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## **Climate change, rice production, and migration in Vietnamese households**

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**Abstract:** This paper analyses the relationship between climate and migration in rural households in Vietnam. We propose an instrumental variable approach that controls for the potential endogeneity between crop production and migration using monthly minimum temperatures in the growing season as an instrument of rice production. 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 is robust to the use of different estimators and plausible violations to exogeneity of the instrument.

**Keywords:** climate change, rice production, migration, Vietnam

**JEL classification:** O15, R23, Q12, Q54

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## 1 Introduction

In South Asia, “internal climate migrants” could number over 40 million, 1.8 per cent of the region’s total population. Climate migrants are projected to increase by a factor of six between 2020 and 2050, and the share of climate migrants in all internal migrants could reach as high as 25 per cent (Rigaud et al., 2018). According to Dasgupta et al. (2007), Viet Nam is one of the countries that will be highly affected by climate change in the years to come. The impact of climate variations is greatly enhanced by the fact that many Vietnamese households have climate-sensitive livelihoods. Despite its ongoing reduction over the last decades, the share of employment in agriculture on total employment is still high, around 44 per cent in 2015, and agriculture still accounts for a significant part of the GDP, around 20 per cent in 2015 (World Development Indicators).<sup>1</sup> Therefore, public awareness about the negative consequence of climate change is rising: Tarp (2017) stressed that commune leaders consider this issue as a key problem for the future development of their communities. In addition, Viet Nam is also experiencing a significant increase in the number of migrants. As reported by Narciso (2017), 6.6 million people migrated within the country from 2004 to 2009. This figure represents an increase of 46 per cent with respect to the number of internal migrants recorded in the 1999 census.

In light of these considerations, this paper aims to investigate the relationship between climate and migration in rural households in Viet Nam. The stream of literature relating these two phenomena is quite lively: the main hypothesis is that climate variations may dramatically affect the livelihood of individuals, thus, leaving them with no other choice than to migrate. Evidence for this hypothesis has been produced across many studies (Dell et al., 2014; Bohra-Mishra et al., 2014; Mueller et al., 2014; Gray and Mueller, 2012). Results, however, have shown a number of difficulties and contingencies (Thiede et al., 2016).

In this paper we claim that climate change affects rice production, the main crop in Viet Nam, and in turn this modifies the set of the economic opportunities, increasing the cost of rice for consumers (therefore reducing their real income), reducing production for small landowners that see a fall in their income and possibly higher expenditure in fertilizers and irrigation to cope with reduced output, and lower labour demand for workers involved in rice production causing unemployment and lower wages. All these occurrences may lead to migration. To this end it is crucial to choose the most appropriate measure of climatic variation. Among social scientists, climate change is frequently approximated by means of average rainfall and temperature levels (Burke et al., 2011; Feng et al. 2010; Dell et al. 2009). Drawing insights from natural science literature, Caruso et al. (2016) recently argued that the use of the average temperature may overshadow the effect that temperatures have on the growth of the main crop cultivated in a country. Using data about rice production in Indonesia, the authors showed that an increase in minimum temperatures in some key months of the life cycle of this crop led to a reduction of rice production. This, in turn, affects the living conditions of people reducing their opportunity-cost to commit violence.

To test these hypotheses, we propose an instrumental variable approach as adopted by Feng et al. (2010). In this work, the authors estimate the effects that climate variations have on migration through the causal mechanism of agricultural productivity in Mexico. To avoid endogeneity between crop production and migration, however, they instrument crop yields using both annual average temperature, annual average precipitation and summer average temperatures. In our work,

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<sup>1</sup> <https://data.worldbank.org/products/wdi>

we adopt this approach, but we use exogenous deviations in monthly minimum temperatures in the growing season as an instrument of rice production. In our analysis, we also include some controls for the specific socio-economic conditions of the households. We find that the rise of the minimum temperature during the core month of the growing season (i.e. June) does cause a reduction in rice production which, in turns, has a positive impact on people's propensity to migrate. This finding is robust to the use of different estimators.

The paper is organized as follows. Section 2 reports some background data on rice production in Viet Nam, while section 3 is devoted to three short literature reviews; the first one concerning the effect of climate change on rice production, the second about climate change and immigration, and the third regarding the effects of climate change on Vietnamese households. Section 4 explains the empirical strategy used to analyze the impact of climate on migration and introduces the data, while in section 5 we report the results. Section 6 concludes.

## 2 Rice production in Viet Nam<sup>2</sup>

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 can be attributed to both the expansion of the rice-harvested area and to higher yield. Rice yield improved to 5.6 t/ha in 2010 from 3.7 t/ha in 1995. Yield has increased because of modern varieties being put into production, higher use of fertilizers, and an improvement in irrigation. The rice area harvested expanded from 6.8 million ha in 1995 to 7.7 million ha in 2016, but annual growth was only 0.2 per cent from 2005 to 2016, since competition for soil has become stiff (urbanization and industrialization being the main contestants). Viet Nam is the fourth largest world rice exporter. The country's rice exports reached 5.3 million tons in 2005 and almost 6.5 million tons in 2015, generating US\$1.4 billion and contributing to 10.3 per cent of total global rice export. The export performance has been flat in the last few years.

Rice remains the staple food. Average annual per capita consumption rose to 141.2 kg in 2009 from 138.8 kg in 1995. However, the share of total calories per person obtained from rice decreased to 51.7 per cent (1,390 kcal) per day in 2009 from 66.6 per cent (1,407 kcal) per day in 1995. A similar trend is in place for per capita protein intake, for which it now amounts to about 40 per cent of daily consumption. These declines are caused by an increase in consumption of wheat and meat.

Mean annual sea level temperatures range from 27°C in the south to 21°C in the extreme north. Mean annual rainfall ranges from 1,300 to 2,300 mm. Rainfall is usually evenly distributed through June to October or November. In the Mekong Delta, the summer monsoon brings 5–6 months of rainfall above 100 mm/month. There are two monsoon seasons: the northeastern winter monsoon and the southwestern summer monsoon.

The population of Viet Nam was 92.70 million in 2016, with an average density of 270 people per km<sup>2</sup>. Seventy per cent of the population lives in rural areas, mainly in the two rice-growing deltas: the Red River Delta in the north and the Mekong River Delta in the south. The country's total labour force was above 54 million, with the labour force in rural areas accounting for 67.9 per cent. The Mekong River Delta produces most of Vietnam's rice. The other rice-growing regions are the

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<sup>2</sup> Data for this section are drawn from GRiSP (2013) and General Statistics Office of Viet Nam (2017).

Red River Delta,<sup>3</sup> northeast, and the north-central coast. The Mekong Delta has three major cropping seasons: spring or early season; autumn or midseason; and winter, long-duration wet-season crop. The largest rice area is cropped during the autumn season followed by a spring crop; only a small area is cropped in winter. Table 1 reports the production seasons.

Table 1. Production seasons

	<b>Planting</b>	<b>Harvesting</b>
Main	May-Aug	Sep-Dec
Winter-spring	Dec-Feb	Apr-Jun
Summer-autumn	Apr-Jun	Aug-Sep

Source: GRiSP (2013).

In 2016, agriculture production faced several challenges caused by adverse weather such as: extremely cold weather in earlier 2016 in the Northern provinces; drought, heavy rain and flood in the central provinces; especially drought-parched in the Central Highlands, and severe saltwater intrusion in the Mekong River Delta.

In the last twenty years, Viet Nam has changed from a highly centralized planned economy to a socialist-oriented market economy. It undertook structural reforms to modernize the economy and to create more competitive export-driven industries and joined the World Trade Organization in January 2007. As a result, the economic structure is changing: agriculture's share of GDP dropped from about 25 per cent in 2000 to 16 per cent in 2016, as the share of the industrial sector surged to 32 per cent and the service sector to 41 per cent of GDP in the same period.

Rice policy in Viet Nam aims to maintaining domestic food security and promoting rice exports. Government intervention is limited in the domestic market and rice exports are made through state-owned trading enterprises, which buy rice from farmers to keep the price stable and to prevent rice importers from haggling for too low prices during the harvest season. Producers are typically small, which reduces their ability to access credit, capital investments and export.

