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Non-linear Impacts of Climate Change on Income and Inequality in Vietnam

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Keywords: Environment, Global Warming, Income, Inequality

JEL Classification: D31, O44, Q5, R13

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March 18, 2019

Abstract

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1 Introduction

1.1 Motivation

The socio-economic impacts of climate change have been identified as a crucial issue globally. Even strong mitigation strategies will lead to some damages at some point (Masson-Delmotte et al., 2018). It is particularly the case in most emerging and developing countries, which are geographically located in fragile areas with respect to climate impacts, and are prone to increased damages because of their dynamically growing economies. The example of Viet Nam is illuminating as it cumulates almost all possible climate-related hazards with a multiplicity of potential impacts (Mora et al., 2018)[1]. 42% of the population was still working in the agricultural sector in 2017 and Viet Nam in general is already subject to a strong climate variability. Results from Burke et al. (2015) predict a decrease of up to 88% of the Vietnamese GDP by 2100 consequently to climate change. This paper tries more specifically to assess how households' revenues react to weather variations, allowing to non-linearity, and in particular extremely hot weather days. It will also disaggregate the impacts into different revenue classes in order to address the link between weather variability and revenue inequalities.

The analysis of potential future climate damages at the global scale has been mired with theoretical and empirical difficulties. Apart from the very theoretical damage functions used in Integrated Assessment Models (Nordhaus, 2018; Dietz and Stern, 2015) or the very crude empirical assessment based on GDP series in Burke et al. (2015), a creditworthy global damage function seems almost out of reach.

Nonetheless, studying the response of a specific population to climate variability can give an important benchmark in order to gain a better understanding of impacts. Indeed, the reasoning in terms of average national effect may not be enough to grasp the issues related to climate change and policies of mitigation or adaptation. It is more than necessary to identify the most stringent fragilities in an economy regarding climate change and thus the question of inequalities goes hand in hand with the one of an average impact.

[1]This work is part of a broader project, called GEMMES Viet Nam, aiming at a global assessment of the socio-economic impacts of climate change as well as adaptation strategies in Viet Nam. It will combine empirical studies on sectoral or social impacts and adaptation strategies together with a macroeconomic assessment of climate damages, taking into account all the uncertainties regarding future climate changes. More qualitative studies of adaptation strategies, as well as localized modelizations of impacts will complete the picture.

Most of the studies that have studied uneven weather impacts have been focused on inter-countries comparisons. Nonetheless, it is very likely that these effects will be unequally shared within countries as well. These unequal effects may be due either to unequal exposition to climate risks (due to the geography or job) or unequal ability to cope with and adapt to climate change (due to individual resources, public provisions or job).

Understanding the impacts of climate change notably on income inequalities is of major importance as it pinpoints the population that should be targeted for specific adaptation programs.

Another motivation to study differentiated within-country climate change effects is the existence of an effect of inequality *per se* on climate change, leading to the so-called "environment-inequality nexus". Inequalities may reinforce climate change through the richest population's irresponsible consumption and through a higher demand and a higher need for economic growth for the rest of the population. Moreover, inequality harms the willingness of the poorest to accept costly climate change mitigation programs and more generally reduces the ability to collectively organize mitigation of climate change (Laurent, 2015).

1.2 Related literature and methodological issues

The literature relating weather variability to incomes has been burgeoning recently, raising a number of methodological issues.

The first methodological stake is to go beyond the simple correlation that "hot countries tend to be poor". Dell et al. (2009) indeed estimated that on average one additional Celsius degree was associated with a 8.5% lower income per capita. Nonetheless, it is of common knowledge that there are other (omitted) variables that tend to make poor countries poorer than just the level of temperatures. For instance, Acemoğlu et al. (2001) argued that disease risk and mortality rate of settlers in the colonial time (that is influenced by local weather) impacted subsequent economic development. This naïve estimation should therefore not be considered as a causality. Panel estimators allow to get rid of country specific unobservables characteristics and therefore to estimate causally the impact of temperatures on incomes. It uses year-to-year fluctuation and amounts to compare the same country to itself under various weather conditions. This methodology has been described in more details in Auffhammer et al. (2013). Using this more reliable approach also leads to a negative relationship between temperatures and growth Dell et al. (2012). An increase of temperatures by one additional Celsius degree would be associated with a reduction of growth by 1.3 percentage point. This relationship is nonetheless only true in developing countries (Viet Nam included).

A second methodological issue, linked with the climate variable, is to take into account non-linear impacts. It is very likely that temperatures will have non-linear effects on incomes: an increase of temperatures by one degree from $12°C$ to $13°C$ will not have the same impact than an increase from $28°C$ to $29°C$. This is a justification for Burke et al. (2015) to use not only average temperatures as explanatory variables as has been done by Dell et al. (2012) but also to add a quadratic term in temperatures. Using this methodology, they find an impact of temperatures on income for both poor and rich countries with an inverted-U shape curve between temperature and income with an optimal temperature for output and productivity at $13°C$. Notably, as mentioned above, their paper enlightens a decrease of Vietnamese GDP in 2100 by 88% under the Business-as-Usual hypothesis (Representative Concentration Pathway 8.5 combined with Shared Socio-Economic Pathways 3 and 5). Deryugina and Hsiang (2017) went further in the study of non-linear impacts using the number of days in temperature bins (number of days per year between $9°C$ and $12°C$ for instance) as explanatory variables. It allows them to be closer to a non-parametric specification. The scale of observation is the county in the US. Their main result is that "the log personal income per capita increases slightly as temperatures rise from cool to moderate, then declines approximately linearly at temperatures above 15°C".

These non-linear weather impacts on the aggregate income are supported by studies that have looked at sectoral or individual outcomes. There is plenty of evidences of negative impacts of weather shocks and notably hot temperatures and heat waves on the agricultural income. Such effect has notably been underlined in a developing countries (Mexico) by Skoufias et al. (2013) and in a developed countries (the US) by Schlenker and Roberts (2009). This paper has also brought methodological innovations, using the number of days in several temperature bins as explanatory variables (number of days between $10°C$ and $13°C$ for instance. Indeed, it is likely that an increase in temperature from $10°C$ to $11°C$ does not have the same impact than an increase from $25°C$ to $26°C$.

Such specification thus allow for a non-linearity in the level of temperature, an a-symetric impact and to have a focus on the tails of the distribution.

There have been fewer studies that have focused on the non-agricultural output, there are nonetheless some strong evidence: Dell et al. (2009) found that the negative impact of hot temperatures on the aggregate income is not only concentrated on the agricultural sector but affects also non-agricultural sectors such as the industrial sector. Hsiang (2010) studied the impacts of heat waves in Caribbean countries and found that unusual warm periods have negative impacts on three out of six non-agricultural sectors. Furthermore, the impacts on some non-agricultural sectors (notably service-oriented ones) even exceeds the impact on the agricultural sector.

In order to explain the negative impacts of temperatures observed on non-agricultural sectors, that seem at first sight less exposed to weather hazards, there have been studies focusing on individual outcomes and behavioural impacts. Such impacts can be decomposed in two main channels. Firstly, temperatures have an impact on the labour supply. Indeed, Graff Zivin and Neidell (2014) have found that on days with a warmer temperature, the quantity of time allocated to work was lower than on cooler days. Secondly, there is an impact of temperatures on the labour productivity or the level of effort. Seppanen et al. (2003) have demonstrated through laboratory experiments that one additional degree above $25°C$ was associated on average with a 2% reduction in human productivity.

Lastly, one can also mention the impact of temperature on non-economic outcomes that can have some feedbacks on economic outcomes as well. For instance, the impact on health and mortality (Deschenes (2014)) or on crime rate and political conflict (Hsiang et al. (2013)).

These issues are at the core of the existing literature on climate impact in Viet Nam. Narloch (2016) worked on the varying income effects of climate variation in rural Viet Nam, using six different specifications for the weather variables. He found a negative impact of temperature on income for a very wide range of occupations, notably: "*average annual temperature that is* $1°C$ *warmer decreases total income by 20 percent*". The impact of precipitations is more nuanced. Interestingly, he found that the impact of temperature is not concentrated only on agricultural incomes but also on other types of businesses. This question could be further explored by studying urban households as well. The study disentangles the effect of annual, seasonal, abnormal and extreme weather.

Nonetheless, using only monthly value may hide some non-linearity and asymetric temperatures effects. Our strategy, described in more details below, will be to use daily temperatures. This has been inspired by the work of Schlenker and Roberts (2009) cited above.

As mentioned above, only little attention has been paid to an unequal "within-area impact" of temperatures on incomes. Narloch (2016) tried to decompose the average impact measured according to several socio-economic indicators (notably Bottom 40% vs. Top 60% income level) but did not find any significantly different effect. As we use a longer time series of the VHLSS database, we will also try to look more deeply into this unequal effect using income ratio and more specific income shares.

Studying only geographical inequalities, *ie* inequalities of exposition depending on the place where people live, Bangalore and Narloch (2016) found that "at the national level, marginalized and vulnerable groups are more exposed to multiple environmental risks. Ethnic minorities and households below the poverty line have the highest risk exposure, while households in higher consumption quintiles and those headed by females live in less risky communes (...) poor rural households are more situated in zones with temperature variability than their urban counterparts". This nonetheless does not imply that within a given geographical area, poor households are more exposed to environmental risks. This paper adopts a more causal approach, studying how different people might respond to a same shock[2].

1.3 Proposed strategy

This paper studies the average and differentiated income response to weather shocks in Viet Nam. Our approach is to study historical short-run reactions to marginal weather shocks to get a benchmark of predicted economic impacts of global warming. We chose here to focus mainly on one unique aspect of climate change which is temperature increase (controlling for precipitations). Also, we do not consider climate change's other specific aspects such as sea-level rise and natural disaster. This choice can be explained by the pre-existence of temperature deviations, on the contrary to other aspects, it makes possible to compute an estimate for global warming effects based on past data only.

[2] Note that of course, people of very different income do not live in exactly the same places, which weakens the possibility of facing exactly the same shock. Morevover, issues of sorting may also arise, for instance wealthiest households may not live in the places where weather shocks are the most severe.

