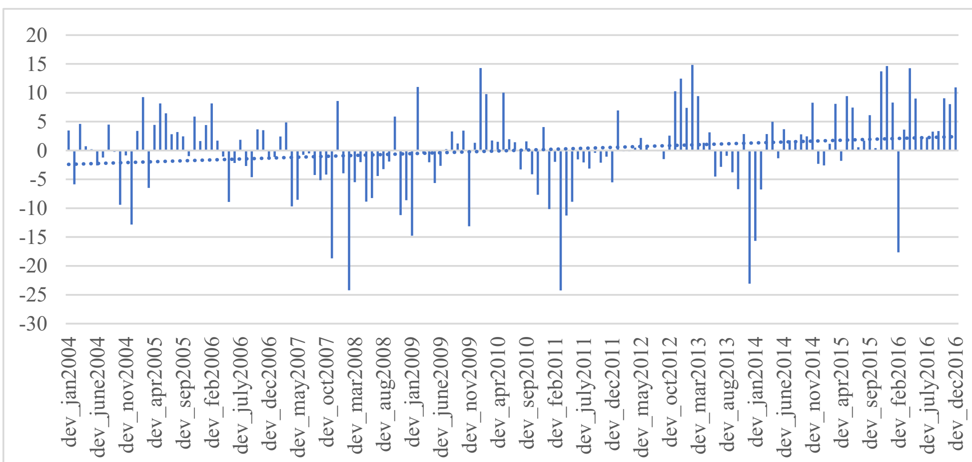

Fig. 2. Monthly deviation of minimum temperatures in Viet Namˆ.
Notes: ˆDeviation in °C*10.
Source: Authors' calculation from CRU TS4.01.

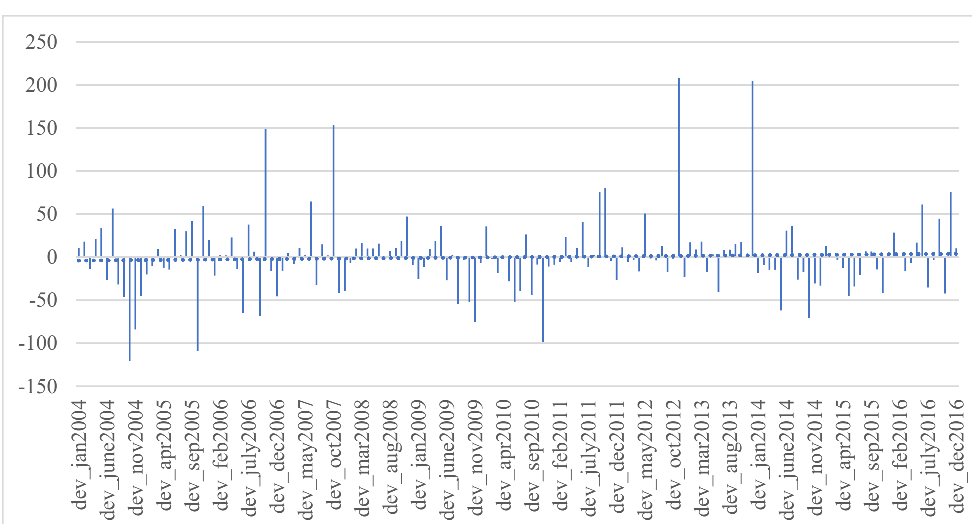

Fig. 3. Monthly deviation of rainfall in Viet Nam.
Notes: ˆDeviation in mm rainfall.
Source: Authors' calculation from CRU TS4.01.

correlation matrix of these variables.[17]

5. Empirical results

5.1. First stage: The impact of climate shocks on rice production

This section describes results from the first stage of our IV estimation as illustrated by Eq. (1).[18] The variable of interest in this stage is our instrument, i.e. the deviation of the minimum temperature. To support our main hypothesis, the coefficient of this variable should be significantly and negatively related to the dependent variable, i.e. rice production, as predicted in the relevant natural science literature (see section 3.1). Results, presented in Table 2, show that there is a significant and negative relationship between the minimum temperature and the dependent variable. In order words, this figure claims that an increase in the minimum temperature brings about a decrease in rice production, thus confirming the negative impact of climate shocks on this crop. More precisely an increase by 0.1 degrees in the deviation of the minimum temperature causes a decrease from 6 to 10% in rice production.

From a methodological point of view, however, the existence of a significant relationship between the deviation from the minimum temperature and rice production is not sufficient to confirm the validity of our instrument. To be valid, our instrument must satisfy two conditions: a) correlation with the endogenous variable (relevance condition); b) exogeneity, i.e. it should not be correlated with the error term (exclusion restriction).

Statistical tests support the relevance of the instrument. The Kleibergen-Paap Wald F statistic shows that the instrument is not weak: the values of the F-test are always above the Stock and Yogo (2005) critical values.

Support for the exclusion restriction, on the other hand, is quite hard to provide. Given the importance of rice production in Viet Nam, we believe that a reduction due to an increase in the minimum temperature indeed plays a key role in determining migration, but we cannot exclude ex-ante that the minimum temperature affects migration through channels other than rice production. Furthermore, the adoption of one instrument does not allow us to use the Hansen J statistics test to check whether the model is over-identified, i.e. that all the instruments used are exogenous.

To test the plausibility of our exclusion restriction, we use the method described by Conley et al. (2012). The ratio γ/α_1 in Table 4 can be interpreted as the maximum hypothetical violation of the exogeneity of the instrument permitted without rejecting the hypothesis that minimum temperature affects migration through rice production (Bentzen et al., 2017). Further explanations of this method are provided in section 5.3.

5.2. Second stage: The determinants of migration

This section describes the results of Eq. (2), with five specifications differing for the covariates included. Specifically, the first specification measures the effect of rice production without the inclusion of any covariates. We then include regressors controlling for household characteristics.

Results show that rice production is negatively related to migration: a decrease of 10% in the quantity of rice produced causes an increase in the probability to migrate by about 2%.[19] It is noteworthy that the magnitude of the effect of declining rice production on the propensity to migrate is not high. However, we find this quite reasonable when considering that we are analyzing the relationship between rice production and migration in the short run. As explained in section 4.2, we use a sample of rural households interviewed between 2010 and 2016.