### 3 Literature

In this section we place our contribution within the three streams of literature to which we contribute. First, we review the natural science literature concerning the effect of climate change on rice production, second, we focus on the link between climate change and immigration, and finally we take stock of the existing results regarding the effects of climate change on Vietnamese households.

#### 3.1 Rice and climate change

Even in the absence of 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 it increases the maintenance respiration requirement of the crops and shorten the time to maturity, thus reducing net growth and productivity. 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 annual mean

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<sup>3</sup> McElwee et al. (2017) find that the increased flood risk in this region will decrease food availability if adaptation is not put in place.

maximum and minimum temperatures have increased by 0.35°C and 1.13°C, respectively, and that grain yield declined by 10 per cent 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 temperature reduced yield, whereas higher maximum temperature raised it. Overall, this would result in a net negative impact on yield from moderate warming, also because prior research indicates that the impact of maximum temperature becomes negative at higher levels.

Although this result holds for other south-eastern countries, studies that focus on China (Huang et al., 2013; Deng et al., 2010; Zhang et al., 2010), find that an increase in temperatures, especially minimum temperatures (Tao et al., 2008), increases rice yields. This apparent contradiction depends on the fact that climate warming may rise yield in cooler climates and lower them in warmer climates (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 impact across countries.<sup>4</sup> Extending the dataset until 2008, Lobell et al. (2011) claim that global warming slightly reduces rice yield in Viet Nam.

Evidence of a negative correlation between sea surface temperature anomaly (SSTA) and rainfall has been provided by Naylor et al. (2007) in a study of Java and Bali, and Roberts et al. (2008) in the Philippines. El Niño events delay rainfall by as much as two months, thereby delaying rice plantings and extending the pre-harvest season when rice prices characteristically rise in consumer markets (Ellis, 1993). The timing of rainfall in the growing season tends to dictate rice-planting patterns for the next 8–9 months, because delayed plantings in the growing season also defer plantings of the dry season crop. The temporary crop reduction is associated with an increase in food prices.

According to FAO (2016: IX), in Viet Nam the 2016 main winter/spring rice crop, which accounts for 45 per cent of annual production nationwide, was negatively affected by limited irrigation availability, following a generally weak rainy season in 2015 associated with El Niño and resulting in intensified saltwater intrusion. The Mekong River Delta, which accounts for half of the winter/spring output, recorded the highest losses with a production reduction of 1.1 million tons year-on-year to 10 million tons.

### **3.2 Climate change and migration**

The standard migration literature focuses on forces considered by migrants as network, pull, and push forces (e.g., Borjas, 1994; Martin and Widgren, 2002). Economic and sociopolitical network forces include forms of various aids. Economic push forces include high unemployment, economic decline, and underdevelopment, while pull forces include employment, prosperity, and development. Sociopolitical push forces include wars and persecution, while pull forces include peace, family unification, and presence of brethren. Reuveny (2007) argues that people can cope with environmental problems in three ways: stay in place and do nothing; stay in place and mitigate changes; or leave affected areas. The choice between these options is based on net perceived benefits and depends on the extent of the problems and mitigation capabilities.<sup>5</sup> Developed

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<sup>4</sup> 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.

<sup>5</sup> 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

countries are likely to mitigate problems through technological innovation, whereas less developed countries are less likely to mitigate such problems because they lack both wealth and expertise.<sup>6</sup> In this sense, migration can be seen as an extreme form of adaptation.

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

We can distinguish two approaches, one macro based on international dataset 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. The majority of the studies finds that rising temperatures have a significant impact on both types of migration. This is particularly true in agriculture-dependent countries, where it works through reducing wages and agricultural productivity. A partial difference involves excess precipitations, which are more relevant for internal migration, although weaker than the effect of temperature, when jointly controlled for. However, these effects are small compared with other causes for migration, and it is likely that it will mainly concern migration between and within African countries.

Estimations involve a number of covariates. The main group of right-hand side variables consider the labour market channel as one of the reasons to decide to migrate: climate change affects jobs opportunities, and people may react leaving their current place. Income and wage are usually included in the regressions to capture this effect. However, they may be hit so bad by climate change that individuals become credit-constrained and therefore unable to collect money to migrate. Ignoring these direct and indirect effects risks drawing mistaken conclusions about the relationship between climate and migration (Beine and Parsons, 2017).<sup>7</sup> Other controlling groups include institutions (in international analyses) and conflict.

### 3.3 Climate change in Viet Nam

A small literature has addressed climate change and natural disasters in Viet Nam. They typically use household surveys (Vietnam Household Living Standard Survey, VHLSS) to analyze the effects of these events in terms of loss in welfare and the way in which households and group cope with them.

Thomas et al. (2010) use household surveys augmented with the natural disaster measures to estimate the welfare effects associated with natural disasters. Short-run losses can be substantial, with riverine floods causing welfare losses of up to 23 per cent and hurricanes reducing welfare by up to 52 per cent inside cities with a population of over 500,000. Households in frequently inundated areas have even been able to turn the floods into an advantage, as long as the flooding is not too severe. There is however no adaptation to hurricanes. Finally, those further away from the large urban centers are not only poorer, but also tend to suffer less from disasters, likely due to the adoption of less risky and less remunerative portfolios and a higher likelihood of receiving disaster relief. Arouri et al. (2015) find that storms, floods, and droughts have negative effects on

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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?

<sup>6</sup> Under certain conditions, in Reuveny (2007) migration may lead to conflict in receiving areas, a result that is challenged by other authors (e.g., Gleditsch et al., 2007).

<sup>7</sup> 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).

household income and expenditure. Households in communes with higher mean expenditure and more equal expenditure distribution are more resilient to natural disasters. Access to micro-credit, internal remittances, and social allowances can help households strengthen the resilience to natural disasters. Bui et al. (2014), correcting for potential endogeneity bias with instrumental variables, and also using Average Treatment Effects on the Treated, find a 6.9 per cent and 7.1 per cent decline in household per capita income and expenditure, respectively.

Narloch (2016) shows that annual, seasonal, abnormal, and extreme weather conditions and weather events are related to income variations. In particular, warmer temperatures and heat extremes can have negative income effects in all climate contexts and for all socioeconomic groups and most income activities. Only staple crops, forestry, and fishing seem to be less sensitive to hotter conditions. Instead, more rainfall is beneficial in drier places but harmful in wetter places, and the incomes of poorer households seem to be negatively affected by wetter conditions, while those of wealthier households are more impacted by drier conditions. In particular, an increase in rainfall levels and flood conditions between 2012 and 2014, which were relatively wet years, is related to reduced income growth between these two years.

Using panel data from rural Vietnam and rainfall data in an instrumental variable approach, Lohmann and Lechtenfeld (2015) find that in the year of droughts populations face an increased risk of illness. Drought-related health shocks also cause financial burden for many households, with health expenditures increasing by 9-17 per cent of total consumption.

A very different approach is taken by Arndt et al. (2015) who adopt a multi-sectoral and dynamic approach and consider the full range of climate projections. Until 2050 the negative impact on agriculture and roads is modest. Larger costs are caused by rising sea levels and cyclone strikes, with a reduction in national income between one and two per cent by 2050 (relative to a historical baseline).

## **4 Data and empirical specification**

### **4.1 Data**

Our dataset uses a balanced version of VARHS household dataset<sup>8</sup> which includes only the families continuously interviewed over the period 2010–16. We drop year 2008 since data on migration were collected starting from 2012 and we use as regressors lagged variables at year 2010. The resulting dataset contains 2,088 households living in 459 communes. Figure 1 maps the communes involved in our analysis.

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<sup>8</sup> For a detailed description of the VARHS dataset we refer to Brandt and Tarp (2017).



Figure 1. The VARHS communes included in our analysis



Source: Authors' own elaboration from VARHS data files.

Our dependent variable is a dummy variable indicating if the family has at least one component which has migrated for working reasons in the two years preceding the interview.<sup>9</sup> Data reporting the reasons of migration are collected in Q11 ancillary files of the VAHRS household dataset. Here, each migrant is listed with the household he belongs to as well as information about its status, education and so on. As shown in table 2, work is the main driver of migration in the VAHRS sample of Vietnamese households: about 45 per cent of people migrated in order to work

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<sup>9</sup> The data do not allow distinguishing between migration within the country and outside the country.

over the period considered while nearly 35 per cent left for study. Other drivers like marriage and army service are far less important.