Combining Income data from the *Vietnamese Household Living Standards Survey* for years 2004-2014 (6 waves of survey) with weather data (mostly temperatures and precipitations), we are able to use local random deviations of income to estimate marginal responses to change in the current weather. After having estimated the average impact of temperatures on Vietnamese income, we will compute separate response functions by income sources, geographic areas, ethnicity and position in the income distribution. These estimates are then used as inputs with climate simulation models to get projections of climate change impacts.

The remaining of this paper is organized as follows; section 2 presents the data used and provides descriptive statistics, section 3 presents the empirical strategy, section 4 summarizes the results, section 5 presents some robustness checks, section 6 uses climatic projections to compute an estimated impact of global warming and finally section 7 concludes and discusses the results.

2 Data and Descriptive Statistics

2.1 Socio-Economic Data

We use data from the Vietnamese Household Living Standards Survey (VHLSS) provided by the General Statistics Office (GSO) of Viet Nam. This dataset consists in a nationally and regionally representative sample of 9 400 households every two years. It is a rotating panel (*ie* for each new wave half of the households are kept in the study and the other half is not surveyed again). This allows us to construct a panel dataset to get rid of unobservable characteristics of households. We are using six waves of VHLSS (2004-2006-2008-2010-2012-2014). This dataset provides information on households' income decomposed by income sources as well as socio-demographic information of the household. It should be noted nonetheless, that the sample surveyed has totally been renewed in 2010, thus, no household is followed successively in 2008 and 2010. We convert all figures in 2010 VND using World Bank Consumer Price Index (CPI). Figure 1 shows the evolution of the average income in Viet Nam during the period of interest, as well as the evolution of each quartile. Note that because we use only survey data, we can only imperfectly depict inequalities in the country, especially for the high-earning groups (top 1%).

It can be seen of Figure 2 that wage income constitutes an increasing share of highest

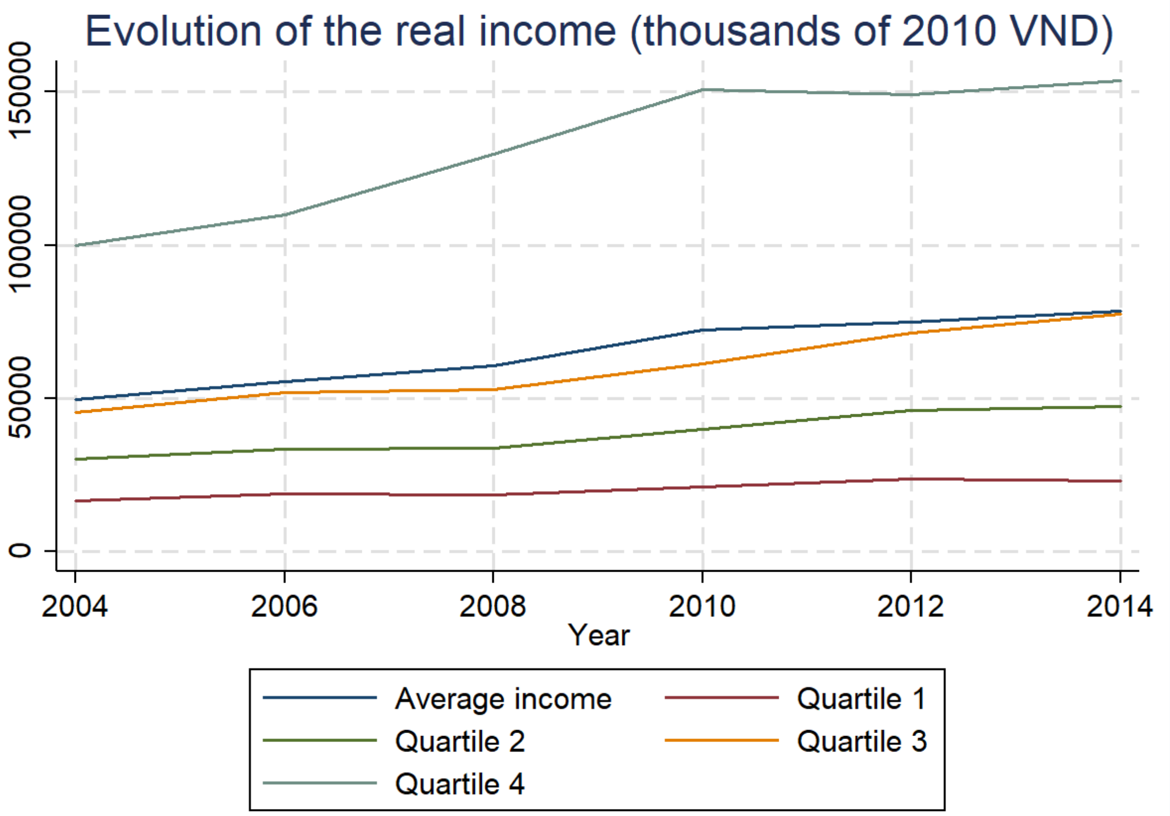

Figure 1: Evolution of the average income (expressed in thousands of constant 2010 VND)

Source: VHLSS (Authors' computation).

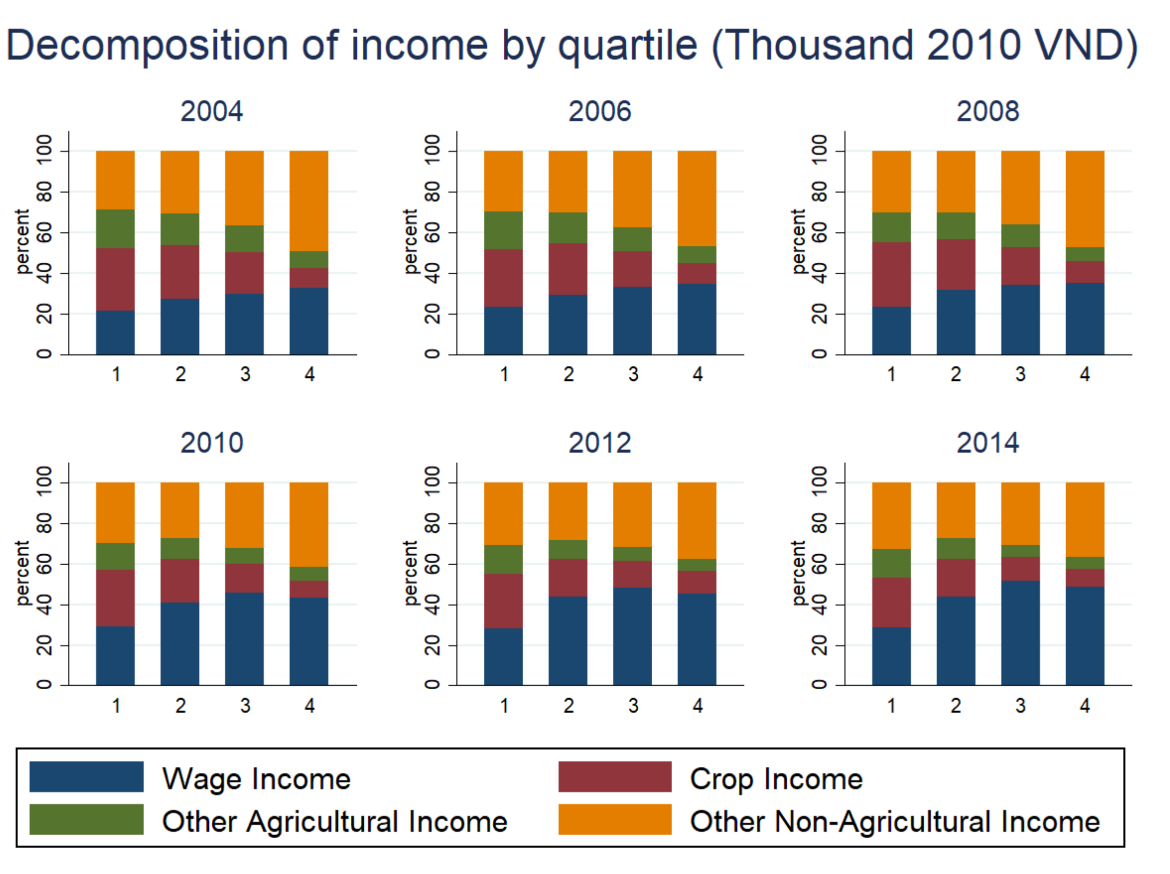

Figure 2: Decomposition of income by sources for each quartile (expressed in percentage)

Source: VHLSS (Authors' computation).

quartiles income. For the poorest nonetheless, wage income changes little. It should also be noticed that agriculture remains an important source of income for lowest quartiles (approx. 50%). Nonetheless, in absolute terms, income from agriculture remains higher for highest deciles (see also Figure 11 in Appendix). This shows that agricultural revenues in a broad sense are an important part in all the segments of the Vietnamese income distribution. This does not however give any *a priori* stylized fact on the expected impact of climate change on the different segments of revenues.

2.2 Climate Data

The climate data used are from the Climate Prediction Center (CPC) of the National Weather Service (provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at https://www.esrl.noaa.gov/psd/). One should note that the daily average temperature in the CPC data is the average of the maximum daily and minimum daily temperatures.