As far as the covariates are concerned, the figures illustrate that migration is more likely among wealthier households. This finding is in line with studies that claim that individuals who leave home must be able to afford the cost of migration and therefore only people in well-off families are able to migrate. For instance, Kubik and Maurel (2016), who studied the effect of climate change on migration in Tanzania, found that this phenomenon is positively related to the variables controlling for household prosperity. Similarly, our results show that the coefficients for these regressors are significant and positive. The only exception is savings, a measure of household mobile wealth, which appears to be negatively related to migration. However, the coefficient is very small, indicating that the effect of this variable is not economically relevant.

Furthermore, household size is positively related to migration, as indicated in the literature while, in contrast, education is not significant. This result can be read together with the effect of education on rice production, which is negative in Table 2. We think this happens because many households with high education per-capita do not produce rice (when we consider the families that have the highest education, i.e., having education higher than the 90th percentile, about 36% of the observations about rice production are equal to zero).[20] Two channels may affect the above-mentioned result: skilled workers are not attracted by rice production, therefore this is simply a matter of occupational choice or cultural traits of households that decide both education and the type of occupation. In principle, we cannot distinguish between these motivations. However, cultural traits do not appear to affect the migration propensity (Table 3), therefore we can think that the occupational choice outweighs the role of cultural traits. Moreover, Viet Nam is a country experiencing a structural transformation from agriculture to manufacturing. Caselli and Coleman II (2001) and Acemoglu and Guerrieri (2008) model a two-sector economy in which agriculture is intensive in unskilled labor. Over time, declining education/training costs and capital deepening induce an increasing proportion of the labor force to move from the unskilled agricultural sector into the skilled nonagricultural sector.

Regarding the variables measuring the availability of credit (the total amount of informal and formal loans), both measures of credit adopted are not significant, further supporting our previous result on wealth: credit-constrained poor households do not find loans to help them to migrate. Furthermore, the number of household members joining local groups and associations is significantly and negatively related to the probability to migrate. This is in line with the literature arguing that a favorable social and institutional environment deters migration (see section 3.2). This reasoning is also supported by the fact that in our analysis Kinh households are less likely to have a migrant among their members. Kinhs are the majority ethnic group in Viet Nam, are better integrated and have more extensive social networks than non-Kinhs (Singhal and Beck, 2017). Finally, the gender of the head of the household does not significantly impact on migration. It is also noteworthy that rainfall is negatively related to migration, but the coefficient is almost zero, so the magnitude of the effect is not relevant.

5.3. Sensitivity analysis: The effect of possible violations of the exclusion restriction

In this paragraph, we use the approach of Conley et al. (2012) to assess possible violations of the exclusion restriction. This approach

[17] In the Appendix, Table A.2 shows the reduced-form estimation of the the effect of the deviation of minimum temperature on migration.

[18] As shown in Tables A.3-A.6 in the Appendix, this result is robust for different specifications and estimators.

[19] This contrasts with households that with education below the 90th percentile, where about 17% of the observations on rice production are zeroes.

[20] Prasad et al. (2006) and Zhen et al. (2020) analyze the response of several rice cultivars to increases in temperature and find that some are more resilient than others.

Table 2
The impact of climate shocks on rice production (first stage, 2SLS).

	(1)	(2)	(3)	(4)	(5)
	Rice, t-2(ln)	Rice, t-2 (ln)	Rice, t-2 (ln)	Rice, t-2 (ln)	Rice, t-2 (ln)
Dev of min temperature, t-2	−1.352***	−1.027***	−0.853***	−0.847***	−0.674***
	(0.298)	(0.166)	(0.167)	(0.167)	(0.169)
Deviation of rainfall, t-2		−0.002***	−0.002***	−0.002***	−0.002***
		(0.001)	(0.001)	(0.001)	(0.001)
Livestock, t-2 (ln)		0.062***	0.069***	0.070***	0.071***
		(0.011)	(0.011)	(0.011)	(0.011)
Fertilizers, t-2 (ln)		0.714***	0.724***	0.724***	0.731***
		(0.017)	(0.016)	(0.016)	(0.016)
Total area owned, t-2 (ln)		0.409***	0.392***	0.393***	0.368***
		(0.032)	(0.030)	(0.030)	(0.030)
Savings, t-2 (ln)		−0.024***	−0.017***	−0.018***	−0.015***
		(0.005)	(0.004)	(0.004)	(0.004)
Household size, t-2		0.097***	0.100***	0.102***	0.091***
		(0.013)	(0.013)	(0.013)	(0.013)
Education, t-2			−0.059***	−0.058***	−0.037***
			(0.008)	(0.008)	(0.008)
Formal loans, t-2 (ln)				−0.005	−0.005
				(0.004)	(0.004)
Informal loans, t-2 (ln)				−0.003	−0.002
				(0.005)	(0.005)
Groups, t-2					−0.070***
					(0.013)
Gender of household head, t-2					0.047
					(0.042)
Kinh, t-2					−0.364***
					(0.064)
Constant	6.169***	−1.345***	−0.850***	−0.851***	−0.457***
	(0.149)	(0.168)	(0.175)	(0.175)	(0.189)
Year FE	yes	yes	yes	yes	yes
Region FE	yes	yes	yes	yes	yes
Kleibergen-Paap rk LM statistic	20.15	38.29	26.26	25.98	16.07
p-value	0.000	0.000	0.000	0.000	0.000
Kleibergen-Paap rk Wald F statistic	20.56	38.20	26.08	21.81	15.97
Conley-Hansen-Rossi γ/α_1	0.71	0.73	0.67	0.66	0.63
adj R-squared	0.0218	0.852	0.855	0.855	0.857
Observations	5234	5199	5199	5199	5199

Notes: Standard errors clustered at household level in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

consists of allowing the instrument to enter the second-stage regression with a coefficient of γ, that is:

$$Migration_{it} = \beta_0 + \beta_1\ Rice_{it-2} + \beta_2\ X_{it-2} + \gamma\ Dev\ min\ temperature\ June_{jt-2} + a_r + y_t + \varepsilon_{it} \quad (4)$$

where γ is a parameter set by the researcher. Eq. (4) is estimated by the UCI (Union of Confidence Intervals) approach, a methodology provided in Conley et al. (2012) which "replaces the original assumption that $\gamma = 0$ with an assumption regarding the minimum and the maximum values which γ may take" (Clarke and Matta, 2017, p. 5). This produces confidence intervals on β at a chosen level of significance. The UCI approach also provides confidence intervals for the controls included in our models. Their coefficients are statistically significant when the intervals produced are below or above zero (Madsen and Murtin, 2017).

