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THE EFFECT OF TEMPERATURE AND EXTREME PRECIPITATION ON ECONOMIC PERFORMANCE: THE CASE OF VIETNAM

ABSTRACT

This study investigates the impact of temperature and extreme precipitation on economic performance. Studies examining the effects of extreme weather on economic growth have often used the frequency of natural disasters or the level of damage caused by natural disasters as a proxy for extreme weather. This study is one of the first to use the threshold of daily precipitation as a proxy of extreme weather, thereby capturing more precise and frequent weather variations that traditional measures may overlook. By using detailed panel data collected from 63 provinces and cities across Vietnam over the period from 2005 to 2018, this research systematically analyses how weather fluctuations influence regional economic performance. For the main empirical estimations, the study employs the Fixed Effects Model (FEM) to control for unobserved, time-invariant provincial characteristics. To further strengthen the robustness of the findings, the Generalised Method of Moments (GMM) is applied, addressing potential endogeneity and serial correlation issues within the dataset. Its results show that extreme precipitation adversely affects economic performance. Provinces that have more extreme precipitation have lower GDP per capita and labour. Temperature has a nonlinear effect on economic performance. The two variables exhibit an inverse U-shape relationship, and the optimal temperature for economic performance in Vietnam is 23 degrees Celsius. This finding provides critical insights for policymakers when considering regional development strategies in the context of climate change.

Keywords: climate change, economic performance, extreme precipitation, FEM, GDP per labour, GDP per capita, GMM, temperature, Vietnam, weather

JEL Classification: O12, O40, Q54, R11

INTRODUCTION

In recent decades, climate change has become one of the biggest concerns among nations. Its disruptive effects have become more apparent with more severe weather events that threaten people's livelihoods worldwide, especially in developing countries (Carleton et al., 2022; Tol, 2024). In this context, the quest to examine, evaluate, predict, and mitigate the economic impacts of climatic conditions has gained increasing attention among scholars. The mounting evidence points to the adverse impacts of extreme weather events such as floods, typhoons, and droughts, which have become more frequent with climate change (Donat et al., 2016). The impact of temperature and precipitation on economic performance has been widely studied, particularly in the context of agricultural productivity, labour supply, and overall economic growth (Burke et al., 2015). However, most existing research relies on broad measures such as the frequency of natural disasters or total damage estimates, overlooking more granular indicators of extreme weather. This study seeks to fill this gap by employing a novel approach: using the threshold of daily precipitation as a proxy for extreme weather events. By focusing on Vietnam, a country highly vulnerable to climate change, this study provides critical insights into the economic implications of extreme weather patterns in developing economies.

In this study, the authors attempt to answer two questions. Firstly, do extreme weather events affect economic growth? Secondly, is there a nonlinear relationship between temperature, precipitation, and economic growth? We expect the relationship between

temperature, precipitation, and economic growth to be quadratic. This study's results will provide empirical evidence of the effects of climate change on economic growth, where the frequency of extreme precipitation is a proxy for climate change. In addition, this study assesses the nonlinear relationship between temperature, precipitation, and GDP per capita to suggest the optimal temperature and precipitation for economic growth. We chose Vietnam as a case for this study because of its geographic diversity and vulnerability to climate change. Vietnam ranked fifth on the Global Climate Risk Index in 2016 and eighth on the Long-Term Climate Risk Index from 1997 to 2016 among 179 assessed countries (Eckstein, Künzel, & Schäfer, 2017). According to the geographic information for Vietnam (2024), 75% of its area is mountains and highlands. Vietnam has over 3,000 km of coastline and two major rivers, the Red and Mekong Rivers. These natural conditions make Vietnam vulnerable to extreme weather, such as storms and floods. Therefore, these geographic characteristics make Vietnam a suitable location to study the impact of climatic conditions on economic growth.