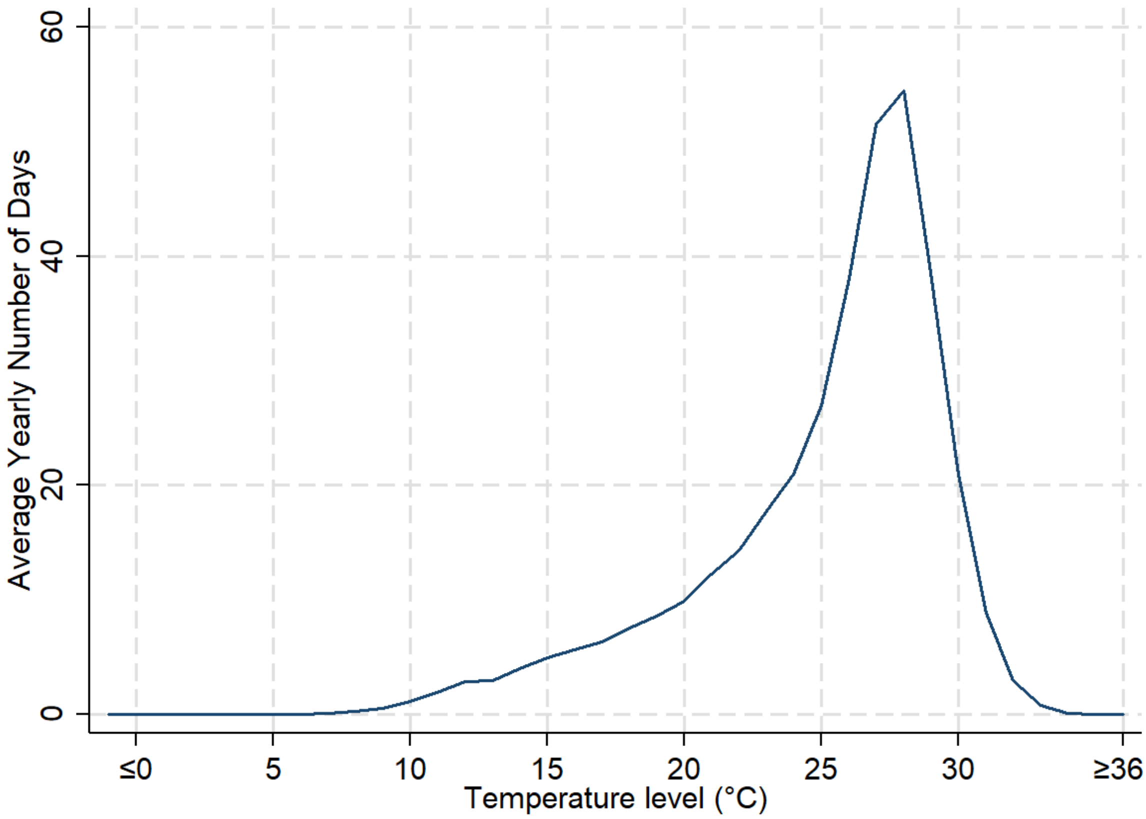

Figure 3: Distribution of days by temperature levels

Using daily information on temperatures allows us to take into account non-linearity in the temperature level[3]. Figure 3 shows the distribution of days by temperature level for each year.

3 Empirical specification

Our main equation of interest estimates by *Ordinary Least Squares* (OLS) the (log) income per capita as a function of the current and previous weather, household and year specific observables and finally household fixed effects. This is summarized by equation (1) below.

$$Y_{i,t} = \sum_{m} (\beta^m \tilde{T}^m_{i,t} + \phi^m \tilde{T}^m_{i,t-1}) + P_{i,t} + P^2_{i,t} + P_{i,t-1} + P^2_{i,t-1} + X_{i,t} + \mu_i + \epsilon_{i,t} \quad (1)$$

[3]Note that we nevertheless do not allow for non-linearity in the number of days in a temperature bin

With:

- $Y_{i,t}$ is the (log) income per capita of household i in year t.
- $\tilde{T}^m_{i,t}$ the number of days of year t for which mean daily temperature have been in the interval m.
- $P_{i,t}$ is the total level of precipitation in commune i in year t[4];
- $X_{i,t}$ is a set of covariates:
  - Age of the household's head
  - Level of education of the household's head
  - Gender of the household's head
  - Ethnic minority
- μ_i household fixed effects;
- $\epsilon_{i,t}$ the error term.

The principal coefficients of interest are here β^m. It may be interpreted as the impact on the level of income of having one additional day in a given temperature interval compared to the reference interval. This equation may be augmented by interaction terms between temperatures and precipitations[5]. This specification allows for an estimation of the non-linear impacts of temperature on income which are crucial. Indeed, it seems unlikely that a temperature rise from 12 to 13 °C would have the same impact than from 29 to 30°C. These non-linear impacts may be summarized by using only means and quadratic terms (as has been done by Dell et al. (2012) or Burke et al. (2015)). But we find our strategy more detailed and reliable, in line with the work of Deryugina and Hsiang (2017).

We use the lagged weather conditions in order to prevent omitted variable bias (Dell et al., 2014). The fixed-effects approach controls for both observable and unobservable characteristics of each household that do not vary over time. We therefore compare a

[4]Note that precipitation intervals will also be used as robustness checks.

[5]Note that we will not make all bins of temperature interact with all bins of precipitation as it would add 140 variables to the specification and present risks of multicolinearity. We will rather compute the number of days inside a temperature bin with substantive rain (ie: with rain higher than 1mm).

household to itself when it experienced several types of weather, it is a *within-estimator*. In brief, the estimated coefficients are computed on local deviations compared to the usual conditions. Following the work of Cameron et al. (2011), we are clustering our standard-errors in two dimensions (two-way clustering). Firstly, within households across years to take into account the serial correlation and allow for heteroskedasticity. Secondly, within regions by year to take into account the spatial auto-correlation.

To assess the impact on inequality, the aforementioned regression will be run separately on each quartile of income. A specific attention will also be devoted on dividing the effect between income sources.

4 Results

4.1 Average effect

Table 1 presents the results of the estimation by OLS of Equation 1. Column (1) regresses the (log) total income per household on temperature bins, precipitation, precipitation squared, lag conditions, head of household's gender and education and household size. Column (2) uses instead of the total income the (log) income per capita. Figure 4 presents the results of column (1) with 95% confidence interval. Temperatures at the tails of the distribution seem to have negative impact on the yearly income. The effect of temperature on income seems to be quite linear from $21°C$ to the the warmest temperature. The order of magnitude could be compared to the average daily contribution to yearly income ($\frac{1}{365} = 0.27\%$)[6].

These results are in line with the findings of the literature on the impact of weather on income, notably Deryugina and Hsiang (2017), though the impact in Viet Nam is far more sizable that in the United States of America. The results seem also to confirm what has been found by Burke et al. (2015) with an optimum level of temperature around $12 - 15°C$.

Our result would indicate the effect of days above $33°C$ on yearly income that is almost 13 times higher than the effect of a day above $30°C$ on yearly income found by Deryugina and Hsiang (2017). This difference in magnitude is not only a consequence

[6]One should nonetheless keep in mind that we are not assuming here that the effect of an abnormally warm day is occurring only on the current days, neither that all days bring the same income contribution to the yearly income

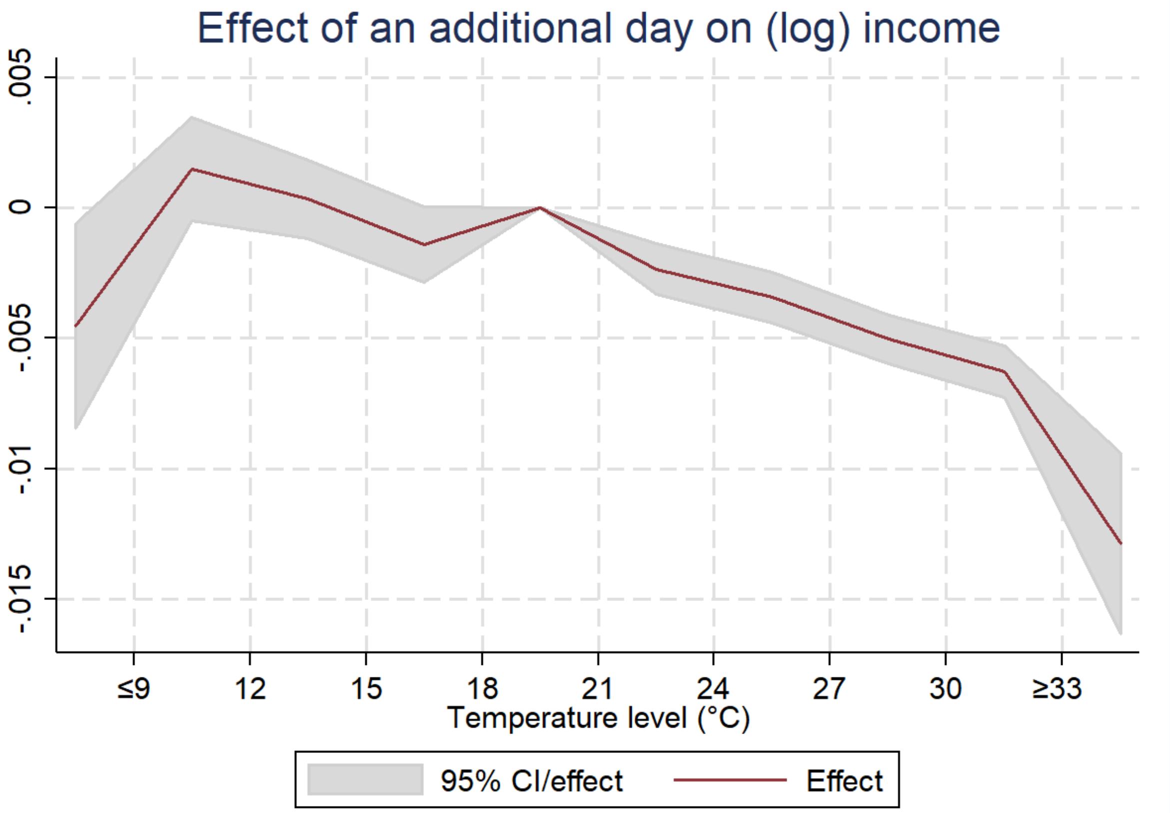

Figure 4: Effect of weather shocks on (log) Income (Column 1 of Table 1)

of the $3°C$ differences in the highest benchmark but also Vietnamese population work far more in agriculture and adaptation possibilities such as air conditioning, well-isolated buildings are less developed. It should also be underlined that we do not use the same kind of data than Deryugina and Hsiang (2017) who used income per capita per county whereas we have survey data that give us income per capita per household. Our dataset may include more variability.

The effect computed above could be decomposed by income sources (notably wage income and income from agriculture). Figure 5 shows the results of the estimation of Equation 1 on the (log) wage income per capita and the (log) agricultural income per capita.