Table 2. Migrants by reason of migration

Reason	%
Work	45.29
Looking for work	1.07
Education	34.44
Marriage	9.74
Army service	3.82
Family unification	1.68
Escaping Natural disasters	0.05
Other	3.91

Source: Authors' own calculation from VARHS dataset.

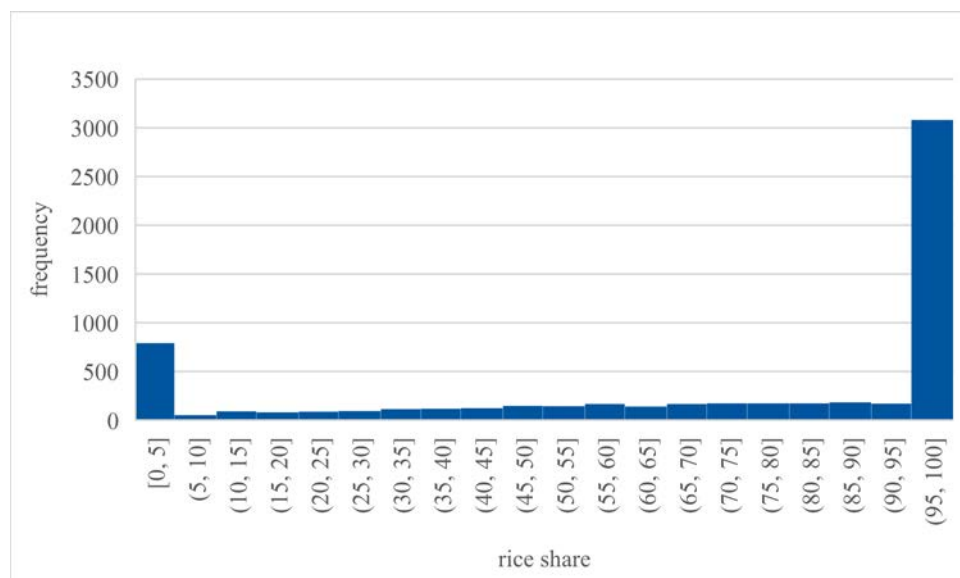
To construct our dependent variable, we selected the households reporting at least one migrant that left for work over the period 2012–16 and we merged this information in our main dataset containing data about VARHS households. It resulted that of 2,088 households about 8 per cent per year reported at least one migrant leaving for work. This number is slightly increasing over the period considered.<sup>10</sup>

Data about rice production are drawn from the VARHS household dataset. As mentioned before, the agricultural sector is still prominent in Vietnamese economy and rice is the main crop grown in Viet Nam. The households in our sample are no exception: 82.33 per cent of them claim that they earn an income from crop agriculture with rice accounting for the large majority of total crop production. Figure 2 reports the share of rice produced over the total production as recorded by the households. The figure shows that a sizable majority of the households grows only rice, while for many it is the main crop.

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<sup>10</sup> Because of the way in which the question is raised in the survey, we cannot ascertain neither whether the migration was internal or international, nor whether it was short- or long-term.

Figure 2. Share of rice on total annual crops production



Source: Authors' own calculation from VARHS dataset.

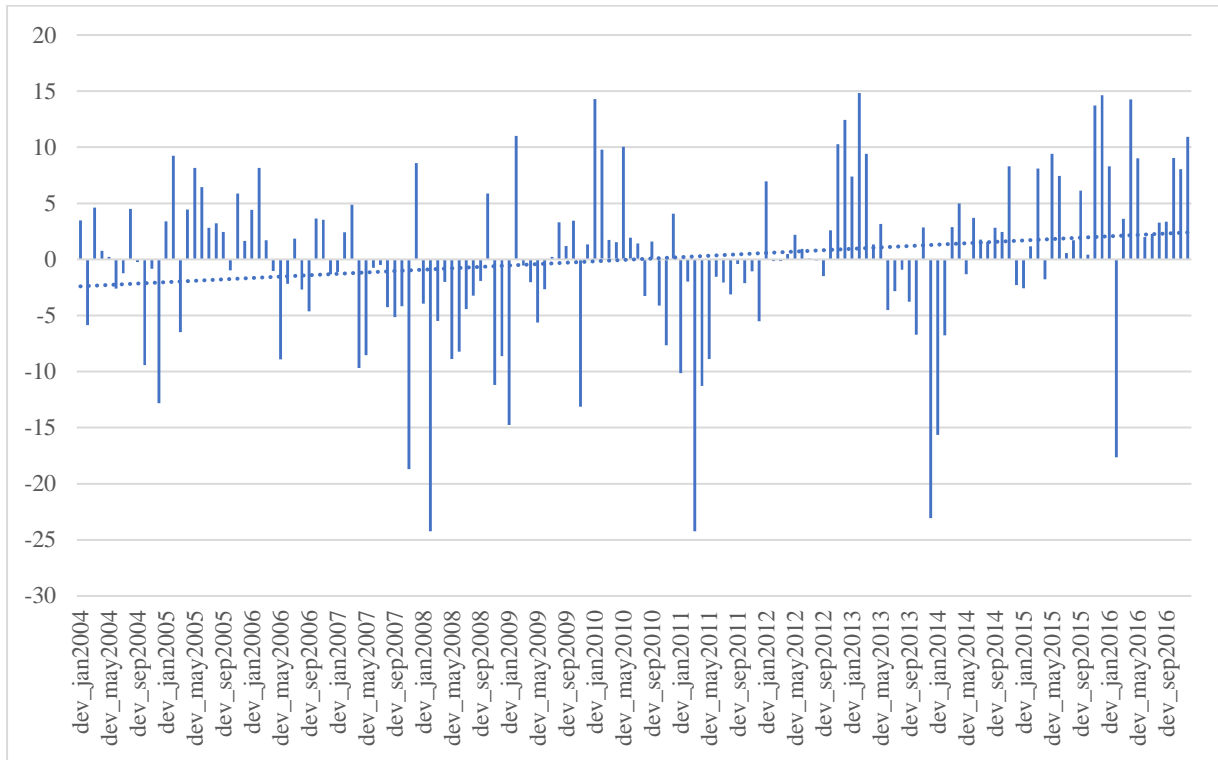
Climatic data are drawn from the CRU TS4.01 of the Climatic Research Unit at the University of East Anglia.<sup>11</sup> This dataset reports monthly time series of rainfall, minimum, mean and maximum temperature from 1901 to 2016 at 0.5 x 0.5-degree grid. Our dataset combines data from the VAHRS household dataset with climate data. This process involved many steps. First, we selected the latitude and longitude of VAHRS communes using data from GADM<sup>12</sup> (Global Administrative Areas), a database that provides the location of the world's administrative areas (boundaries). Then, we grouped communes into 56 0.5 x 0.5-degree grids to which we attributed their minimum temperature and precipitation values as reported by CRU TS4.01. Finally, we computed the monthly deviations of observed minimum temperature and rainfall from the monthly average.<sup>13</sup> Figures 3 and 4 provide climate patterns resulting from plotting these two variables. Figure 3 shows that there is a tendency towards an increase in minimum temperatures since 2010. Conversely, the patterns in figure 4 do not show any increase in rainfall. The absence of a clear pattern in deviations in rainfall leads us to drop this variable from our analysis.

<sup>11</sup> Data source: [http://wps-web1.ceda.ac.uk/submit/form?proc\\_id=Subsetter](http://wps-web1.ceda.ac.uk/submit/form?proc_id=Subsetter)

<sup>12</sup> Data source: <https://gadm.org/>

<sup>13</sup> To reduce the influence of outliers when calculating the mean, 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).