This study uses panel data from 63 provinces and cities in Vietnam to analyse the impact of climate change on economic growth. The economic data were collected from the General Statistics Office of Vietnam (GSO, 2021). Climate data for daily temperature and precipitation in the 63 provinces/cities were collected from the National Aeronautics and Space Administration (NASA, 2021). The extreme value for precipitation was calculated from the daily precipitation data. A fixed effects model (FEM) was used to analyse the impact of climate change on economic growth in Vietnam, and the generalised method of moments (GMM) was then used to test the robustness of the results.

LITERATURE REVIEW

Diverse studies have shown that climate change disrupts various economic activities, adversely affecting economic growth (Henseler & Schumacher, 2019; Tol, 2024; Zhao et al., 2018). Climatic conditions affect economic activities such as agricultural output (Puri et al., 2022), service output (Hsiang, 2010), industrial output (Dell et al., 2009), labour productivity (Al Refaie et al., 2021), and electricity consumption (Zhang et al., 2019).

Many studies have confirmed the effect of climate on economic output, where temperature and precipitation are the two main variables used to represent climatic conditions. Some empirical studies have shown that temperature has a nonlinear effect on economic growth (Alagidede et al., 2016; Burke et al., 2015; Kumar & Khanna, 2019; Nordhaus, 2006; Zhao et al., 2018) while others have shown that temperature has a linear effect on economic growth (Dell et al., 2009; Dell et al., 2012; Henderson et al., 2018). Burke et al. (2015) confirmed a quadratic relationship between temperature and economic growth. The optimal annual mean temperature is 13.6 degrees Celsius, and macroeconomic productivity declines strongly at higher temperatures. When investigating the relationship between temperature, precipitation, and Gross Cell Product (GCP), Zhao et al. (2018) also found a nonlinear relationship between GCP and temperature when the gross value was added in a square region bounded by 1° latitude and 1° longitude. The effect of temperature on economic growth is stronger in underdeveloped countries, where the optimal temperature for economic growth is 16 degrees Celsius.

Unlike temperature, precipitation has little or no effect on economic growth in rich countries (Dell et al., 2012; Henseler & Schumacher, 2019; Zhao et al., 2018). However, Damania et al. (2020) showed a concave relationship between precipitation and Gross Domestic Product (GDP) growth in developing countries. Precipitation affects economic growth in developing countries because the economic activities in these regions primarily depend on agriculture, which is easily affected by the amount of precipitation. Similarly, Barrios et al. (2010) concluded that rainfall is a primary factor for economic growth in Sub-Saharan Africa (SSA) but not in other developed countries. Their simulations suggested that the current gap in GDP per capita in SSA relative to other countries could have been 15%–40% lower if the rainfall had been the same as in previous years.

Most studies examining the effect of climate factors on economic growth have used mean values of annual temperature and precipitation as a proxy for climate (Alagidede et al., 2016; Burke et al., 2015; Damania et al., 2020; Henseler & Schumacher, 2019; Kalkuhl & Wenz, 2020; Zhao et al., 2018). Mean values always have limitations, such as not capturing extreme weather events (Kotz et al., 2021). Studies examining the impact of extreme weather on economic growth have often used the frequency of natural disasters or the level of damage caused by natural disasters as a proxy for extreme weather (Arouri et al., 2015; Nguyen & Pham, 2020; Noy & DuPont, 2018; Parida et al., 2020). Few studies have used the threshold of daily precipitation as a proxy for extreme weather, especially in developing countries such as Vietnam. This study is one of the first to use the threshold of daily precipitation as a proxy for extreme weather. When studying the impact of climate change on economic growth, this measurement will enrich the proxies for climate change.

AIMS AND OBJECTIVES

This study aims to investigate the impact of temperature and extreme precipitation on economic performance. Economic performance is represented by GDP per capita and GDP per labourer. More specifically, the research has two main objectives. First, the nonlinear impact of temperature on economic performance is analysed. We expect that these two variables have an inverse U-shape relationship. Secondly, the impact of extreme precipitation on economic performance is analysed. We expect that extreme precipitation negatively impacts economic performance. By providing empirical evidence on the impact of temperature and extreme precipitation on economic performance in Vietnam, it offers actionable insights for policymakers and contributes to the broader discourse on climate change and economic resilience.