The effect of warm days is not concentrated on the agricultural income alone, as one could have been expecting. The effect on agricultural income is a bit stronger in magnitude than the effect on wage income, though the difference is not significant. The order of magnitude is the same than for the overall income.

The negative effect of cold temperatures seems to disappear and a potentially positive

VARIABLES	(1) (log) income	(2) (log) income per capita
# days in $]-\infty; 9°C]$	-0.00553***	-0.00453**
	(0.00198)	(0.00200)
# days in $]9°C; 12°C]$	0.000973	0.00148
	(0.00100)	(0.00100)
# days in $]12°C; 15°C]$	-0.000684	0.000336
	(0.000773)	(0.000767)
# days in $]15°C; 18°C]$	-0.00157**	-0.00141*
	(0.000738)	(0.000733)
# days in $]21°C; 24°C]$	-0.00192***	-0.00234***
	(0.000494)	(0.000494)
# days in $]24°C; 27°C]$	-0.00319***	-0.00344***
	(0.000490)	(0.000492)
# days in $]27°C; 30°C]$	-0.00456***	-0.00504***
	(0.000472)	(0.000474)
# days in $]30°C; 33°C]$	-0.00589***	-0.00627***
	(0.000502)	(0.000502)
# days in $]33°C; +\infty]$	-0.0127***	-0.0129***
	(0.00180)	(0.00177)
prec_year		0.00372***
		(0.000630)
prec_year^2		-7.86e-06***
		(1.54e-06)
hh size	0.178***	
	(0.00377)	
Observations	120,380,320	120,380,320
R-squared	0.162	0.045
Number of households	36,838	36,838
HH FE	YES	YES
Lag included	YES	YES
Cluster	Hh AND Region× Year	
*** p<0.01, ** p<0.05, * p<0.1		

Table 1: Regression of the (log) income on weather conditions

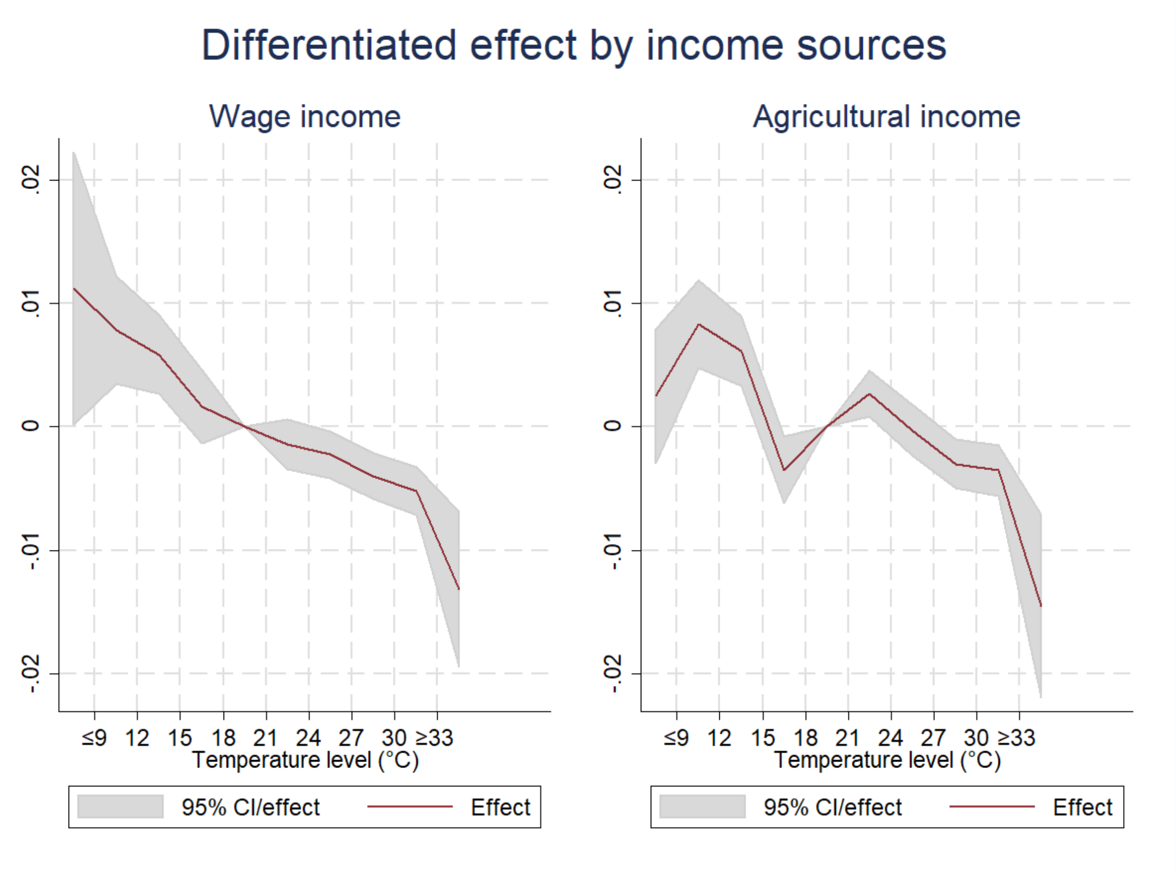

Figure 5: Effect of weather shocks on (log) Income by income sources

effect of (moderately) cold temperatures seems to emerge (in agreement with Burke et al. (2015)).

It is important to notice that the estimation is automatically less precise when decomposing the total effect because the number of observations is considerably reduced.

4.2 Decomposition by income groups

The estimation strategy can be applied to various income groups. The population can notably be divided into four quartile and one can estimate the coefficients associated to each quartile. This is what is represented on Figure 6). The impact of extremely warm days seem to be concentrated on the lowest three quartiles (that are the closest in terms of income as can be seen on Figure 1 above. The estimation seems to indicate that the poorer the households, the higher the sensitivity to extremely warm days, though most differences are not statistically significant[7]. The effect of more moderately warm days

[7]Note that because the sample is four times smaller in these estimations, the confidence interval are automatically broader.

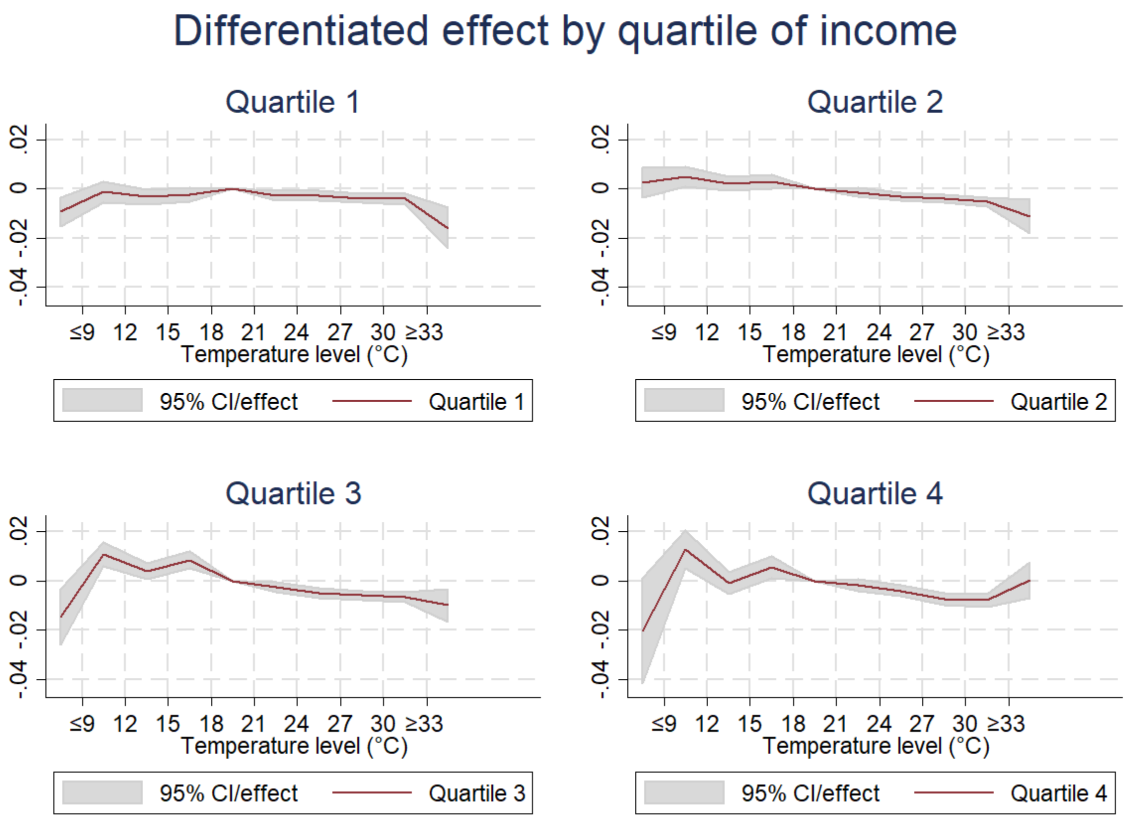

Figure 6: Effect of weather shocks on (log) Income by income quartile (with CI)

seem to be more equally shared among the income distribution.

The Z-test $Z = \frac{\beta_1 - \beta_2}{\sqrt{se^2_{\beta_1} + se^2_{\beta 2}}}$ of different coefficients for the first and the last quartile is significant, allowing to reject the null hypothesis that the effect of extremely warm days is the same for all branches of the population. The inter-quartile range, which is a measure of inequality, is therefore increasing when such warm days occur.

5 Robustness Checks

5.1 More detailed precipitation data

Because the main focus of this paper is to measure the effect of temperatures on income, we have for now only used simple measures of precipitation. Namely, only the average yearly rainfall level, rainfall squared and past rainfall have entered the regressions. One can nonetheless object that the effect of precipitation is more subtle and that not taking this aspect into account may lead to an omitted variable bias (OVB) because temperatures and precipitation are correlated.