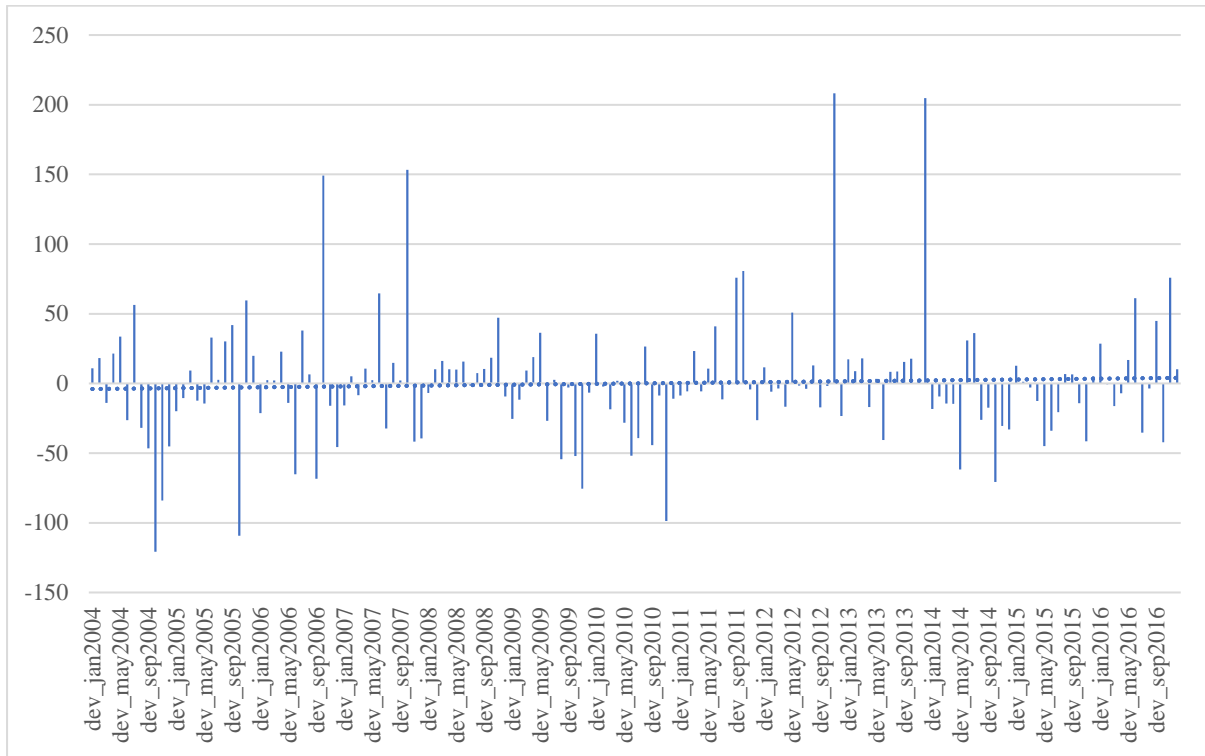
Figure 3. Monthly deviation of minimum temperature in Viet Nam^



Notes: ^Deviation in °C\*10

Source: Authors' own calculation from CRU TS4.01.

Figure 4. Monthly deviation of rainfall in Viet Nam



Notes: ^Deviation in mm rainfall

Source: Authors' own calculation from CRU TS4.01.

## 4.2 Method and estimation

Our aim is to identify the impact of climate change on migration throughout the channel of rice production. To test this hypothesis, we adopt an instrumental variable (IV) approach<sup>14</sup> using the deviation of minimum temperature during rice growing season as instrument for rice production. This variable indicates how much a month has been warmer or colder when compared to the average month. The choice of this instrument is in line with what is described by the scientific literature about rice and climate change which claimed, as reported in section 3.1, that if a shock occurs at this stage of the process, future crops are severely affected. As illustrated in the rice calendar (see table 1), the core of the growing period is over the period from May to July. In particular, we use deviations recorded in June because it is in the middle of the growing phase of rice in Viet Nam where rice is more vulnerable to shocks. Thus, to test our model we estimate the following equation:

$$Migration_{it} = \beta_0 + \beta_1 Rice_{it-1} + \beta_2 X_{it-1} + \varepsilon_{it} \quad (1)$$

where the subscript  $i$  indicates the household,  $Rice$  is the proportion of rice production which is explained by the instruments and  $X$  is the set of covariates.

The first stage regression of this equation is:

$$Rice_{it-1} = f(Dev \ min \ temperature \ June_{jt-1}, X_{it-1}) \quad (2)$$

<sup>14</sup> This approach has been proposed for the study of climate change and conflict by Miguel et al. (1994).

Where the subscript  $j$  indicates the cell of the grid for which we have climate data,  $Dev_{min} temperature June e$  is the deviation of minimum temperature in June.

Rice production (and consequently the deviations) as well as the covariates are lagged. Specifically, to describe migration in year 2016 we use variables of year 2014 while to analyze the phenomenon in 2014 we use factors of 2012 and so on. This choice is due to the retrospective nature of our dependent variable. When asked about migration the interviewee is questioned if the household has a member who has left in the last two years. This means that migration already happened before the interview was made. Therefore, migration should be explained by factors that occurred in years before the interview.

The choice of covariates depends on the established literature and data availability. We include a set of covariates describing the households' economic and social conditions. As seen in section 3.2, the propensity of an individual to migrate can be affected by these characteristics. Therefore, we first account for household's financial and human capital as well as their demographic characteristics (Bohra-Mishra et al., 2014). Beside traditional measures like income, education and the size of the households, the total area and the number of livestock owned are also included as controls for rural households' wealth. As proxy for the job market characteristics, we adopt the number of days worked per household member in wage work.

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, therefore, the availability of money can positively impact on migration. Furthermore, we also control for the quality of the social and institutional environment that, as previously mentioned, is considered by migrants as a pull force. To do so, the number of household member joining local groups and organizations is used as proxy. Finally, we include in our model two variables indicating the ethnicity of the household and the gender of the household head, respectively. In doing so, we want to take into account the different migration dynamics that these two disadvantaged groups may present (Narciso, 2017). Table 3 lists definitions of variables and descriptive statistics. Table A1 in the Appendix reports the correlation matrix of these variables.

Table 3. Summary Statistics

Variable	Description	Obs.	Mean	Std. Dev.	Min	Max
Migration	If the hh has at least one component who has left for work	6,264	0.080	0.271	0.000	1.000
Rice, t-1 (ln)	What was the total quantity of rice produced?	5,234	6.100	3.017	0.000	12.548
Livestock, t-1 (ln)	Number of all livestock currently owned	6,264	1.975	1.769	0.000	12.429
Fertilizers, t-1 (ln)	Value in total production: Chemical fertilizers (urea, NPK, phosphate)	5,436	5.611	3.347	0.000	12.742
Total area owned, t-1 (ln)	Total area owned	6,264	7.892	1.572	0.000	12.175
Household size, t-1 (ln)	Number of hh members	6,264	1.346	0.480	0.000	2.639
Household income, t-1 (ln)	Real, annual hh income	6,214	10.418	2.628	0.000	15.126
Days worked, t-1 (ln)	Days worked per hh member in wage work in last 12 months	6,264	2.168	2.361	0.000	5.889
Education, t-1 (ln)	Education per capita	6,264	2.172	0.483	0.000	2.674
Formal loans, t-1 (ln)	Total amount of formal loans	6,264	3.023	4.669	0.000	15.447
Informal loans, t-1 (ln)	Total amount of informal loans	6,264	1.354	3.355	0.000	15.010
Groups, t-1 (ln)	Number of hh members join local groups, or associations	6,264	1.008	0.483	0.000	2.398
Kinh, t-1	1 if the hh is kinh; 0 otherwise	6,264	0.802	0.399	0.000	1.000

Gender of household head, t-1	1 if the hh has a male head; 0 otherwise	6,264	0.777	0.416	0.000	1.000
Dev of min temperature, t-1	Deviation of the minimum temperature from the average value in the period 2004– 2016 in June, C*10	6,264	2.341	1.855	-1.462	6.231

Source: Authors' own calculation from VARHS dataset.

In light of the binary nature of our dependent variable and of the IV approach chosen, three different estimators are employed. First, we adopt a TSLS estimator as baseline model. The use of OLS fits well in the first stage where the dependent variable (rice) is continuous and it is also appropriate in the second stage for our binary dependent variable. We, then, adopt a generalized linear model to implement both a logit and a probit model with endogenous regressors. The GLM is a generalization of an ordinary linear regression model where the response variable can have errors non-normally distributed (Nelder and Wedderburn, 1972). This model is estimated in Stata by the qvf routine (Hardin and Schmiediche, 2003) which performs it by using maximum quasi-likelihood and also allows for instrumental variables.<sup>15</sup> The Qvf routine, however, presents some limitations. The coefficients are not generally interpretable and marginal effects cannot be computed. Thus, despite the presence of statistically significant coefficients, it is possible only to infer a qualitative relation between our variables of interest.