METHODS

Empirical model

In this study, a fixed effects model (FEM) was used to analyse the impact of temperature and extreme precipitation on economic performance and the generalised method of moments (GMM) was then used to test the robustness of the results. The authors use the percentile of daily precipitation as the threshold to determine the frequency of extreme weather. This study employed the following empirical model to study the effects of extreme precipitation on economic performance:

$$Y_{it} = \alpha + \beta_0 Y_{it-1} + \beta_1 Ext_{it} + \gamma X_{it} + \eta_i + \mu_t + \varepsilon_{it} \quad (1)$$

In Equation (1), the dependent variable, Y_{it} , is the natural logarithm of deflated GDP per capita or labour of province or city i in the year t . Ext_{it} is the frequency of extreme precipitation events occurring in province or city i in the year t . Y_{it-1} represents a one-year lagged natural logarithm of deflated GDP per capita or labour, which is included in the regression equation because time-series GDP often show autocorrelation (Sequeira et al., 2018). X_{it} represents control variables, including population growth rate, labour growth rate, and mean daily temperature and precipitation in province or city i in the year t . A previous study demonstrated that population and labour growth rates impact economic growth in Vietnam (Truong, 2020). Also, η_i and μ_t are the provincial and year fixed effects, while ε_{it} is the error term.

The authors also assessed the nonlinear relationship between temperature, precipitation, and economic growth using the following model:

$$Y_{it} = \delta + \theta_0 Y_{it-1} + \theta_1 Pre_{it} + \theta_2 Pre_{it}^2 + \theta_3 Temp_{it} + \theta_4 Temp_{it}^2 + \rho Z_{it} + \tau_i + \varphi_t + \vartheta_{it} \quad (2)$$

In Equation (2), Y_{it} is the natural logarithm of deflated GDP per capita or labour in province or city i in the year t . Pre_{it} and $Temp_{it}$ denote the mean daily precipitation and temperature values, respectively, in province or city i in the year t . The squared terms of precipitation and temperature, Pre_{it}^2 and $Temp_{it}^2$, are included because we expect a nonlinear relationship between economic outcome and temperature and precipitation. Damania et al. (2020) demonstrated that rainfall and temperature nonlinearly impact GDP growth. Also, Z_{it} represents control variables, including population growth rate, labour growth rate, and extreme precipitation in province or city i in the year t . In addition, τ_i and φ_t are the provincial and year fixed effects, while ϑ_{it} is the error term.

Many other unobserved time-invariant variables may also determine a region's economic activities and performance, such as other geographic factors that we could not include in our analysis. The authors used a FEM to derive the benchmark results to control for those variables. Endogeneity might also arise due to the correlation between the explanatory variables and the error term. Therefore, the study used the GMM to test the robustness of our results, which has been claimed to be a suitable method for managing endogeneity in growth models (Truong, 2020).

Variables and Data Constructs

The study obtained the data from NASA (2021) and the GSO (2021). The climatic data, including daily precipitation and temperature, obtained from NASA's website covers 63 provinces and cities and spans 2005 to 2018. The authors obtained GDP and labour data from the 2010, 2012, 2015, and 2018 statistical yearbooks of 63 provinces/cities published by the GSO (2021). The study did not collect data during and after the COVID-19 pandemic because it adversely affected economic performance (Dang & Hieu, 2024); data during this period could bias the regression analysis results. Because the data contains missing values, the number of observations differs for many variables. Table 1 summarises the data used in the empirical analysis.

Table 1. Data summary. Notes: NWE (Northwest and Northeast region), SEA (Southeast region), MKD (Mekong Delta region), CEH (Central Highland region), CEC (Central Coast region), and VND (Vietnamese Dong).