Following Fletcher and Marksteiner (2017), we use different ranges for γ (see Table 4). First, since the reduced-form effect of minimum temperature on migration is positive (see Table A.2), we assume that the exclusion restriction is only a problem for our analysis if our instrument positively influences the dependent variable (Bentzen et al., 2017). Therefore, we fix the lower bound of $\gamma_{[min]}$ at 0 (no effect) and allow growing positive violations of the exogeneity assumption up to $\gamma_{[max]}$, which corresponds to different percentages of the minimum temperature reduced-form effect on migration (see Table A.2). In detail, we first assume small violations, i.e. include small percentages of the minimum temperature reduced-form effect on migration in the second stage. The larger the violations, the higher the level of endogeneity in the model.

The main findings of this analysis are twofold. On the one hand, the effect of rice production on migration remains negative even if we allow for substantial violations of the exclusion restriction. The ratios provided in Table 2 are derived by dividing the largest possible positive value of $\gamma_{[max]}$. These ratios indicate that the coefficient for rice production remains significant even if more than 60% of the overall effect of our instrument on the dependent variable is not captured by the channel of rice production. Conley et al. (2012) showed that these ratios are sensitive to the strength of the instrument, which decreases as more control variables are included in the model, i.e. in columns (4, 5).

On the other hand, our sensitivity analysis also shows that the higher the endogeneity of our instrument, the more the controls become not significant. Specifically, some controls like savings, precipitation and the ethnicity of the family, are particularly sensitive to violations of the exclusion restriction. When more than half of the effect of minimum temperature on migration is not channeled by rice production, land ownership also loses its significance. In conclusion, while we cannot rule out that minimum temperature affects migration through other channels, results from the Conley test show that rice production is a very important explanatory variable for why people migrate from their homes.

Table 3
Determinants of migration (second stage, 2SLS).

	(1)	(2)	(3)	(4)	(5)
	Migration	Migration	Migration	Migration	Migration
Rice, t-2 (ln)	−0.140***	−0.190***	−0.196***	−0.192***	−0.234***
	(0.042)	(0.046)	(0.057)	(0.056)	(0.079)
Deviation of precipitation, t-2		−0.000**	−0.000*	−0.000**	−0.000**
		(0.000)	(0.000)	(0.000)	(0.000)
Livestock, t-2 (ln)		0.019***	0.020***	0.019***	0.022***
		(0.004)	(0.005)	(0.005)	(0.007)
Fertilizers, t-2 (ln)		0.142***	0.146***	0.143***	0.175***
		(0.033)	(0.041)	(0.041)	(0.058)
Total area owned, t-2 (ln)		0.070***	0.072***	0.070***	0.081***
		(0.020)	(0.023)	(0.023)	(0.030)
Savings, t-2 (ln)		−0.003*	−0.003*	−0.003*	−0.003*
		(0.002)	(0.002)	(0.002)	(0.002)
Household size, t-2		0.026***	0.027***	0.026***	0.028***
		(0.006)	(0.007)	(0.007)	(0.008)
Education, t-2			−0.002	−0.002	−0.001
			(0.004)	(0.004)	(0.004)
Formal loans, t-2 (ln)				0.002	0.002
				(0.001)	(0.001)
Informal loans, t-2 (ln)				0.002	0.002
				(0.002)	(0.002)
Groups, t-2					−0.016**
					(0.007)
Gender of household head, t-2					0.020
					(0.014)
Kinh, t-2					−0.071*
					(0.037)
Constant	0.891***	−0.260***	−0.251***	−0.248***	−0.208***
	(0.247)	(0.084)	(0.072)	(0.072)	(0.071)
Year FE	yes	yes	yes	yes	yes
Region FE	yes	yes	yes	yes	yes
R2 adj	0.016	0.025	0.033	0.036	0.036
Observations	5234	5199	5199	5199	5199

Notes: Instrument: deviation of the minimum temperature (June t–2). Standard errors clustered at household level in parentheses.
*** $p < 0.01$
** $p < 0.05$.
* $p < 0.1$.

6. Robustness checks

A number of robustness checks can be carried out. First, we run two placebo tests using either the deviation of maximum temperature or average temperature (Tables 5-6) as instrument. Our key intuition, supported by the literature in biology and agriculture, is that minimum temperature is effective in explaining the reduction in rice production. Hence, a significant coefficient for maximum temperature and average temperature would contradict our main findings.

The results in Table 5 show no significant relationship between the deviation of maximum temperature and rice production in almost all our models. Only in model 2 the two variables are positively and significantly related at the 10% level. The values of Kleibergen-Paap Wald F statistics, however, are very low suggesting that the deviation of maximum temperature, even where significant, is too weakly correlated with rice production to be used as an appropriate instrument. Interestingly, this result conflicts with Welch et al. (2010), which reported a positive effect of maximum temperature in a few locations across Asia.

Furthermore, results in Table 6 indicate that deviations in the average temperature are also not significantly related to rice production. We only found a positive correlation between these two variables in specification 1 which does not include any control (as in Tables 2-3). In this specification, the values of Kleibergen-Paap Wald F statistics are low, also suggesting a weak correlation.