## 5 Empirical results

### 5.1 Baseline results

#### 5.1.1 First stage: the impact of climate change on rice production

This section describes results from the first stage of our IV estimation as illustrated by Equation (2).<sup>16</sup> 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 with the dependent variable, i.e. rice production, as predicted in the natural science literature in the field (see section 3.1). Results, presented in table 4, 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 change on this crop.

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 verify the validity of our instrument. In order to be valid, our instrument is required to satisfy two conditions: a) it has to be correlated with the endogenous variable (relevance condition); b) it has to be exogenous, that is it should not be correlated with the error term (exclusion restriction).

Statistical tests support the relevance of the instrument. We first control for under-identification using the Kleibergen-Paap LM statistic which checks whether the instrument is correlated with the endogenous regressor. The p-values always reject the null that the equation is under-identified.

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<sup>15</sup> Dube and Vargas (2013) and Caruso et al. (2016) employed the qvf routine to estimate the impact of climate-related changes of crop intensity on violence.

<sup>16</sup> In the Appendix, Table A2 reports the reduced-form estimation of the the effect of deviation of the minimum temperature on migration.

Furthermore, since nonzero correlation is not sufficient for strong identification, we also use Kleibergen-Paap Wald F statistic to test for weak identification. The figures for this test clearly show that the instrument is not weak: the values of the F-test are always above the Stock and Yogo (2005) critical values.

Table 4. The impact of climate change of rice production (first stage, TSLS)

VARIABLES	(1) Rice, t-1 (ln)	(2) Rice, t-1 (ln)	(3) Rice, t-1 (ln)	(4) Rice, t-1 (ln)	(5) Rice, t-1 (ln)
Dev min temperature, t-1	-0.135*** (0.030)	-0.099*** (0.017)	-0.085*** (0.016)	-0.085*** (0.016)	-0.066*** (0.017)
Livestock, t-1 (ln)		0.057*** (0.011)	0.068*** (0.011)	0.069*** (0.011)	0.072*** (0.011)
Fertilizers, t-1 (ln)		0.713*** (0.017)	0.687*** (0.018)	0.688*** (0.018)	0.696*** (0.017)
Total area owned, t-1 (ln)		0.410*** (0.032)	0.372*** (0.029)	0.373*** (0.029)	0.344*** (0.028)
Household size, t-1 (ln)		0.339*** (0.044)	0.313*** (0.043)	0.319*** (0.043)	0.269*** (0.043)
Household income, t-1 (ln)			0.104*** (0.008)	0.104*** (0.008)	0.106*** (0.008)
Days worked, t-1 (ln)			0.016 (0.010)	0.016 (0.010)	0.014 (0.010)
Education, t-1 (ln)			-0.415*** (0.052)	-0.410*** (0.052)	-0.286*** (0.051)
Formal loans, t-1 (ln)				-0.006* (0.004)	
Informal loans, t-1 (ln)				-0.001 (0.005)	
Groups, t-1 (ln)					-0.246*** (0.044)
Kinh, t-1					-0.395*** (0.062)
Gender of household head, t-1					0.023 (0.040)
Constant	7.060*** (0.292)	-1.640*** (0.220)	-1.507*** (0.226)	-1.514*** (0.226)	-1.100*** (0.226)
Year dummies	yes	yes	yes	yes	yes
Region dummies	yes	yes	yes	yes	yes
Kleibergen-Paap rk LM statistic p-value	20.147 0	35.823 0	27.024 0	26.809 0	15.951 0
Kleibergen-Paap rk Wald F statistic	20.517	35.675	26.873	26.653	15.818
Adjusted R <sup>2</sup>	0.022	0.851	0.861	0.861	0.864
Conley-Hansen-Rossi $\gamma/\alpha_1$	0.71	0.72	0.65	0.69	0.63
Observations	5,234	5,199	5,159	5,159	5,159

Notes: Standard errors clustered at regional level in parentheses; \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Source: Authors' own calculation from VARHS dataset.

Supporting the exclusion restriction, on the other hand, is quite difficult. Although we believe that, given the importance of rice production in Viet Nam, its reduction caused by an increase in the minimum temperature indeed plays a key role in determining migration, we cannot exclude ex-ante that minimum temperature affects migration throughout other channels than rice production. Furthermore, the adoption of one instrument does not allow to use the Hansen J statistics test that checks whether the model is over-identified i.e. that all the instruments employed are exogenous.



To test the plausibility of our exclusion restriction, we use the method described by Conley et al. (2012).<sup>17</sup> The ratio  $\gamma / \alpha_1$  in table 4 can be interpreted as the maximum hypothetical violations of the exogeneity of the instrument we can allow for without rejecting that the minimum temperature affects migration through rice production (Bentzen et al., 2017). Further explanations about this method will be provided in section 5.2.2.

### 5.1.2 Second stage: the determinants of migration

In this section we describe results of Equation (1), estimated with the three different methods explained in section 4.2. As presented in tables 4-6, we adopt five models which differ according to the covariates included and all have standard errors clustered at regional level. Specifically, the first model measures the effect of rice production without the inclusion of any covariate. We, then, include those regressors controlling for the economic and social conditions of the households.

Table 5. Determinants of migration (second stage, TSLS)

VARIABLES	(1) Migration	(2) Migration	(3) Migration	(4) Migration	(5) Migration
Rice, t-1 (ln)	-0.140*** (0.042)	-0.198*** (0.048)	-0.212*** (0.058)	-0.207*** (0.057)	-0.257*** (0.084)
Livestock, t-1 (ln)		0.019*** (0.004)	0.022*** (0.005)	0.022*** (0.005)	0.026*** (0.007)
Fertilizers, t-1 (ln)		0.147*** (0.034)	0.149*** (0.040)	0.145*** (0.039)	0.182*** (0.058)
Total area owned, t-1 (ln)		0.073*** (0.021)	0.074*** (0.023)	0.072*** (0.023)	0.086*** (0.030)
Household size, t-1 (ln)		0.108*** (0.021)	0.089*** (0.023)	0.085*** (0.023)	0.093*** (0.028)
Household income, t-1 (ln)			0.020*** (0.006)	0.019*** (0.006)	0.025*** (0.009)
Days worked, t-1 (ln)			0.015*** (0.003)	0.015*** (0.003)	0.015*** (0.003)
Education, t-1 (ln)			-0.053* (0.028)	-0.052* (0.027)	-0.046 (0.029)
Formal loans, t-1 (ln)				0.002 (0.001)	
Informal loans, t-1 (ln)				0.002 (0.002)	
Groups, t-1 (ln)					-0.059** (0.026)
Kinh, t-1					-0.074* (0.042)
Gender of household head, t-1					0.018 (0.014)
Constant	0.951*** (0.278)	-0.395*** (0.113)	-0.467*** (0.120)	-0.457*** (0.119)	-0.461*** (0.130)
Year dummies	yes	yes	yes	yes	yes
Region dummies	yes	yes	yes	yes	yes
Observations	5,234	5,199	5,159	5,159	5,159

Notes: Instrument: deviation of the minimum temperature (June t-1). Standard errors clustered at regional level in parentheses; \*\*\* p<0.01, \*\* p<0.05, \* p<0.1. Source: Authors' own calculation from VARHS dataset.

<sup>17</sup> This approach has been recently used by different authors who cannot exclude possible violations of the exogeneity assumption: among them, Dinuccio and Prado (2012), Satyanath et al. (2017), Nunn and Wantchekon (2011), Auer (2013), Fatas and Mihov (2013), Bentzen et al. (2017), Madsen and Murtin (2017), and Fletcher and Marksteiner (2017).