Variables	Description	Observations	Mean and SD All re- gions	Mean Lowest re- gion	Mean Highest re- gion
Y	GDP per capita (VND million)	858	28.209 (29.349)	17.283 NWE	76.501 SEA
Y1	GDP per labour (VND million)	801	50.051 (54.001)	28.599 NWE	137.864 SEA
dlnP	Population growth rate	819	0.010 (0.012)	0.004 MKD	0.026 SEA
dlnL	Labour growth rate	693	0.014 (0.028)	0.005 MKD	0.029 SEA
Pre	Mean precipitation (mm)	882	4.047 (1.262)	2.681 CEH	4.658 CEC
Temp	Mean temperature (°C)	882	24.535 (2.519)	21.261 NWE	27.576 MKD
Ext	Extreme precipitation	882	0.178 (0.422)		

The authors first computed the natural logarithm of GDP per capita and GDP per labour using deflated GDP data to capture provincial economic performance. The base year for calculating deflated GDP was 2010. As shown in Table 1, Vietnam's mean GDP per capita from 2005 to 2018 was low, just around VND 28 million (equivalent to USD 1,244). However, the annual GDP growth rate is high, around 6% (Nguyen, 2024).

Population and labour growth rates were calculated as the difference between the logarithm of population and labour at time t and the logarithm of population and labour at time $t-1$. As presented in Table 1, the mean annual population and labour force growth rates were about 1.0% and 1.4%, respectively. The Mekong Delta (MKD) region had the lowest population and labour growth rates, at just around 0.4% and 0.5%, while the SEA region had the highest rates, at around 2.6% and 2.9%. This phenomenon is due to Vietnam's migration trend. Each year, thousands of people migrate from the MKD region to the SEA region for employment opportunities, and the SEA region receives migrant labour from all over the country.

To examine the effect of climatic conditions on economic performance, the authors use mean temperature, mean precipitation, and extreme precipitation as proxies for climatic conditions. We computed these variables based on the daily data provided by NASA (2021). The mean daily precipitation of province/city i in the year t is the sum of precipitation of all days in the year t divided by the number of days in the year t . Similarly, the mean daily temperature of province/city i in the year t is the sum of the temperature of all days in the year t divided by the number of days in the year t .

The authors used a percentile method to determine extreme weather events. The extreme weather variable reflects the number of days a province/city experiences extreme daily precipitation, surpassing the threshold. Vietnam is often impacted by tropical storms, which are followed by heavy rains and flooding (Arouri et al., 2015). Therefore, the extreme precipitation variable can capture extreme weather in Vietnam. Since exposure to extreme rainfall or weather events is comparable within regions, the authors define the threshold of extreme precipitation as the 99.95th percentile of the distributions of daily precipitation from 2005 to 2018 within each region instead of nationwide. Table 2 presents the threshold for each region. The CEC region, often hit by severe rainfall and storms, had the highest threshold among regions, followed by the RRD region. The SEA and MKD regions had the lowest thresholds.

Table 2. Precipitation threshold by region.

Region	RRD	NEW	CEC	CEH	SEA	MKD
Daily precipitation threshold (99.95 th percentile; mm)	104.48	77.59	156.22	72.09	59.51	55.13

The authors assessed correlations among the independent variables to avoid multicollinearity in the regression equation. The correlation matrix (Table 3) showed weak correlations among the independent variables; therefore, multicollinearity should not be an issue. The following section will use these independent variables for FEM and GMM regression.

Table 3. Correlation matrix.

Variable	L.Iny	L.Iny1	Pre	Ext	Temp	dlnP	dlnL
L.Iny	1.000						
L.Iny1	0.994	1.000					
Pre	0.156	0.160	1.000				
Ext	0.008	0.017	0.240	1.000			
Temp	0.381	0.409	-0.160	-0.006	1.000		
dlnP	0.236	0.236	-0.103	-0.051	-0.044	1.000	
dlnL	-0.002	0.023	-0.122	-0.035	-0.064	0.511	1.000

RESULTS

Effects of Extreme Precipitation on Economic Performance

The authors examined the effects of extreme precipitation on provincial economic performance measured by GDP per capita or labour. Table 4 presents regression results for Equation (1) using FEMs. Columns (1) and (2) show the results with GDP per capita as the dependent variable, while columns (3) and (4) show the results with GDP per labour as the dependent variable. The control variables included lagged GDP, population and labour growth rates, and mean temperature and precipitation. All regressions also included year fixed effects to control for unobservable changes within each year. The independent variables in equations (1) and (2), as well as equations (3) and (4), are different to check the robustness of the impact of extreme precipitation on economic performance.