7. Conclusions

This paper addresses the relationship between temperature shocks and migration by focusing on the channel of rice production. By exploiting the link between minimum temperature and rice production, the object of a stream of literature in the natural sciences, we identify a specific link previously missing in the literature. Viet Nam is our testbed, given the availability of fine-grained household data. In an economy in which rice is the staple food, the negative impact of the increasing minimum temperature on rice crops may cause people to migrate because there are fewer jobs in agriculture and/or because the same effort produces less reward than before. Results show that the rise of the minimum temperature during the core month of the growing season (June) causes a reduction in rice production which, in turn, has a positive impact on the propensity to migrate. This finding is robust to the use of different estimators. The magnitude of the effect of a decrease in rice production on the probability to migrate, however, is not high. This is not surprising since our analysis is carried out over 6 years. We expect future research to focus on a much longer period to evaluate the impact of systematic increases in the minimum temperature in countries where rice production is essential for the livelihood of their citizens.

Our study has two important implications for the development of Vietnamese rural households in the face of climate shocks. First, it sheds light on the link between climate variations, agricultural production and migration allowing policy makers to fully understand how this phenomenon may impact people's lives and to predict future population movements. Furthermore, this study also discloses that households that are largely dependent on rice revenues are deemed to be severely affected by variations in the temperatures. This finding encourages the adoption of alternative crops that may be more resistant to climate

Table 4
Sensitivity analysis using Conley test of plausible exogeneity.

	(1)		(2)		(3)		(4)		(5)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Violation size: 20% of reduced-form).										
γ_{max}		0.035		0.036		0.031		0.030		0.029
Deviation of rainfall, t-2			−0.001	0.000	−0.001	0.000	−0.001	0.000	−0.001	0.000
Livestock, t-2 (ln)			0.010	0.026	0.009	0.028	0.009	0.028	0.009	0.033
Fertilizers, t-2 (ln)			0.066	0.196	0.058	0.214	0.056	0.210	0.058	0.270
Total area owned, t-2 (ln)			0.025	0.103	0.022	0.110	0.021	0.108	0.021	0.131
Savings, t-2 (ln)			−0.006	0.000	−0.006	0.000	−0.005	0.000	−0.006	0.000
Household size, t-2			0.014	0.035	0.012	0.038	0.012	0.037	0.011	0.041
Education, t-2					−0.009	0.006	−0.009	0.006	−0.007	0.007
Formal loans, t-2 (ln)							0.000	0.004	0.000	0.004
Informal loans, t-2 (ln)							−0.001	0.004	−0.001	0.005
Groups, t-2									−0.028	−0.002
Gender of household head, t-2									−0.003	0.043
Kinh, t-2									−0.133	0.000
Rice, t-1 (ln)	−0.209	−0.052	−0.265	−0.084	−0.289	−0.073	−0.284	−0.071	−0.364	−0.074
Constant	0.351	1.246	−0.390	−0.081	−0.360	−0.106	−0.352	−0.099	−0.305	−0.070
Violation size: 40% of reduced-form										
γ_{max}		0.070		0.073		0.062		0.060		0.058
Deviation of rainfall, t-2			−0.001	0.000	−0.001	0.000	−0.001	0.000	−0.001	0.000
Livestock, t-2 (ln)			0.008	0.026	0.007	0.028	0.007	0.028	0.007	0.033
Fertilizers, t-2 (ln)			0.044	0.196	0.036	0.214	0.035	0.210	0.035	0.270
Total area owned, t-2 (ln)			0.013	0.103	0.011	0.110	0.010	0.108	0.009	0.131
Savings, t-2 (ln)			−0.006	0.001	−0.006	0.000	−0.005	0.001	−0.006	0.001
Household size, t-2			0.011	0.035	0.010	0.038	0.009	0.037	0.008	0.041
Education, t-2					−0.009	0.008	−0.009	0.007	−0.007	0.008
Formal loans, t-2 (ln)							0.000	0.004	0.000	0.004
Informal loans, t-2 (ln)							−0.001	0.004	−0.001	0.005
Groups, t-2									−0.028	0.000
Gender of household head, t-2									−0.003	0.043
Kinh, t-2									−0.133	0.011
Rice, t-1 (ln)	−0.209	−0.032	−0.265	−0.053	−0.289	−0.043	−0.284	−0.042	−0.364	−0.042
Constant	0.225	1.246	−0.390	−0.053	−0.360	−0.094	−0.352	−0.087	−0.305	−0.070
Violation size: 60% of reduced-form.										
γ_{max}		0.105		0.109		0.093		0.091		0.088
Deviation of rainfall, t-2			−0.001	0.000	−0.001	0.000	−0.001	0.000	−0.001	0.000
Livestock, t-2 (ln)			0.007	0.026	0.005	0.028	0.005	0.028	0.004	0.033
Fertilizers, t-2 (ln)			0.022	0.196	0.013	0.214	0.012	0.210	0.009	0.270
Total area owned, t-2 (ln)			0.000	0.103	−0.001	0.110	−0.002	0.108	−0.003	0.131
Savings, t-2 (ln)			−0.006	0.002	−0.006	0.001	−0.005	0.001	−0.006	0.001
Household size, t-2			0.008	0.035	0.007	0.038	0.006	0.037	0.005	0.041
Education, t-2					−0.009	0.010	−0.009	0.009	−0.007	0.009
Formal loans, t-2 (ln)							0.000	0.004	0.000	0.004
Informal loans, t-2 (ln)							−0.001	0.004	−0.001	0.005
Groups, t-2									−0.028	0.002
Gender of household head, t-2									−0.003	0.043
Kinh, t-2									−0.133	0.023
Rice, t-1 (ln)	−0.209	−0.012	−0.265	−0.022	−0.289	−0.012	−0.284	−0.010	−0.364	−0.006
Constant	0.094	1.246	−0.390	−0.023	−0.360	−0.079	−0.352	−0.072	−0.305	−0.070
Violation size:maximal										
γ_{max}		0.124		0.133		0.104		0.100		0.092
Deviation of rainfall, t-2			−0.001	0.000	−0.001	0.000	−0.001	0.000	−0.001	0.000
Livestock, t-2 (ln)			0.005	0.026	0.005	0.028	0.004	0.028	0.004	0.033
Fertilizers, t-2 (ln)			0.007	0.196	0.005	0.214	0.005	0.210	0.005	0.270
Total area owned, t-2 (ln)			−0.008	0.103	−0.006	0.110	−0.006	0.108	−0.005	0.131
Savings, t-2 (ln)			−0.006	0.002	−0.006	0.001	−0.005	0.001	−0.006	0.001
Household size, t-2			0.006	0.035	0.006	0.038	0.005	0.037	0.005	0.041