Table 6. Determinants of migration (second stage, logit)

VARIABLES	(1) Migration	(2) Migration	(3) Migration	(4) Migration	(5) Migration
Rice, t-1 (ln)	-1.886*** (0.548)	-1.275*** (0.244)	-2.817*** (0.767)	-2.715*** (0.754)	-3.571*** (1.140)
Livestock, t-1 (ln)		0.167*** (0.034)	0.289*** (0.070)	0.278*** (0.069)	0.352*** (0.097)
Fertilizers, t-1 (ln)		1.003*** (0.178)	1.995*** (0.527)	1.924*** (0.518)	2.541*** (0.794)
Total area owned, t-1 (ln)		0.357*** (0.106)	1.000*** (0.305)	0.958*** (0.299)	1.190*** (0.410)
Household size, t-1 (ln)		0.997*** (0.156)	1.303*** (0.312)	1.239*** (0.310)	1.385*** (0.384)
Household income, t-1 (ln)			0.250*** (0.090)	0.240*** (0.088)	0.333*** (0.129)
Days worked, t-1 (ln)			0.209*** (0.043)	0.211*** (0.042)	0.217*** (0.048)
Education, t-1 (ln)			0.142 (0.477)	0.136 (0.465)	0.180 (0.494)
Formal loans, t-1 (ln)				0.017 (0.015)	
Informal loans, t-1 (ln)				0.027 (0.019)	
Groups, t-1 (ln)					-0.883** (0.366)
Kinh, t-1					-1.181** (0.562)
Gender of household head, t-1					0.228 (0.200)
Constant	9.082** (3.627)	-5.076*** (0.539)	-12.319*** (1.769)	-12.053*** (1.734)	-12.139*** (1.933)
Year dummies	yes	yes	yes	yes	yes
Region dummies	yes	yes	yes	yes	yes
Observations	5,234	5,199	5,159	5,159	5,159

Notes: Instrument: deviation of the minimum temperature (June t-1). Standard errors clustered at regional level in parentheses; \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Source: Authors' own calculation from VARHS dataset.

Table 7. Determinants of migration (second stage, probit)

VARIABLES	(1) Migration	(2) Migration	(3) Migration	(4) Migration	(5) Migration
Rice, t-1 (ln)	-0.941*** (0.272)	-1.336*** (0.317)	-1.414*** (0.386)	-1.373*** (0.381)	-1.781*** (0.571)
Livestock, t-1 (ln)		0.122*** (0.028)	0.146*** (0.035)	0.141*** (0.035)	0.177*** (0.049)
Fertilizers, t-1 (ln)		0.998*** (0.226)	1.000*** (0.265)	0.971*** (0.262)	1.266*** (0.397)
Total area owned, t-1 (ln)		0.487*** (0.141)	0.501*** (0.153)	0.485*** (0.151)	0.594*** (0.205)
Household size, t-1 (ln)		0.759*** (0.140)	0.660*** (0.157)	0.630*** (0.157)	0.702*** (0.192)
Household income, t-1 (ln)			0.126*** (0.045)	0.122*** (0.044)	0.166*** (0.064)
Days worked, t-1 (ln)			0.106*** (0.021)	0.107*** (0.021)	0.110*** (0.024)
Education, t-1 (ln)			-0.010 (0.224)	-0.010 (0.218)	0.014 (0.232)
Formal loans, t-1 (ln)				0.009 (0.008)	
Informal loans, t-1 (ln)				0.014 (0.010)	
Groups, t-1 (ln)					-0.444** (0.183)
Kinh, t-1					-0.570** (0.282)
Gender of household head, t-1					0.104 (0.100)
Constant	4.361** (1.799)	-4.786*** (0.750)	-6.149*** (0.873)	-6.054*** (0.862)	-6.073*** (0.951)
Year dummies	yes	yes	yes	yes	yes
Region dummies	yes	yes	yes	yes	yes
Observations	5,234	5,199	5,159	5,159	5,159

Notes: Instrument: deviation of the minimum temperature (June t-1). Standard errors clustered at regional level in parentheses; \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Source: Authors' own calculation from VARHS dataset.

Results show that rice production is negatively correlated with migration: a decrease in the quantity of rice produced increases the probability to migrate. This result is robust across different specifications and estimators.

As far as the covariates are concerned, figures illustrate that migration is more likely among the wealthier households. This finding is in line with those studies claiming that individuals leaving their homeplace must be able to afford the cost of migration and, therefore, only those belonging to well-off families are able to migrate. In particular, studying the effect of climate change on migration in Tanzania, Maurel and Kubic (2016) found that this phenomenon is positively related with those variables controlling for the prosperity and the size of the households such as the number of livestock, the area owned, income and education. Similarly, our results show that the coefficients for these regressors are significant and positive. In contrast with the literature in the field, however, education is not always significant and, when significant, negatively related with migration. This may be due to the exclusion of the individuals who migrate for studying from our sample.

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 income: 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 with 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. Kinh people are the majority ethnic group in Viet Nam, are better integrated and enjoy a bigger social network than non-Kinh people (Singhal and Beck, 2017). Finally, the gender of the household is not significantly impacting on migration. Estimating by logit and probit yields robust results.

## 5.2 Robustness checks

### 5.2.1 Sensitivity analysis: the effect of possible violations of the exclusion restriction

In this paragraph, we use the approach proposed by Conley et al. (2012) to assess the robustness of our results to possible violations of the exclusion restriction. This approach consists in letting the instrument enter the second-stage regression with a coefficient of  $\gamma$ , that is

$$Migration_{it} = \beta_0 + \beta_1 Rice_{it-1} + \beta_2 X_{it-1} + \gamma Dev\ min\ temperature\ June_{jt-1} + \varepsilon_{it} \quad (3)$$

where  $\gamma$  is a parameter set by the econometrician. Equation 3 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  $\gamma$  may take” (Clarke and Matta, 2017, p. 5). This produces confidence intervals on  $\beta$  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  $\gamma$  (see tables 8-12). First, since the reduce-effect of minimum temperature on migration is positive (see table B.1), 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 we allow growing positive violations of the exogeneity assumption as large as  $\gamma_{[max]}$ , which corresponds to different percentages of the minimum temperature reduced-form effect on migration (see table B.1). In detail, we first assume small violations, that is we include small percentages of the minimum temperature reduced-form effect on migration in the second stage (see tables 8-10). The larger the violations, the highest the level of endogeneity in the model. Eventually, we find the largest possible positive value of  $\gamma_{[max]}$  for which rice production is still significant at the 10 per cent level (see table 11). Results show how our analysis changes when increasing parts of the reduced-form effect of minimum temperature on migration is not captured by rice production. Table 12 describes the outcomes of our estimation when the endogeneity is such to invalidate our hypothesis.

The main findings of this analysis are twofold. On the one hand, we observe that the effect of rice production on migration remains negative even if we allow for substantial violations of the exclusion restriction. The ratio provided in table 4 are derived from table 11 dividing the largest possible positive value of  $\gamma_{[max]}$ , for which rice production is still significant at 10 per cent level by the reduced-form coefficient of the minimum temperature on migration. These ratios indicate that the coefficient for rice production remains significant even if more than 60 per cent of the overall effect of our instrument on the dependent variable is not captured by the channel of rice

production. It is noteworthy that these ratios are, as shown by Conley et al. (2012), sensitive to the strength of the instrument, which decreases as more control variables are included into the model, i.e. in columns (4) and (5). Table 12, moreover, illustrates that to make our IV results insignificant, two-thirds of the overall effect of our instrument would have to come through some omitted third variable.

Our sensitivity analysis, on the other hand, also shows that the higher the endogeneity of our instrument, the more controls become not significant. Specifically, tables 8–9 point out that education as well as the ethnicity of the household 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, other controls, like the household income and land owned, lose their significance (see tables 10–12). This finding leads us to re-assess some of the results in tables 4–7 since it supports the idea that potential violation of the exogeneity of the instrument may lead to some measurements errors. However, while we cannot rule out that minimum temperature affects migration through other channels, rice production still is an important explanation of why people migrate from their home.