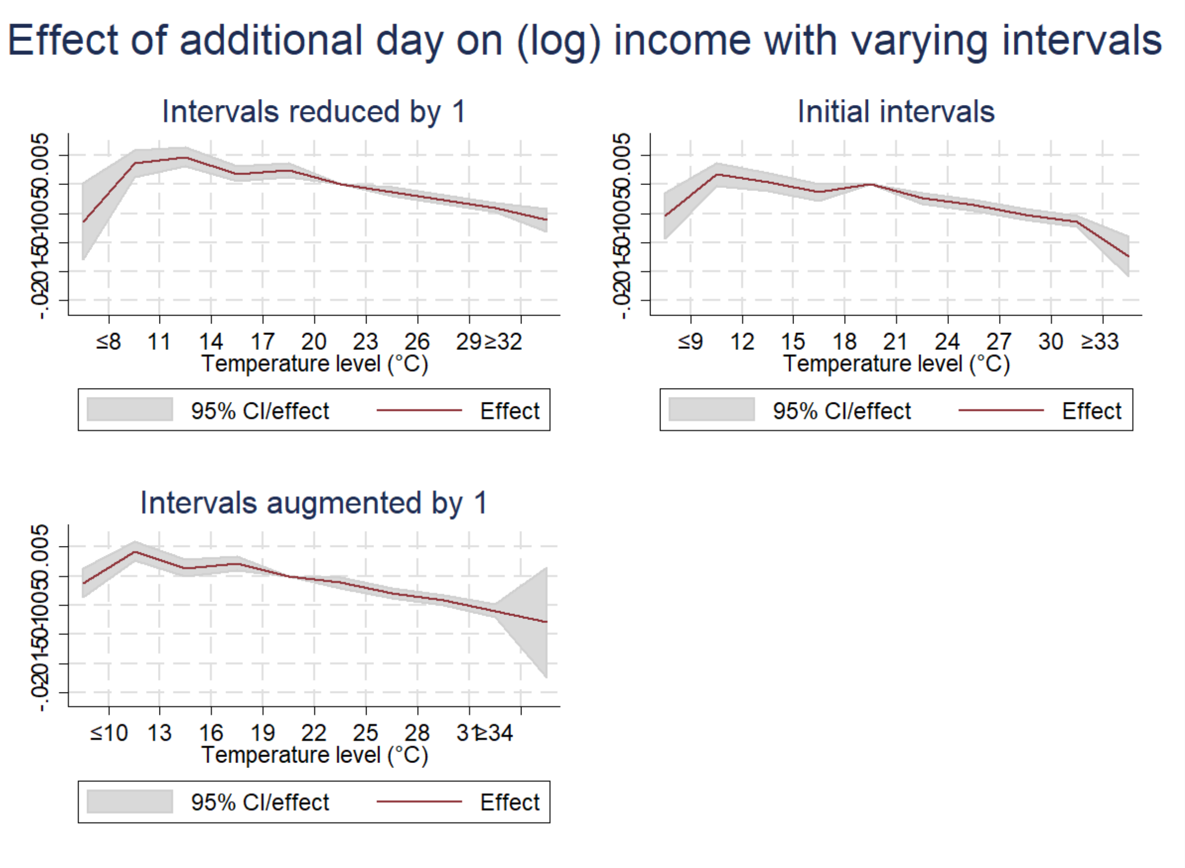

Figure 7: Main regression with other intervals

We have therefore also estimated the same equations than before but instead of using yearly precipitation measures we use the number of days that fall into each interval of precipitations ([0mm;1mm], [1mm;5mm], [5mm;10mm], [10mm;15mm], [15mm;20mm], [20mm;50mm], [50mm; 75mm], [75mm; 100mm], [100mm; $+\infty$]). The interval [0mm;1mm] is taken as the reference interval.

Columns (1) and (3) show the initial regressions of Table 1, columns (2) and (4) show the same estimation using the new explanatory variables for precipitation. We can see that the main coefficients of interest are almost unchanged using either one type of explanatory variables or the other.

5.2 Varying intervals

One potential limit to the above findings would be that the results are specific to the intervals chosen. We therefore test if we find the same results (or at least the same insights) when the intervals vary. For the three specifications presented above we re-estimate the results switching the temperature bins by 1° C (*ie*: instead of using bins

VARIABLES	(1) (log) income	(2)	(3) (log) income per capita	(4)
temp_under$_9$	-0.00553***	-0.00510**	-0.00427**	-0.00453**
	(0.00198)	(0.00202)	(0.00204)	(0.00200)
temp_9_12	0.000973	0.000438	0.000658	0.00148
	(0.00100)	(0.00100)	(0.00100)	(0.00100)
temp_12_15	-0.000684	-0.000343	0.000612	0.000336
	(0.000773)	(0.000805)	(0.000798)	(0.000767)
temp_15_18	-0.00157**	-0.00127*	-0.00104	-0.00141*
	(0.000738)	(0.000743)	(0.000738)	(0.000733)
temp_21_24	-0.00192***	-0.00174***	-0.00217***	-0.00234***
	(0.000494)	(0.000502)	(0.000501)	(0.000494)
temp_24_27	-0.00319***	-0.00299***	-0.00339***	-0.00344***
	(0.000490)	(0.000508)	(0.000509)	(0.000492)
temp_27_30	-0.00456***	-0.00447***	-0.00501***	-0.00504***
	(0.000472)	(0.000492)	(0.000493)	(0.000474)
temp_30_33	-0.00589***	-0.00600***	-0.00642***	-0.00627***
	(0.000502)	(0.000513)	(0.000512)	(0.000502)
temp_above$_3$3	-0.0127***	-0.0121***	-0.0123***	-0.0129***
	(0.00180)	(0.00180)	(0.00175)	(0.00177)
prec_1_5		6.81e-05	1.50e-05	
		(0.000200)	(0.000201)	
prec_5_10		-0.000995**	-0.000992**	
		(0.000411)	(0.000408)	
prec_10_15		0.000180	0.000479	
		(0.000644)	(0.000651)	
prec_15_20		-9.20e-05	-0.00130	
		(0.000913)	(0.000913)	
prec_20_50		-0.000227	-0.000290	
		(0.000614)	(0.000613)	
prec_50_75		0.00584***	0.00661***	
		(0.00192)	(0.00192)	
prec_75_100		0.00214	0.00124	
		(0.00363)	(0.00360)	
prec_above$_1$00		0.00105	-0.000447	
		(0.00475)	(0.00478)	
hh size	0.178***	0.177***		
	(0.00377)	(0.00379)		
prec_year	0.00310***			0.00372***
	(0.000629)			(0.000630)
prec_year ^{2}	-6.47e-06***			-7.86e-06***
	(1.54e-06)			(1.54e-06)
Observations	120,380,320	120,380,320	120,380,320	120,380,320
R-squared	0.162	0.160	0.043	0.045
Number of hid2	36,838	36,838	36,838	36,838
HH FE	YES	YES	YES	YES
Lag included	YES	YES	YES	YES
Interaction included	YES	YES	YES	YES

Hh AND Region× Year
*** p<0.01, ** p<0.05, * p<0.1

Table 2: Regression of the (log) income on weather conditions

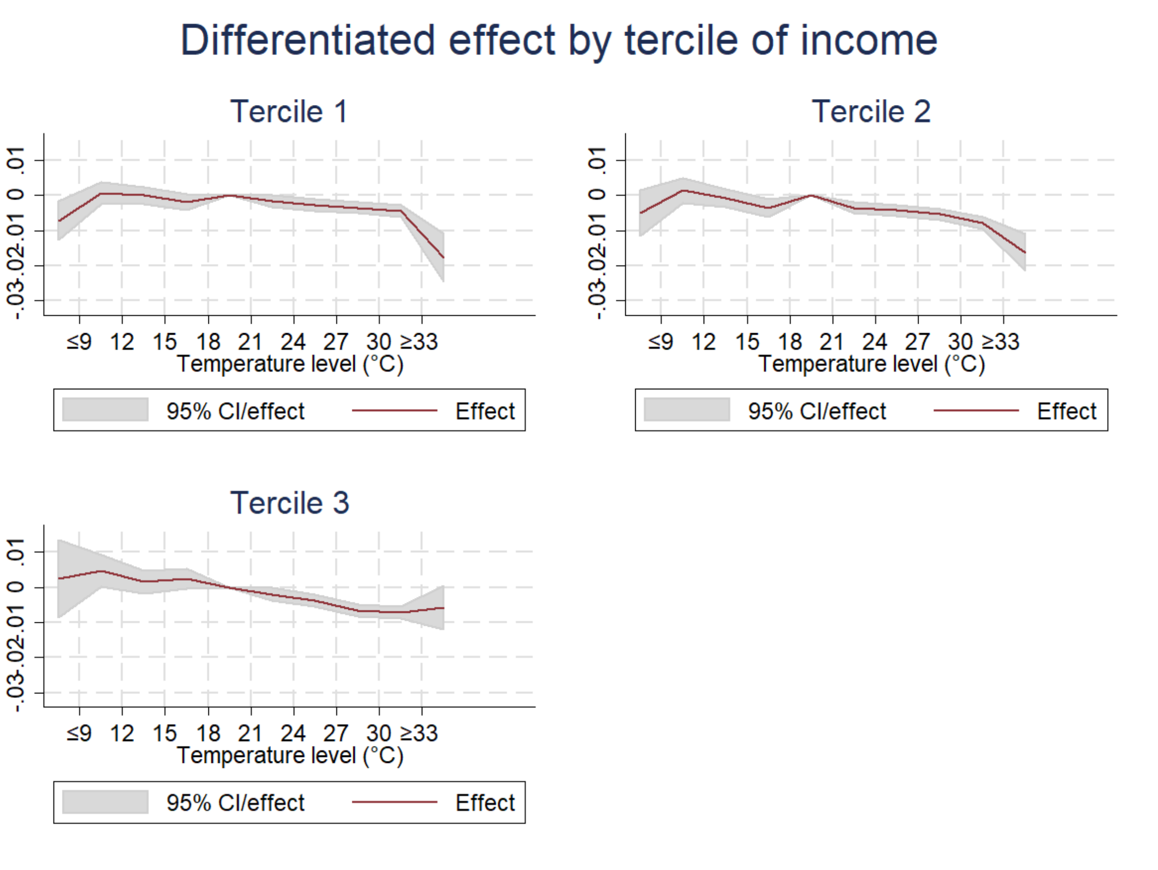

Figure 8: Effect of weather shocks on (log) Income by income tercile (with CI)

$[9°C; 12°C[$, $[12°C; 15°C[$, etc.; we use $[8°C; 11°C[$, $[11°C; +14°C[$, etc. and $[10°C; 13°C[$, $[13°C; 16°C[$, etc.). The coefficients obtained are displayed on Figure 7.