(continued on next page)

Table 4 (*continued*)

	(1)		(2)		(3)		(4)		(5)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Education, t-2					−0.009	0.010	−0.009	0.010	−0.007	0.009
Formal loans, t-2 (ln)							0.000	0.004	0.000	0.004
Informal loans, t-2 (ln)							−0.001	0.004	−0.001	0.005
Groups, t-2									−0.028	0.003
Gender of household head, t-2									−0.003	0.043
Kinh, t-2									−0.133	0.024
Rice, t-1 (ln)	−0.20912	−0.00001	−0.26529	−0.00061	−0.28887	−0.00043	−0.28419	−0.00068	−0.36356	−0.00110
Constant	0.020	1.246	−0.390	−0.002	−0.360	−0.074	−0.352	−0.067	−0.305	−0.070

Table 5
Placebo test, 2SLS (deviation of the maximum temperature as instrument).***

	(1)	(2)	(3)	(4)	(5)
First stage					
Dependent variable: Rice, t-2 (ln)					
Dev max temperature, t-2	−0.141	0.158**	0.106	0.108	0.029
	(0.116)	(0.068)	(0.067)	(0.067)	(0.067)
Second stage					
Dependent variable: Migration					
Rice, t-2 (ln)	−0.234	0.270*	0.486	0.466	1.930
	(0.216)	(0.152)	(0.340)	(0.323)	(4.499)
Year FE	yes	yes	yes	yes	yes
Region FE	yes	yes	yes	yes	yes
Kleibergen-Paap rk LM statistic	1.47	5.33	2.49	2.57	0.19
p-value	0.225	0.021	0.114	0.109	0.665
Kleibergen-Paap rk Wald F statistic	1.47	5.35	2.50	2.58	0.19
Observations	5234	5199	5159	5159	5159

Notes: When using the deviation of the maximum temperature as the instrument we estimate all the five models adopted previously as shown in Tables 2-3. Here, we report only the coefficients for our variable of interest, i.e. the deviation of maximum temperature in the first stage and the quantity of rice produced in the second stage. Standard errors clustered at household level in parentheses. In this regression, the Conley test is not used because, as argued by Conley et al. (2012), the relevance of the instrument is more important than its exogeneity. In other words, the Conley test does not work if the instrument is not relevant.

*** $p < 0.01$.

** $p < 0.05$.

* $p < 01$

Table 6
Placebo test, 2SLS (deviation of the average temperature as instrument).

	(1)	(2)	(3)	(4)	(5)
First stage					
Dependent variable: Rice, t-2 (ln)					
Dev avg. temperature, t-2	−0.531***	0.008	−0.067	−0.063	−0.128
	(0.178)	(0.115)	(0.112)	(0.113)	(0.112)
Second stage					
Dependent variable: Migration					
Rice, t-2 (ln)	−0.176***	−2.637	−1.686	−1.761	−0.896
	(0.076)	(7.250)	(2.845)	(3.183)	(0.806)
Year FE	yes	yes	yes	yes	yes
Region FE	yes	yes	yes	yes	yes
Kleibergen-Paap rk LM statistic	8.90	0.13	0.36	0.31	1.31
p-value	0.003	0.715	0.550	0.577	0.252
Kleibergen-Paap rk Wald F statistic	8.89	0.13	0.36	0.31	1.31
Observations	5234	5199	5159	5159	5159

Notes: When using the deviation of the average temperature as instrument we estimate all the five models adopted previously as reported in Tables 2-3. Here, we report only the coefficients for our variable of interest, that is the deviation of the average temperature in the first stage and the quantity of rice produced in the second stage. Standard errors clustered at household level in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 01$. In this regression, the Conley test is not used because, as argued by Conley et al. (2012), the relevance of the instrument is more important than its exogeneity. In other words, the Conley test does not work if the instrument is not relevant.

variations [21] as well as the introduction of ad hoc policies to support the most climate-sensitive households.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A.1
Correlation matrix.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1) Rice, t-2 (ln)	1.000															
(2) Dev of min temperature, t-2	−0.045	1.000														
(3) Deviation of rainfall, t-2	−0.064	0.188	1.000													
(4) Dev of max temperature, t-2	0.003	0.507	−0.005	1.000												
(5) Dev of average temperature, t-2	−0.012	0.714	0.053	0.965	1.000											
(6) Livestock, t-2 (ln)	0.344	0.027	0.027	0.062	0.058	1.000										
(7) Savings, t-2	−0.018	0.018	0.026	0.005	0.009	0.066	1.000									
(8) Fertilizers, t-2 (ln	0.896	−0.010	−0.044	−0.004	−0.006	0.293	0.002	1.000								
(9) Household size, t-2	0.245	−0.037	−0.009	0.043	0.023	0.156	0.044	0.160	1.000							
(10) Total area owned, t-2 (ln)	0.662	−0.021	−0.052	0.132	0.101	0.344	0.045	0.558	0.285	1.000						
(11) Education, t-2	0.001	0.115	0.056	−0.061	−0.014	0.024	0.172	0.105	−0.002	−0.087	1.000					
(12) Formal loans, t-2 (ln)	0.117	−0.043	−0.097	0.026	0.008	0.111	−0.057	0.119	0.124	0.133	0.088	1.000				
(13) Informal loans, t-2 (ln)	0.052	0.028	−0.020	0.008	0.015	0.031	−0.041	0.065	0.055	0.026	0.051	−0.067	1.000			
(14) Groups, t-2	0.094	0.063	0.136	−0.059	−0.029	0.155	0.093	0.136	0.157	0.075	0.224	0.039	0.029	1.000		
(15) Gender of household head, t-2	0.162	−0.013	0.002	−0.003	−0.007	0.156	0.073	0.125	0.241	0.208	0.082	0.068	0.016	0.129	1.000	
(16) Kinh, t-2	−0.197	0.068	−0.076	−0.091	−0.053	−0.232	0.063	−0.053	−0.303	−0.362	0.410	−0.022	0.032	0.033	−0.168	1.000

Source: Authors' calculations from VARHS dataset.