Table 8. Sensitivity analysis using Conley test of plausible exogeneity (violation size: 20 per cent of reduced-form)

	(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
$\gamma_{max}$		0.003		0.004		0.003		0.003		0.003
Livestock, t-1 (ln)			0.0097	0.0257	0.0118	0.0311	0.0111	0.0303	0.0123	0.0380
Fertilizers, t-1 (ln)			0.0664	0.2036	0.0644	0.2141	0.0614	0.2096	0.0641	0.2779
Total area owned, t-1 (ln)			0.0245	0.1079	0.0269	0.1120	0.0253	0.1095	0.0259	0.1350
Household size, t-1 (ln)			0.0631	0.1421	0.0429	0.1264	0.0388	0.1223	0.0403	0.1388
Household income, t-1 (ln)					0.0061	0.0301	0.0057	0.0295	0.0061	0.0397
Days worked, t-1 (ln)					0.0100	0.0197	0.0100	0.0197	0.0099	0.0208
Education, t-1 (ln)					-0.0988	0.0040	-0.0973	0.0032	-0.0934	0.0090
Formal loans, t-1 (ln)							-0.0004	0.0036		
Informal loans, t-1 (ln)							-0.0002	0.0050		
Groups, t-1 (ln)									-0.1023	-0.0100
Kinh, t-1									-0.1419	0.0061
Gender of household head, t-1									-0.0052	0.0406
Rice, t-1 (ln)	-0.2091	-0.0545	-0.2775	-0.0851	-0.3064	-0.0888	-0.3001	-0.0849	-0.3947	-0.0879
Constant	0.3783	1.4075	-0.5802	-0.1625	-0.6650	-0.2330	-0.6527	-0.2250	-0.6760	-0.2200

Source: Authors' own calculation from VARHS dataset.

Table 9. Sensitivity analysis using Conley test of plausible exogeneity (violation size: 40 per cent of reduced-form)

	(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
$\gamma_{max}$		0.007		0.007		0.007		0.006		0.006
Livestock, t-1 (ln)			0.0084	0.0257	0.0093	0.0311	0.0092	0.0303	0.0100	0.0380
Fertilizers, t-1 (ln)			0.0480	0.2036	0.0378	0.2141	0.0414	0.2096	0.0408	0.2779
Total area owned, t-1 (ln)			0.0144	0.1079	0.0130	0.1120	0.0148	0.1095	0.0148	0.1350
Household size, t-1 (ln)			0.0550	0.1421	0.0317	0.1264	0.0303	0.1223	0.0323	0.1388
Household income, t-1 (ln)					0.0022	0.0301	0.0027	0.0295	0.0027	0.0397
Days worked, t-1 (ln)					0.0097	0.0197	0.0098	0.0197	0.0098	0.0208
Education, t-1 (ln)					-0.0988	0.0187	-0.0973	0.0141	-0.0934	0.0172
Formal loans, t-1 (ln)							-0.0004	0.0037		
Informal loans, t-1 (ln)							-0.0002	0.0050		
Groups, t-1 (ln)									-0.1023	-0.0030
Kinh, t-1									-0.1419	0.0182
Gender of household head, t-1									-0.0052	0.0406
Rice, t-1 (ln)	-0.2091	-0.0322	-0.2775	-0.0593	-0.3064	-0.0501	-0.3001	-0.0557	-0.3947	-0.0545
Constant	0.2182	1.4075	-0.5802	-0.1250	-0.6650	-0.1818	-0.6527	-0.1863	-0.6760	-0.1907

Source: Authors' own calculation from VARHS dataset.

Table 10. Sensitivity analysis using Conley test of plausible exogeneity (violation size: 60 per cent of reduced-form)

	(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
$\gamma_{max}$		0.010		0.011		0.010		0.010		0.010
Livestock, t-1 (ln)			0.0065	0.0257	0.0074	0.0311	0.0065	0.0303	0.0067	0.0380
Fertilizers, t-1 (ln)			0.0227	0.2036	0.0169	0.2141	0.0134	0.2096	0.0075	0.2779
Total area owned, t-1 (ln)			0.0002	0.1079	0.0020	0.1120	0.0000	0.1095	-0.0012	0.1350
Household size, t-1 (ln)			0.0437	0.1421	0.0228	0.1264	0.0180	0.1223	0.0205	0.1388
Household income, t-1 (ln)					-0.0009	0.0301	-0.0014	0.0295	-0.0023	0.0397
Days worked, t-1 (ln)					0.0094	0.0197	0.0094	0.0197	0.0094	0.0208
Education, t-1 (ln)					-0.0988	0.0305	-0.0973	0.0297	-0.0934	0.0293
Formal loans, t-1 (ln)							-0.0004	0.0039		
Informal loans, t-1 (ln)							-0.0002	0.0050		
Groups, t-1 (ln)									-0.1023	0.0073
Kinh, t-1									-0.1419	0.0360
Gender of household head, t-1									-0.0052	0.0406
Rice, t-1 (ln)	-0.2091	-0.0147	-0.2775	-0.0238	-0.3064	-0.0197	-0.3001	-0.0150	-0.3947	-0.0066
Constant	0.0928	1.4075	-0.5802	-0.0719	-0.6650	-0.1403	-0.6527	-0.1305	-0.6760	-0.1465

Source: Authors' own calculation from VARHS dataset.



Table 11. Sensitivity analysis using Conley test of plausible exogeneity (violation size: maximal)

	(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
$\gamma_{max}$		0.012		0.013		0.011		0.011		0.10
Livestock, t-1 (ln)			0.0055	0.0257	0.0067	0.0311	0.0058	0.0303	0.0067	0.0380
Fertilizers, t-1 (ln)			0.0096	0.2036	0.0097	0.2141	0.0062	0.2096	0.0075	0.2779
Total area owned, t-1 (ln)			-0.0071	0.1079	-0.0018	0.1120	-0.0038	0.1095	-0.0012	0.1350
Household size, t-1 (ln)			0.0377	0.1421	0.0197	0.1264	0.0148	0.1223	0.0205	0.1388
Household income, t-1 (ln)					-0.0020	0.0301	-0.0025	0.0295	-0.0023	0.0397
Days worked, t-1 (ln)					0.0093	0.0197	0.0093	0.0197	0.0094	0.0208
Education, t-1 (ln)					-0.0988	0.0346	-0.0973	0.0338	-0.0934	0.0293
Formal loans, t-1 (ln)							-0.0004	0.0040		
Informal loans, t-1 (ln)							-0.0002	0.0050		
Groups, t-1 (ln)									-0.1023	0.0073
Kinh, t-1									-0.1419	0.0360
Gender of household head, t-1									-0.0052	0.0406
Rice, t-1 (ln)	-0.2091	-0.0025	-0.2775	-0.0054	-0.3064	-0.0093	-0.3001	-0.0045	-0.3947	-0.0066
Constant	0.0060	1.4075	-0.5802	-0.0437	-0.6650	-0.1258	-0.6527	-0.1156	-0.6760	-0.1465

Source: Authors' own calculation from VARHS dataset.

Table 12. Sensitivity analysis using Conley test of plausible exogeneity (violation size: 75 per cent of reduced-form)

	(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
$\gamma_{max}$		0.013		0.014		0.013		0.012		0.012
Livestock, t-1 (ln)			0.0050	0.0257	0.0053	0.0311	0.0050	0.0303	0.0049	0.0380
Fertilizers, t-1 (ln)			0.0029	0.2036	-0.0050	0.2141	-0.0012	0.2096	-0.0105	0.2779
Total area owned, t-1 (ln)			-0.0109	0.1079	-0.0096	0.1120	-0.0078	0.1095	-0.0099	0.1350
Household size, t-1 (ln)			0.0346	0.1421	0.0133	0.1264	0.0115	0.1223	0.0140	0.1388
Household income, t-1 (ln)					-0.0042	0.0301	-0.0036	0.0295	-0.0050	0.0397
Days worked, t-1 (ln)					0.0090	0.0197	0.0092	0.0197	0.0092	0.0208
Education, t-1 (ln)					-0.0988	0.0431	-0.0973	0.0380	-0.0934	0.0360
Formal loans, t-1 (ln)							-0.0004	0.0040		
Informal loans, t-1 (ln)							-0.0002	0.0050		
Groups, t-1 (ln)									-0.1023	0.0131
Kinh, t-1									-0.1419	0.0458
Gender of household head, t-1									-0.0052	0.0406
Rice, t-1 (ln)	-0.2091	0.0038	-0.2775	0.0040	-0.3064	0.0121	-0.3001	0.0063	-0.3947	0.0192
Constant	-0.0385	1.4075	-0.5802	-0.0292	-0.6650	-0.0956	-0.6527	-0.1003	-0.6760	-0.1214

Source: Authors' own calculation from VARHS dataset.