The main insights of the above findings is not challenged by making the intervals vary. We again find that medium temperatures (around 12-15°C) have a slightly positive effect on incomes and high temperatures from 21°C have a negative impact on incomes. Note that the effect for days above 34°C is very imprecise though, this can easily be explained by the low number of observations for such warm days.

5.3 Other population decomposition

The decomposition could also be done by tercile (see Figure 8 in Appendix). The tendency found with four quartiles seem to be confirmed by the decomposition in only three groups: high negative effects of extremely warm days on the lower and middle classes (bottom 66-75%), whereas the effect seem to be more negligible for the highest quartile.

6 Simulations

We can use the previous estimations of the impact of additional warm days on the average income of Vietnamese households to derive the potential impacts of future global warming. This is done under several important and strong hypotheses that will be detailed below. The idea of this kind of estimation is not to predict with certainty the future impact of global warming in terms of household revenue losses, but rather to have a picture of possible futures depending on the future climate change in Viet Nam.

The future climate projections are obtained from the Regional Climate Model version 4.3 (RegCM) Giorgi et al. (2012). RegCM is a hydrostatic, limited-area model with a sigma vertical coordinate. In this study, the model was implemented with 18 vertical -levels with the top level set at 5 mb and with a horizontal resolution of 25 km.

The physical options used for the RegCM4.3 experiment in this study are the radiative transfer scheme of the NCAR Community Climate Model (CCM3) Kiehl et al. (1996), the sub-grid explicit moisture (SUBEX) scheme for large-scale precipitation Pal et al. (2007), the planetary boundary layer scheme of Holtslag and Moeng (1991), the MIT-Emanuel convective scheme Nilsson and Emanuel (1999), the BATS1e ocean flux scheme Dickinson et al. (1993). This setting is based on the sensitivity experiments conducted previously by the Coordinated Regional Climate Downscaling Experiment -Southeast Asia (CORDEX-SEA) community Cruz et al. (2017); Juneng et al. (2016); Ngo-Duc et al. (2017). Boundary and initial conditions of RegCM are provided by the outputs of the CNRM5 GCM model Voldoire et al. (2013).

In order to compute the estimated yearly impact of global warming, we compute for each year and for each temperature bin the difference between the new conditions induced by warming (moving average on twenty years every year, on the two RCPs 8.5 and 4.5) and a reference average of the years $1986 - 2005$. These differences are then multiplied by the coefficients computed in the previous parts. We thus get the relative impact on revenues of the change in climate in each pixel of the Viet Nam map.

The results appear on figure 10. They show that in all cases, loss of revenues reach the highest levels in the Red River Delta and in Northern mountains. Households in these regions see their revenue shrink by up to 25% by 2030 already, and 50% by 2050. After 2050, the full effect of the RCP8.5 appears, and the two scenarios really diverge. Revenue losses affect nearly all Viet Nam in 2090 in the case of the RCP8.9, although with

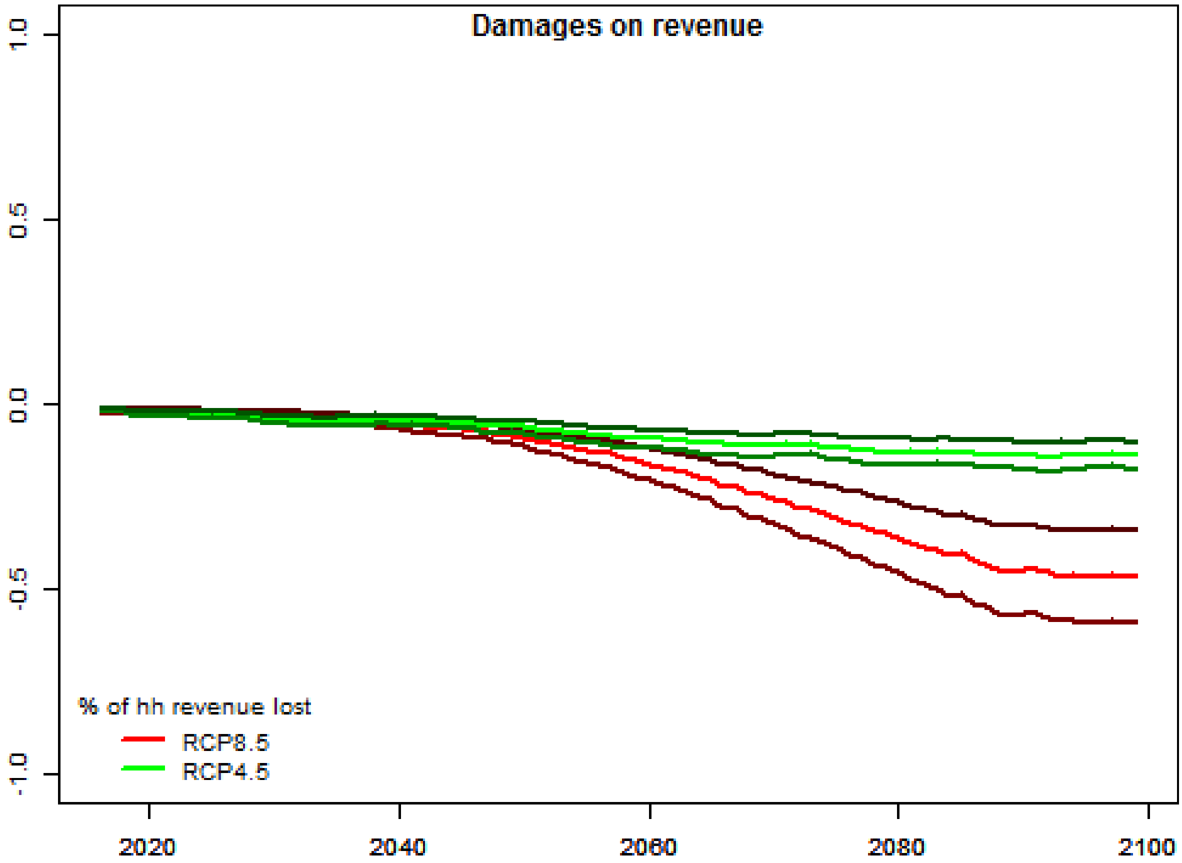

Figure 9: Aggregate damage on revenue (2010 population weight)

different scales. Most of the northern region is affected up to 75% to 100% of its revenues, while all the coastal areas start being affected as well. Paradoxically, the Southern region seems to be nearly exempt of impacts except in the long run for the RCP8.5 scenario. This should not be a matter of optimism however if we recall that we did not take into account sea-level rise or extreme events, which are the main climate-induced challenges facing the Mekong river region and Ho Chi Minh City.

On aggregate, we can also calculate the average loss in revenues for Viet Nam as a whole, by considering the population weighted temperature at different points (See 9. We find that damages reach in the worst-case scenario around 50% of households' revenues in the RCP8.5 case. If mitigation efforts at the world level occur, then the impact might only be around 10% of households' revenues. These numbers are in line with the study of Burke et al. (2015), although they are the result of a very different methodology.

It is important to recall that we have here computed only short-term response to climate shocks. Apply the previous estimates to future weather conditions assumes that the income sensitivity to weather will not change. Adaptation behaviors are indeed likely to arise and possibly reduce the magnitude of the impact.

7 Conclusion and Discussion

This paper has explored the complex relationship between incomes and weather shocks in Viet Nam. We used a methodology that combines a panel dataset that allows to get rid of unobservable characteristics and estimate a causal impact and daily measures of weather that gives precise non-linear effects of temperatures. We are thus able to compute the marginal response of Vietnamese households' income to the occurrence of additional days in temperature ranges. This methodology allows us to apply these previous estimates to the future weather conditions estimated by the IPCC.

The magnitude of the main result of this study has two important methodological implications. First of all, it is very important to allow for non-linear impacts of the temperature on incomes. Secondly, the estimates computed on a developing country such as Viet Nam may differ dramatically from the one computed for the United States (see Deryugina and Hsiang (2017)), which could therefore not be applied worldwide.

It should nonetheless be underlined that there are several differences between the characteristics of the weather shocks we have used and climate change. Firstly, we have computed only short-term reaction functions to weather shocks. These short-term reaction functions may differ significantly from the long-term ones, notably because of the capacities to adapt to warmer temperatures (air conditioning for instance, technical change or factor reallocation). Moreover, if future weather shocks are better anticipated, economic agents may be more prepared and thus less sensitive to such shocks. If warm temperatures are more anticipated it may lead to lower the impacts. Secondly, even if we have allowed a non-linear relationship in the level of temperature, we have not allowed a non-linear impact of the number of days in each threshold, it may be likely that the fifth days above $33°C$ does not have the same impact than the first one. Thirdly, we have imputed the same impact to all days above $33°C$ to be the same, disregarding if it was $33°C$ or $36°C$. Nonetheless, the occurrence of days far above $33°C$ will increase with climate change and it is very likely that such days will be more detrimental for the income level that days just above $33°C$.

It is important to underline that our analysis has been only focused on temperature variations and thus is in a way a kind of partial equilibrium analysis. We indeed do not take into account other climate change impact such as storms, typhoon, sea rise, biodiversity changes, etc. that are intrinsically related to global warming. All these elements are likely to increase the magnitude of the impact estimated here.

Lastly, because the income data from surveys are imperfect (not entirely representative of the entire distribution, notably for the highest part, small sample issues, lack of exhaustiveness), this paper would gain from an access to fiscal data at the municipality or district level. Notably, having the average yearly level of income per municipality and its decomposition in decile or quartile could lead to more subtle findings.

References

Acemoğlu, D., Johnson, S., and Robinson, J. A. (2001). The Colonial Origins of Comparative Development: An Empirical Investigation. *The American Economic Review*, 91(5):1369–1401.