Table A.2
Reduced form.

	(1)	(2)	(3)	(4)	(5)
	Migrated_work	Migrated_work	Migrated_work	Migrated_work	Migrated_work
Dev of min temperature, t-2	0.175***	0.182***	0.155***	0.151***	0.146***
	(0.032)	(0.034)	(0.035)	(0.034)	(0.035)
Deviation of rainfall, t-2		−0.000	−0.000	−0.000	−0.000
		(0.000)	(0.000)	(0.000)	(0.000)
Livestock, t-2 (ln)		0.007***	0.006**	0.005**	0.005**
		(0.002)	(0.002)	(0.002)	(0.002)
Fertilizers, t-2 (ln)		0.006***	0.004***	0.004***	0.004***
		(0.001)	(0.001)	(0.001)	(0.001)
Total area owned, t-2 (ln)		−0.007**	−0.004	−0.005	−0.004
		(0.003)	(0.003)	(0.003)	(0.003)
Savings, t-2 (ln)		0.001	0.000	0.001	0.000
		(0.001)	(0.001)	(0.001)	(0.001)
Household size, t-2		0.008***	0.007***	0.007***	0.007***

(*continued on next page*)

[21] GLM are "a subset of ML estimators that are based on a density in the linear exponential family (LEF)" (Cameron and Trivedi, 2009, p.321). This class of models includes nonlinear least squares, Poisson, probit, logit, binomial, and exponential regression models. This model is estimated in Stata by the qvf routine (Hardin et al., 2003) which performs it by using maximum quasi-likelihood and also allows for instrumental variables.

Table A.2 (*continued*)

	(1)	(2)	(3)	(4)	(5)
	Migrated_work	Migrated_work	Migrated_work	Migrated_work	Migrated_work
		(0.002)	(0.002)	(0.002)	(0.002)
Education, t-2			0.009***	0.008***	0.008***
			(0.001)	(0.001)	(0.001)
Formal loans, t-2 (ln)				0.003***	0.003***
				(0.001)	(0.001)
Informal loans, t-2 (ln)				0.002*	0.002*
				(0.001)	(0.001)
Groups, t-2					0.000
					(0.003)
Gender of household head, t-2					0.009
					(0.009)
Kinh, t-2					0.015
					(0.014)
Constant	0.029***	−0.009	−0.083***	−0.083***	−0.101***
	(0.011)	(0.024)	(0.025)	(0.025)	(0.030)
Year FE	yes	yes	yes	yes	yes
Region FE	yes	yes	yes	yes	yes
Observations	6264	5436	5436	5436	5436

Notes: Standard errors clustered at household level in parentheses. ***p < 0.01, **p < 0.05, *p < 01.

A.1. Robustness checks: alternative estimators

In the main text, we used the LPM to produce our estimates. In this model, the probability of a household having at least one component who left for work is linear in the coefficients. The linearity assumption, however, is not very realistic. Therefore, the change in probabilities due to a unit change in the independent variable is unlikely to be constant. As the probability of an event occurring is close to one (or to zero), the marginal effect of the independent variable is very small. We, therefore, propose alternative approaches to the LPM. As argued by Lewbel et al. (2012), even if the LPM is a good approximation of marginal effects, it is wise to use other models to test the robustness of the predicted effects.

We first adopt a generalized linear model (GLM) estimator to implement both logit and probit models with endogenous regressors.[22] Conditional probability functions are used where the relationship with the independent variables is non-linear. Specifically, the probability of an event occurring approaches its bounds at slower and slower rates as X_i becomes very small or very large. In addition, we also adopt a control function approach. This approach is different from the IV method.[23] Instead of regressing the values of the endogenous regressor predicted in the first stage on the dependent variable, the fitted values of the error from the first stage are used as an additional regressor in the second stage. Results are shown in Tables A.3, A.4 and A.5. Figures are of the same sign and equally significant to OLS estimates.

We also provide the average marginal effects for the control function approach in Table A.6. Results are mostly in line with the LMP: an increase of 10% in rice production raises the probability of migrating by about 2%. Unfortunately, the qvf routine which enables estimation of the GLM model does not allow the marginal effect to be calculated for the logit and probit models as stated in Hardin et al. (2003).

Table A.3
Determinants of migration (second stage, logit).

	(1)	(2)	(3)	(4)	(5)
	Migration	Migration	Migration	Migration	Migration
Rice, t-2 (ln)	−1.886***	−2.544***	−2.714***	−2.628***	−3.268***
	(0.548)	(0.598)	(0.762)	(0.751)	(1.071)
Deviation of rainfall, t-2		−0.005**	−0.006**	−0.006**	−0.007**
		(0.002)	(0.003)	(0.003)	(0.003)
Livestock, t-2 (ln)		0.250***	0.262***	0.251***	0.298***
		(0.057)	(0.069)	(0.069)	(0.091)
Fertilizers, t-2 (ln)		1.919***	2.047***	1.985***	2.470***
		(0.427)	(0.551)	(0.544)	(0.783)
Total area owned, t-2 (ln)		0.926***	0.995***	0.956***	1.131***
		(0.265)	(0.318)	(0.313)	(0.412)
Savings, t-2 (ln)		−0.040*	−0.043*	−0.037*	−0.042*
		(0.023)	(0.022)	(0.022)	(0.026)
Household size, t-2		0.340***	0.376***	0.360***	0.393***
		(0.075)	(0.092)	(0.092)	(0.115)
Education, t-2			0.033	0.032	0.055
			(0.061)	(0.060)	(0.059)
Formal loans, t-2 (ln)				0.021	0.019
				(0.015)	(0.017)
Informal loans, t-2 (ln)				0.021	0.022

(*continued on next page*)

[22] The actual values of the endogenous regressors are still included in the second stage but the first-stage residuals control for endogeneity (Terza et al., 2008). Thus, the error term in the second stage is independent of both the exogenous regressor and the residuals and it is possible to estimate the second stage as an ordinary probit model. This model is estimated using ivprobit routine in Stata.