### 5.2.2 Placebo test

To check the robustness of our results, we run a placebo test using the deviation of maximum temperature<sup>18</sup> as instrument in place of the deviation of minimum temperature. According to Welch et al. (2010), an increase in the maximum temperature has a positive effect on crops, although this effect is more than offset by the negative impact of rising minimum temperature (see section 3.1). Hence, a significantly negative coefficient for this variable would contradict our main findings. Nevertheless, our results show that there is no significant relationship between the deviation of maximum temperature and rice production in almost all our models (table 13). Only in model 2 the two variables are positively and significantly related at 10 per cent level. The values of Kleibergen-Paap Wald F statistics, however, are very low suggesting that the deviation of maximum temperature, even where it is significant, is too weakly correlated with rice production to be used as an appropriate instrument.

Table 13. Placebo test, TSLS (deviation of max temperature as instrument)

	(1)	(2)	(3)	(4)	(5)
<b>First stage</b>					
Dependent variable: Rice, t-1 (ln)					
Dev max temperature, t-1	-0.014 (0.012)	0.014** (0.007)	0.008 (0.007)	0.008 (0.007)	-0.002 (0.006)
Adjusted R <sup>2</sup>	0.020	0.849	0.860	0.860	0.863
<b>Second stage</b>					
Dependent variable: Migration					
Rice, t-1 (ln)	-0.234 (0.216)	0.261 (0.164)	0.581 (0.537)	0.536 (0.485)	-2.288 (6.329)
Year dummies	yes	yes	yes	yes	yes
Region dummies	yes	yes	yes	yes	yes
Kleibergen-Paap rk LM statistic	1.475	4.215	1.353	1.438	0.131
p-value	0.225	0.040	0.245	0.230	0.717
Kleibergen-Paap rk Wald F statistic	1.469	4.221	1.352	1.437	0.131
Observations	5,234	5,199	5,159	5,159	5,159

Notes: When using the deviation of maximum temperature as instrument we estimate all the five models adopted previously as reported in tables 4-7. Here, we report only the coefficients for our variable of interest, that is the deviation of maximum temperature in the first stage and the quantity of rice produced in the second stage. Standard errors clustered at regional level in parentheses; \*\*\* p<0.01, \*\* p<0.05, \* p<0.1. In this regression, we do not use the Conley test 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.

Source: Authors' own calculation from VARHS dataset.

## 6 Conclusions

This paper addressed the relationship between climate change and migration by focusing on the channel of rice production. By exploiting the link between minimum temperature and rice production, which is the object of a stream of literature in the natural sciences, we identify a specific link that was missing in the literature. Viet Nam, the fifth world rice producer, has been our testbed given the availability of fine-grained household data. In an economy in which rice is the staple food, the negative impact of increasing minimum temperature on rice crops may cause people to migrate possibly because there are fewer jobs

18 Descriptive statistics of deviation of maximum temperature are Obs.: 6,264; Mean: -1.169; Std. Dev.: 5.093; Min: -8.231; Max: 9.231

in agriculture and because the same effort pays less than before. Results show that the rise of the minimum temperature during the core month of the growing season (i.e. June) causes a reduction in rice production which, in turn, has a positive impact on people's propensity to migrate. This finding is robust to the use of different estimators.

Our study has two important implications for the development of Vietnamese rural households in the face of climate change. First, it sheds light on the link between climate variations, agriculture production and migration allowing the policy makers to fully understand how this phenomenon may impact on people's lives and to predict future population movements. Furthermore, this study also discloses some consequences of the excessive dependence of Vietnamese households from rice crops: households that are largely dependent from rice revenues are deemed to be severely affected by variations in the temperatures. This finding encourages the adoption of alternative crops who may be more resistant to climate variations as well as the introduction of ad hoc policies to support the most climate-sensitive households. As claimed by Reuveny (2007), government intervention mitigates the effect of climate change on migration.

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## Appendix

Table A1. Correlation matrix

	Rice, t-1 (ln)	Livestock, t-1 (ln)	Fertilizers, t-1 (ln)	Total area owned, t-1 (ln)	Household size, t-1 (ln)	Household income, t-1 (ln)	Days worked, t-1 (ln)	Education, t-1 (ln)	Formal loans, t-1 (ln)	Informal loans, t-1 (ln)	Groups, t-1 (ln)	Kinh, t-1 (ln)	Gender of household head, t-1 (ln)	Dev of min temperature, t-1
Rice, t-1 (ln)	1.000													
Livestock, t-1 (ln)	0.342	1.000												
Fertilizers, t-1 (ln)	0.896	0.289	1.000											
Total area owned, t-1 (ln)	0.656	0.289	0.536	1.000										
Household size, t-1 (ln)	0.276	0.154	0.216	0.295	1.000									
Household income, t-1 (ln)	0.505	0.159	0.413	0.345	0.231	1.000								
Days worked, t-1 (ln)	0.194	-0.008	0.185	0.037	0.209	0.293	1.000							
Education, t-1 (ln)	0.057	0.066	0.149	0.012	0.181	0.152	0.172	1.000						
Formal loans, t-1 (ln)	0.117	0.100	0.116	0.155	0.157	0.082	-0.011	0.096	1.000					
Informal loans, t-1 (ln)	0.048	0.034	0.072	0.042	0.074	0.019	-0.014	0.053	-0.061	1.000				
Groups, t-1 (ln)	0.097	0.167	0.158	0.072	0.168	0.109	0.077	0.216	0.065	0.022	1.000			
Kinh, t-1	-0.194	-0.192	-0.069	-0.328	-0.252	-0.041	0.034	0.330	-0.024	0.016	0.029	1.000		
Gender of household head, t-1	0.160	0.146	0.137	0.211	0.296	0.098	0.006	0.111	0.074	0.018	0.132	-0.155	1.000	
Dev of min temperature, t-1	-0.045	0.022	-0.008	-0.007	-0.042	0.214	0.170	0.081	-0.035	0.020	0.050	0.063	-0.016	1.000

Source: Authors' own calculation from VARHS dataset.

Table A2 Reduced-form. the effect of deviation of the minimum temperature on migration

VARIABLES	(1) Migration	(2) Migration	(3) Migration	(4) Migration	(5) Migration
Dev min temperature, t-1	0.017*** (0.003)	0.018*** (0.003)	0.017*** (0.003)	0.016*** (0.003)	0.016*** (0.003)
Livestock, t-1 (ln)		0.007*** (0.002)	0.007*** (0.002)	0.007*** (0.002)	0.007*** (0.002)
Fertilizers, t-1 (ln)		0.005*** (0.001)	0.004*** (0.001)	0.003** (0.001)	0.003** (0.001)
Total area owned, t-1 (ln)		-0.007** (0.003)	-0.004 (0.003)	-0.004 (0.003)	-0.002 (0.003)
Household size, t-1 (ln)		0.042*** (0.007)	0.023*** (0.008)	0.020** (0.008)	0.025*** (0.009)
Household income, t-1 (ln)			-0.003* (0.002)	-0.002 (0.002)	-0.003* (0.002)
Days worked, t-1 (ln)			0.011*** (0.002)	0.011*** (0.002)	0.011*** (0.002)
Education, t-1 (ln)			0.033*** (0.006)	0.030*** (0.006)	0.025*** (0.006)
Formal loans, t-1 (ln)				0.003*** (0.001)	
Informal loans, t-1 (ln)				0.002** (0.001)	
Groups, t-1 (ln)					0.003 (0.008)
Kinh, t-1					0.027* (0.014)
Gender of household head, t-1					0.011 (0.009)
Constant	-0.037** (0.015)	-0.071** (0.028)	-0.142*** (0.029)	-0.138*** (0.029)	-0.172*** (0.034)
Year dummies	yes	yes	yes	yes	yes
Region dummies	yes	yes	yes	yes	yes
Observations	6,264	5,436	5,391	5,391	5,391

Notes: Standard errors clustered at regional level in parentheses; \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Source: Authors' own calculation from VARHS dataset.