Auffhammer, M., Hsiang, S., Schlenker, W., and Sobel, A. (2013). Using weather data and climate model output in economic analyses of climate change. *Review of Environmental Economic Policy*, 7:181–198.

Bangalore, M. and Narloch, U. (2016). Environmental risks and poverty. *World Bank - POlicy Research Working Paper*, 7763.

Burke, M., Hsiang, S. M., and Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature*, 527(7577):235–239.

Cameron, A. C., Gelbach, J. B., and Miller, D. L. (2011). Robust inference with multiway clustering. *Journal of Business & Economic Statistics*, 29(2):238–249.

Cruz, F., Narisma, G., Dado, J., Singhruck, P., Tangang, F., Linarka, U., Wati, T., Juneng, L., Phan-Van, T., Ngo-Duc, T., et al. (2017). Sensitivity of temperature to physical parameterization schemes of regcm4 over the cordex-southeast asia region. *International Journal of Climatology*, 37(15):5139–5153.

Dell, M., Jones, B. F., and Olken, B. A. (2009). Temperature and Income: Reconciling New Cross-Sectional and Panel Estimates. *American Economic Review*, 99(2):198–204.

Dell, M., Jones, B. F., and Olken, B. A. (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics*, 4(3):66–95.

Dell, M., Jones, B. F., and Olken, B. A. (2014). What Do We Learn from the Weather? The New Climate-Economy Literature. *Journal of Economic Literature*, 52(3):740–798.

Deryugina, T. and Hsiang, S. M. (2017). The marginal product of climate. *NBER Working Paper*, No. 24072.

Deschenes, O. (2014). Temperature, human health, and adaptation: A review of the empirical literature. *Energy Economics*, 46:606–619.

Dickinson, E., Henderson-Sellers, A., and Kennedy, J. (1993). Biosphere-atmosphere transfer scheme (bats) version 1e as coupled to the ncar community climate model.

Dietz, S. and Stern, N. (2015). Endogenous growth, convexity of damage and climate risk: how nordhaus' framework supports deep cuts in carbon emissions. *The Economic Journal*, 125(583):574–620.

Giorgi, F., Coppola, E., Solmon, F., Mariotti, L., Sylla, M., Bi, X., Elguindi, N., Diro, G., Nair, V., Giuliani, G., et al. (2012). Regcm4: model description and preliminary tests over multiple cordex domains. *Climate Research*, 52:7–29.

Graff Zivin, J. and Neidell, M. (2014). Temperature and the allocation of time: Implications for climate change. *Journal of Labor Economics*, 32(1):1–26.

Holtslag, A. and Moeng, C.-H. (1991). Eddy diffusivity and countergradient transport in the convective atmospheric boundary layer. *Journal of the Atmospheric Sciences*, 48(14):1690–1698.

Hsiang, S., Burke, M., and Miguel, E. (2013). Quantifying the influence of climate on human conflict. *Science*, 341(6151).

Hsiang, S. M. (2010). Temperatures and cyclones strongly associated with economic production in the caribbean and central america. *Proceedings of the National Academy of sciences*, 107(35):15367–15372.

Juneng, L., Tangang, F., Chung, J. X., Ngai, S. T., Tay, T. W., Narisma, G., Cruz, F., Phan-Van, T., Ngo-Duc, T., Santisirisomboon, J., et al. (2016). Sensitivity of southeast asia rainfall simulations to cumulus and air-sea flux parameterizations in regcm4. *Climate Research*, 69(1):59–77.

Kiehl, T., Hack, J., Bonan, B., Boville, A., Briegleb, P., Williamson, L., and Rasch, J. (1996). Description of the ncar community climate model (ccm3).

Laurent, E. (2015). Inequality as pollution, pollution as inequality - the social-ecological nexus. *Working Paper*, page 21.

Masson-Delmotte, V., Zhai, P., Pörtner, H., Roberts, D., Skea, J., Shukla, P., Pirani, A., Chen, Y., Connors, S., Gomis, M., et al. (2018). Ipcc, 2018: Summary for policymakers. *Global Warming of*, 1.

Mora, C., Spirandelli, D., Franklin, E. C., Lynham, J., Kantar, M. B., Miles, W., Smith, C. Z., Freel, K., Moy, J., Louis, L. V., et al. (2018). Broad threat to humanity from cumulative climate hazards intensified by greenhouse gas emissions. *Nature Climate Change*, page 1.

Narloch, U. (2016). The varying income effects of weather variation : Initial insights from rural vietnam. *World Bank Working Paper*.

Ngo-Duc, T., Tangang, F. T., Santisirisomboon, J., Cruz, F., Trinh-Tuan, L., Nguyen-Xuan, T., Phan-Van, T., Juneng, L., Narisma, G., Singhruck, P., et al. (2017). Performance evaluation of regcm4 in simulating extreme rainfall and temperature indices over the cordex-southeast asia region. *International Journal of Climatology*, 37(3):1634–1647.

Nilsson, J. and Emanuel, K. (1999). Equilibrium atmospheres of a two-column radiative-convective model. *Quarterly Journal of the Royal Meteorological Society*, 125(558):2239–2264.

Nordhaus, W. (2018). Evolution of modeling of the economics of global warming: changes in the dice model, 1992–2017. *Climatic Change*, 148(4):623–640.

Pal, J. S., Giorgi, F., Bi, X., Elguindi, N., Solmon, F., Gao, X., Rauscher, S. A., Francisco, R., Zakey, A., Winter, J., et al. (2007). Regional climate modeling for the developing world: the ictp regcm3 and regcnet. *Bulletin of the American Meteorological Society*, 88(9):1395–1410.

Schlenker, W. and Roberts, M. J. (2009). Nonlinear temperature effects indicate severe damages to US crop yields under climate change. *Proceedings of the National Academy of sciences*, 106(37):15594–15598.

Seppanen, O., J., F. W., and David, F. (2003). Control of temperature for health and productivity in offices. *Lawrence Berkeley National Laboratory*.

Skoufias, E., Vinha, K., and Conroy, H. (2013). The impacts of climate variability on welfare in rural Mexico. *Population and Environment*, 34(3).

Voldoire, A., Sanchez-Gomez, E., y Mélia, D. S., Decharme, B., Cassou, C., Sénési, S., Valcke, S., Beau, I., Alias, A., Chevallier, M., et al. (2013). The cnrm-cm5. 1 global climate model: description and basic evaluation. *Climate Dynamics*, 40(9-10):2091–2121.

Appendix

To have a more detailed understanding of what drive these effects, the overall income of each quartile could also be decomposed between wage and agricultural income:

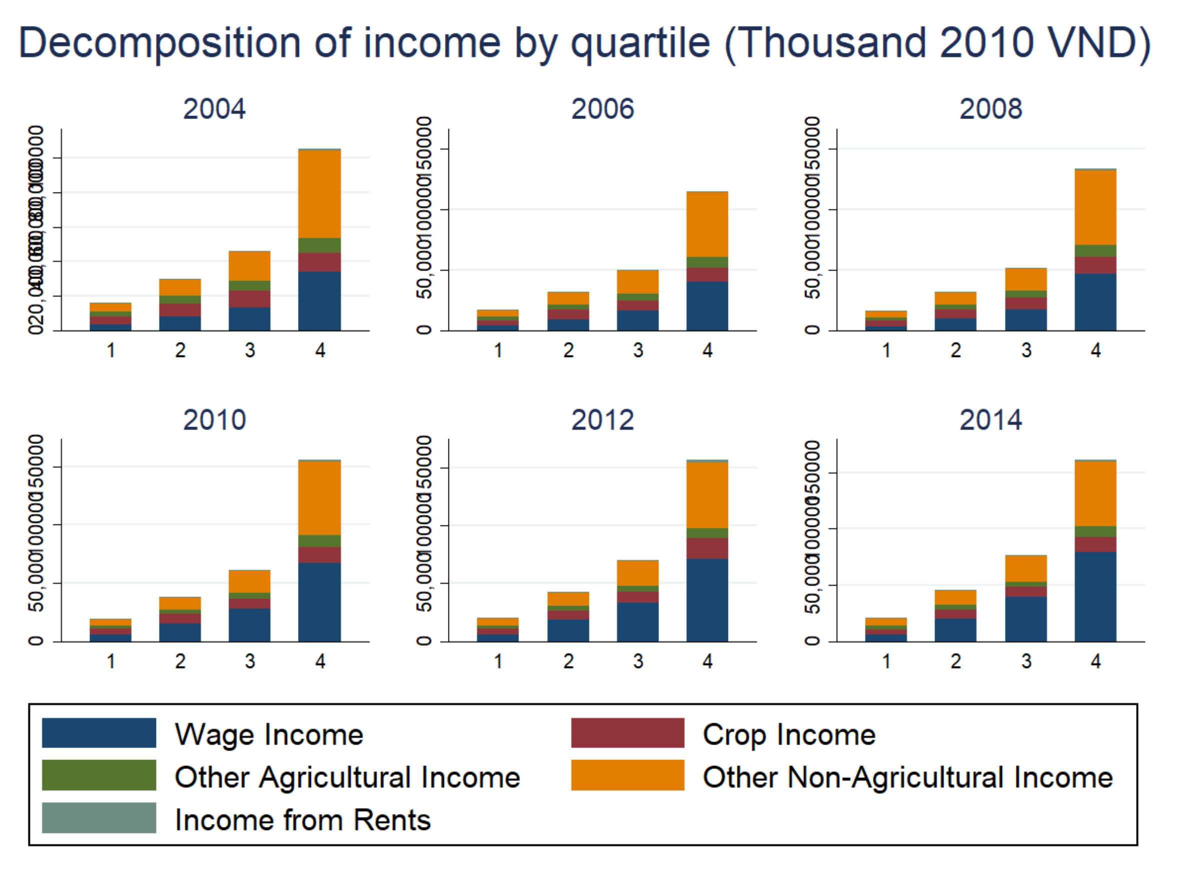

Figure 10. Decomposition in income sources in absolute terms

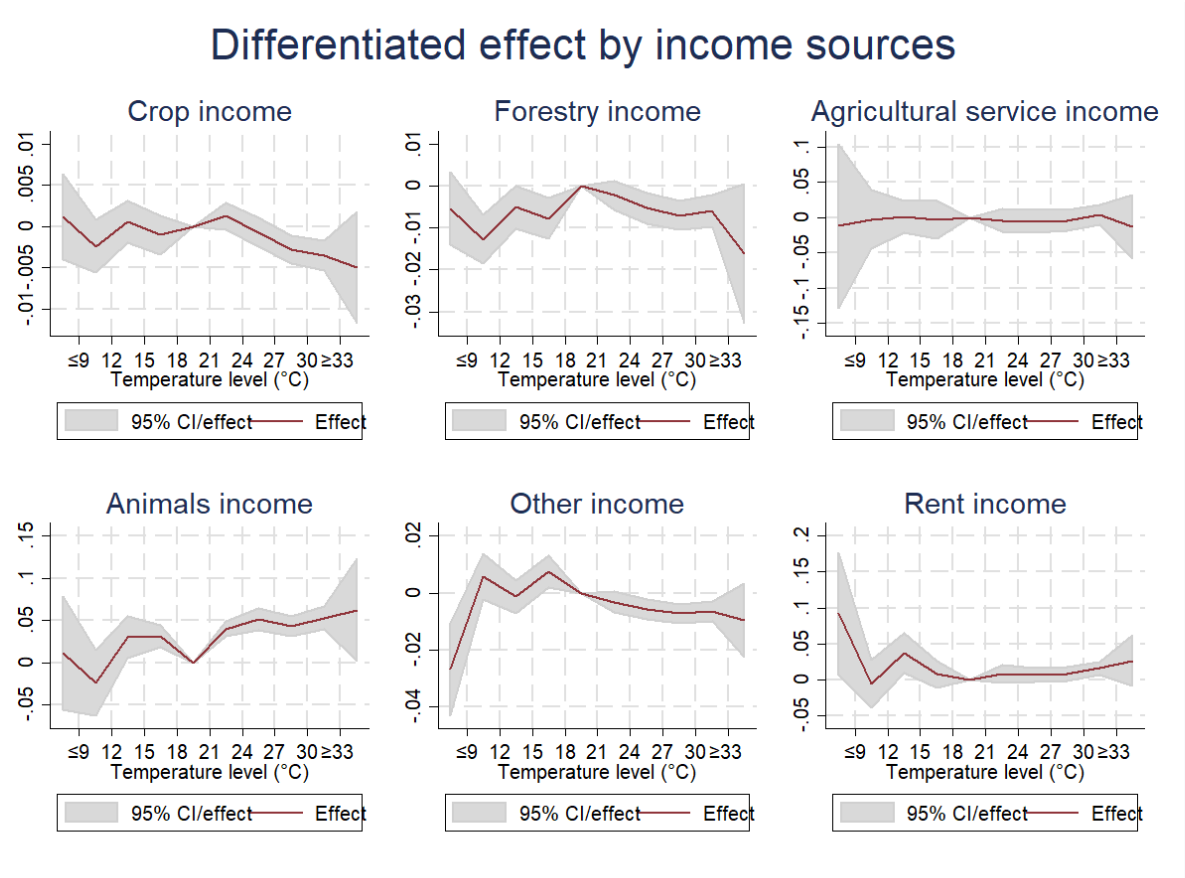

Figure 11. Effect of weather shocks on (log) Income by income sources (with CI)

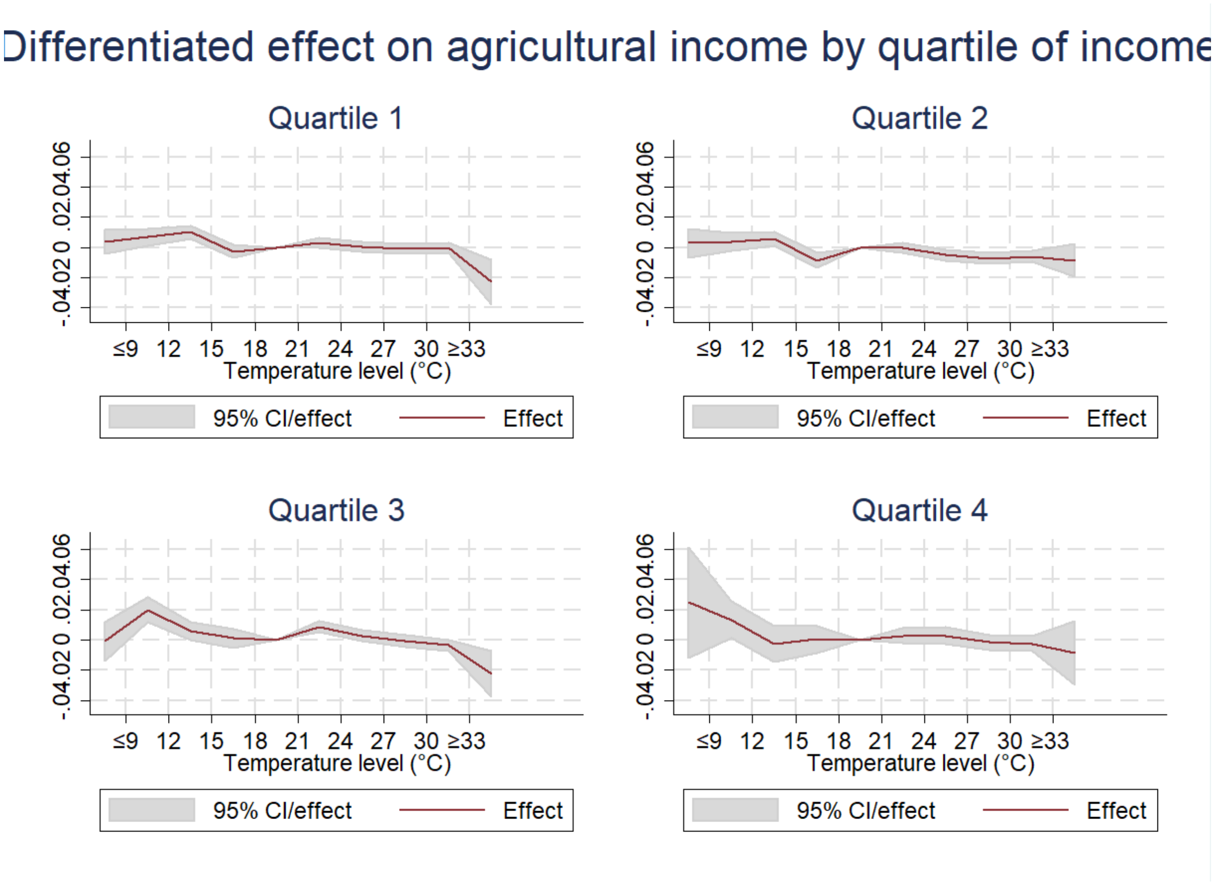

Figure 12. Effect of weather shocks on (log) Agricultural Income by income quartile

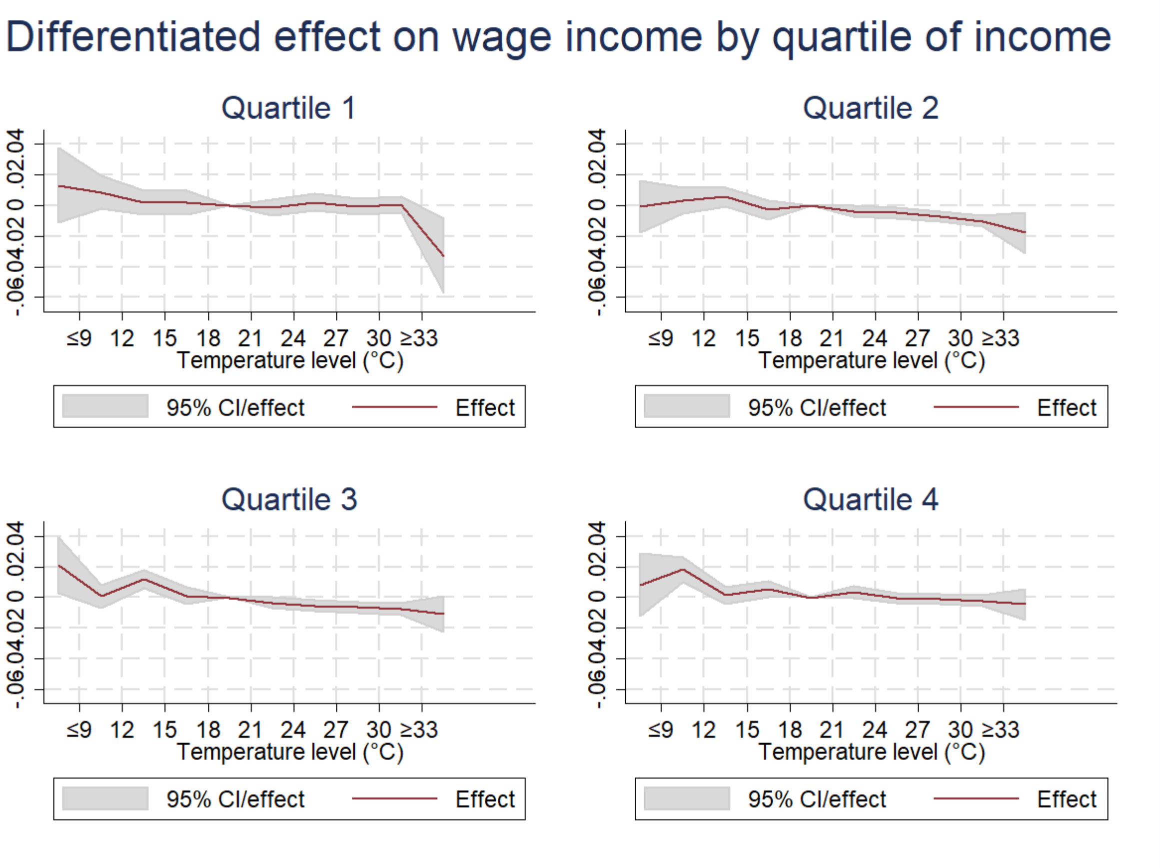

Figure 13. Effect of weather shocks on (log) Wage Income by income quartile (with CI)