[23] Data and replication files are available at https://data.mendeley.com//datasets/hzmf847tb9/1

Table A.3 (*continued*)

	(1)	(2)	(3)	(4)	(5)
	Migration	Migration	Migration	Migration	Migration
				(0.019)	(0.021)
Groups, t-2					−0.234**
					(0.101)
Gender of household head, t-2					0.278
					(0.202)
Kinh, t-2					−1.044**
					(0.503)
Constant	9.082**	−8.608***	−9.478***	−9.383***	−9.145***
	(3.627)	(1.348)	(1.343)	(1.317)	(1.417)
Year FE	yes	yes	yes	yes	yes
Region FE	yes	yes	yes	yes	yes
Observations	5234	5199	5199	5199	5199

Notes: Instrument: deviation of the minimum temperature (June t–2). Standard errors clustered at household level in parentheses. ***p < 0.01, **p < 0.05, *p < 01.

Table A.4
Determinants of migration (second stage, probit).

	(1)	(2)	(3)	(4)	(5)
	Migration	Migration	Migration	Migration	Migration
Rice, t-2 (ln)	−0.944***	−1.273***	−1.344***	−1.309***	−1.626***
	(0.275)	(0.300)	(0.381)	(0.377)	(0.536)
Deviation of rainfall, t-2		−0.002**	−0.003**	−0.003**	−0.004**
		(0.001)	(0.001)	(0.001)	(0.002)
Livestock, t-2 (ln)		0.125***	0.131***	0.126***	0.149***
		(0.028)	(0.035)	(0.035)	(0.046)
Fertilizers, t-2 (ln)		0.957***	1.012***	0.986***	1.227***
		(0.215)	(0.275)	(0.273)	(0.392)
Total area owned, t-2 (ln)		0.465***	0.494***	0.478***	0.565***
		(0.133)	(0.158)	(0.157)	(0.206)
Savings, t-2 (ln)		−0.022*	−0.023**	−0.020*	−0.023*
		(0.011)	(0.011)	(0.011)	(0.013)
Household size, t-2		0.172***	0.189***	0.181***	0.197***
		(0.038)	(0.046)	(0.046)	(0.058)
Education, t-2			0.013	0.013	0.024
			(0.030)	(0.029)	(0.029)
Formal loans, t-2 (ln)				0.011	0.010
				(0.008)	(0.008)
Informal loans, t-2 (ln)				0.011	0.011
				(0.010)	(0.011)
Groups, t-2					−0.118**
					(0.050)
Gender of household head, t-2					0.130
					(0.101)
Kinh, t-2					−0.522**
					(0.252)
Constant	4.387**	−4.432***	−4.807***	−4.777***	−4.657***
	(1.821)	(0.675)	(0.666)	(0.657)	(0.705)
Year FE	yes	yes	yes	yes	yes
Region FE	yes	yes	yes	yes	yes
Observations	5234	5199	5199	5199	5199

Notes: Instrument: deviation of the minimum temperature (June t–2). Standard errors clustered at household level in parentheses. ***p < 0.01, **p < 0.05, *p < 01.

Table A.5
Determinants of migration (second stage, control function approach).

	(1)	(2)	(3)	(4)	(5)
	Migration	Migration	Migration	Migration	Migration
Rice, t-2 (ln)	−0.305***	−0.742***	−0.747***	−0.742***	−0.788***
	(0.014)	(0.054)	(0.062)	(0.065)	(0.058)
Deviation of rainfall, t-2		−0.001***	−0.001**	−0.002**	−0.002***
		(0.001)	(0.001)	(0.001)	(0.001)
Livestock, t-2 (ln)		0.072***	0.072***	0.071***	0.072***
		(0.012)	(0.012)	(0.012)	(0.011)
Fertilizers, t-2 (ln)		0.561***	0.564***	0.561***	0.596***
		(0.039)	(0.044)	(0.046)	(0.042)
Total area owned, t-2 (ln)		0.266***	0.271***	0.267***	0.271***
		(0.038)	(0.038)	(0.040)	(0.036)
Savings, t-2 (ln)		−0.012**	−0.012**	−0.011**	−0.011**
		(0.005)	(0.005)	(0.005)	(0.005)

(*continued on next page*)

Table A.5 (*continued*)

	(1)	(2)	(3)	(4)	(5)
	Migration	Migration	Migration	Migration	Migration
Household size, t-2		0.099***	0.104***	0.102***	0.095***
		(0.013)	(0.013)	(0.013)	(0.013)
Education, t-2			0.008	0.007	0.012
			(0.018)	(0.018)	(0.016)
Formal loans, t-2 (ln)				0.006	0.005
				(0.005)	(0.005)
Informal loans, t-2 (ln)				0.006	0.005
				(0.006)	(0.005)
Groups, t-2					−0.057***
					(0.015)
Gender of household head, t-2					0.063
					(0.047)
Kinh, t-2					−0.250***
					(0.077)
Constant	1.298***	−2.159***	−2.255***	−2.289***	−1.825***
	(0.199)	(0.160)	(0.294)	(0.298)	(0.373)
Year FE	yes	yes	yes	yes	yes
Region FE	yes	yes	yes	yes	yes
Observations	5234	5199	5199	5199	5199

Notes: Instrument: deviation of the minimum temperature (June t–2). Standard errors clustered at household level in parentheses. ***p < 0.01, **p < 0.05, *p < 01.

Table A.6
Average marginal effects (second stage, control function approach).

	Migration	Migration	Migration	Migration	Migration
Rice, t-2 (ln)	−0.076	−0.206	−0.209	−0.205	−0.230
	(0.0003)	(0.0011)	(0.0011)	(0.0011)	(0.0011)
Deviation of rainfall, t-2		0.000	0.000	0.000	0.000
		(0.0000)	(0.0000)	(0.0000)	(0.0000)
Livestock, t-2 (ln)		0.020	0.020	0.020	0.021
		(0.0001)	(0.0001)	(0.0001)	(0.0001)
Fertilizers, t-2 (ln)		0.156	0.158	0.155	0.174
		(0.0008)	(0.0008)	(0.0008)	(0.0009)
Total area owned, t-2 (ln)		0.074	0.076	0.074	0.079
		(0.0004)	(0.0004)	(0.0004)	(0.0004)
Savings, t-2 (ln)		−0.003	−0.003	−0.003	−0.003
		(0.0000)	(0.0000)	(0.0000)	(0.0000)
Household size, t-2		0.028	0.029	0.028	0.028
		(0.0001)	(0.0002)	(0.0001)	(0.0001)
Education, t-2			0.002	0.002	0.003
			(0.0000)	(0.0000)	(0.0000)
Formal loans, t-2 (ln)				0.002	0.001
				(0.0000)	(0.0000)
Informal loans, t-2 (ln)				0.002	0.002
				(0.0000)	(0.0000)
Groups, t-2					−0.017
					(0.0001)
Gender of household head, t-2					0.018
					(0.0001)
Kinh, t-2					−0.073
					(0.0004)
Constant	0.324	−0.600	−0.630	−0.633	−0.532
	(0.0014)	(0.0032)	(0.0033)	(0.0034)	(0.0026)
Observations	5234	5199	5199	5199	5199

Note: Bootstrapped standard errors in parentheses.

A.2. Robustness check: a closer look at household's wealth

In the baseline estimations, we have jointly considered three measures of wealth among the explanatory variables: livestock, savings and total area owned. Since, as shown in Table A.1 there is some correlation between these variables (in particular between livestock and area owned), we re-estimate the model considering only one type of wealth at once. As shown in Tables A.7 and A.8, results are robust: the minimum temperature negatively impacts on rice production which, in turn, negatively affect migration. As far as the covariates are concerned, we found that savings are not significant both in the first and in the second stage when included without any other type of wealth, whereas the other variables are significantly positive, as in the baseline results in both stages. This result points towards some correlation between the wealth variables, which possibly explains the opposite signs between mobile and immobile wealth that we find in the baseline results.

Table A.7
The impact of climate shocks on rice production (first stage, 2SLS).

	(1)	(2)	(3)	(4)
	Rice, t-2 (ln)	Rice, t-2 (ln)	Rice, t-2 (ln)	Rice, t-2(ln)
Dev of min temperature, t-2	−0.674*****, *	−0.654***	−0.662***	−0.689***
	(0.169)	(0.185)	(0.171)	(0.186)
Deviation of rainfall, t-2	−0.002***	−0.002***	−0.002***	−0.002***
	(0.001)	(0.001)	(0.001)	(0.001)
Livestock, t-2 (ln)	0.071***	0.106***		
	(0.011)	(0.012)		
Total area owned, t-2 (ln)	0.368***		0.379***	
	(0.030)		(0.030)	
Savings, t-2 (ln)	−0.015***			−0.007
	(0.004)			(0.005)
Year FE	yes	yes	yes	yes
Region FE	yes	yes	yes	yes
Kleibergen-Paap rk LM statistic	16.07	12.66	15.24	13.91
P value	0.000	0.000	0.000	0.000
Kleibergen-Paap rk Wald F statistic	15.97	12.54	15.13	13.82
adj R-squared	0.857	0.837	0.855	0.834
Observations	5199	5199	5199	5199

Notes: The whole set of covariates is used in the estimations. Standard errors clustered at household level in parentheses. ***p < 0.01, **p < 0.05, *p < 01.

Table A.8
Determinants of migration (second stage, 2SLS).

	(1)	(2)	(3)	(4)
	Migration	Migration	Migration	Migration
Rice, t-2 (ln)	−0.234***	−0.240***	−0.235***	−0.228***
	(0.079)	(0.086)	(0.081)	(0.079)
Deviation of precipitation, t-2	−0.000**	−0.001**	−0.000**	−0.001**
	(0.000)	(0.000)	(0.000)	(0.000)
Livestock, t-2 (ln)	0.022***	0.031***		
	(0.007)	(0.010)		
Total area owned, t-2 (ln)	0.081***		0.085***	
	(0.030)		(0.032)	
Savings, t-2 (ln)	−0.003*			−0.001
	(0.002)			(0.001)
Year FE	yes	yes	yes	yes
Region FE	yes	yes	yes	yes
R2 adj	0.036	0.036	0.035	0.035
Observations	5199	5199	5199	5199

Notes: The whole set of covariates is used in the estimations. Instrument: deviation of the minimum temperature (June t–2). Standard errors clustered at household level in parentheses. ***p < 0.01, **p < 0.05, *p < 01.

A.3. Robustness check: an alternative measure for climate shocks

To further test the robustness of our results, we construct temperature shocks defined as residuals from the time trend. In doing so, we control for possible spurious correlations problems that may arise if both deviations of the minimum temperature and rice production would be trending (for example, because of technical progress). Results, however, are robust: temperature shocks negatively impact rice production which, in turn, negatively impact migration.

Table A.9
The impact of climate shocks on rice production using residuals from a time trend as an alternative measure of climate shocks.

	(1)	(2)	(3)	(4)	(5)
First stage					
Dependent variable: Rice, t-2 (ln)					
Min temperature, t-2	−0.202***	−0.153***	−0.138***	−0.139***	−0.117***
	(0.051)	(0.018)	(0.018)	(0.018)	(0.018)
Second stage					
Dependent variable: migration	−0.074***	−0.075***	−0.065***	−0.064**	−0.071**
	(0.027)	(0.026)	(0.028)	(0.028)	(0.035)
Year FE	yes	yes	yes	yes	yes
Region FE	yes	yes	yes	yes	yes
Kleibergen-Paap rk LM statistic	15.32	66.72	55.12	55.37	39.09
p-value	0.000	0.000	0.000	0.000	0.000
Kleibergen-Paap rk Wald F statistic	15.52	73.00	60.59	60.80	42.56
Observations	5234	5199	5199	5199	5199

Notes: When using the residual from the time trend as the instrument we estimate all the five models adopted previously as shown in Tables 2-3. To calculate this time trend, we use the same reference period we used to calculate deviations of the minimum temperature as explained in section 4.2. Here, we report only the coefficients for our variable of interest, i.e. the minimum temperature shocks in the first stage and the quantity of rice produced in the second stage. Standard errors clustered at household level in parentheses. ***p < 0.01, **p < 0.05, *p < 01.

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