Our results support evidence that extreme precipitation negatively affects economic performance. As shown in Table 4, the estimated coefficients for this variable are significantly negative in all regressions. Other similar studies have often used the frequency of natural disasters, such as storms, floods, and droughts, to study the impacts of climate change on Vietnam's economy (Aroui et al., 2015; Nguyen & Pham, 2020). By taking a different approach, utilizing extreme precipitation to depict extreme weather events, this study strengthens the evidence for the negative effects of climate change on economic activities in Vietnam. Moreover, the estimated coefficients for extreme precipitation in columns (3) and (4) are larger and more significant than those in columns (1) and (2), suggesting that the effects of extreme precipitation are greater on economic productivity than on the overall economic well-being of provinces and cities.

Table 4. Extreme precipitation and economic performance. Note: Standard errors are shown in parentheses. *** and ** indicate significance at $p < 0.01$ and 0.05 respectively.

Variable	(1) Per capita GDP	(2) Per capita GDP	(3) Per labour GDP	(4) Per labour GDP
Extreme precipitation	-0.0125** (0.00565)	-0.0142** (0.00581)	-0.0178*** (0.00617)	-0.0183*** (0.00631)
Mean precipitation		0.00280 (0.00351)		0.00199 (0.00382)
Mean temperature		-0.00455 (0.00926)		0.00276 (0.0103)
Lag of GDP per capita	0.842*** (0.0211)	0.842*** (0.0212)		
Lag of GDP per labourer			0.786*** (0.0256)	0.785*** (0.0260)
Population growth rate	-0.643** (0.260)	-0.664** (0.261)		
Labour growth rate			-0.849*** (0.103)	-0.848*** (0.103)
Constant	0.500*** (0.0526)	0.605** (0.236)	0.810*** (0.0838)	0.738*** (0.255)
Year fixed effect	Yes	Yes	Yes	Yes
Observations	782	782	672	672
R2	0.969	0.969	0.946	0.946
Number of provinces/cities	63	63	63	63

The results of the control variables align with expectations. The estimated coefficients for lagged GDP per capita or labour are significantly positive, while those for population and labour growth rate are negative. Regions with higher incomes in the previous year are associated with higher incomes in the current year. The coefficients are also <1, meaning that regions with higher income tend to have lower economic growth rates, aligning with another study that proved the convergence theory of economic growth (Hoeffler, 2002).

The nonsignificant mean precipitation and temperature results confirmed no linear association between climatic variables and economic performance. These results are similar to those of Henseler and Schumacher (2019) and Zhao et al. (2018). Precipitation does not affect economic performance because rainfall has both positive and negative effects. If rainfall is moderate, the rain will help develop agriculture. If the rainfall is too heavy, it will cause floods and landslides. The effects of temperature on economic performance appear nonlinear. In the next part, the study tests the nonlinear relationship between temperature, precipitation, and economic performance.

Nonlinear Effects of Climatic Variables on Economic Performance

The authors detected nonlinear effects of mean daily precipitation and temperature on annual provincial GDP per capita or labour using the empirical model in Equation (2). Table 5 presents the regression results for Equation (2) using FEMs. Columns (1), (2), and (3) show the results with GDP per capita as the dependent variable, while column (4) shows the results with GDP per labour as the dependent variable. The control variables included lagged GDP, population or labour growth rates, and extreme precipitation. All regressions also included year fixed effects to control for unobservable changes within each year. The independent variables in equations (1), (2) and (3) are different to check the robustness of the impact of temperature on Per capita GDP.

Table 5. Nonlinear relationship between climatic variables and economic performance. Note: Standard errors are shown in parentheses. ***, **, and * indicate significance at $p < 0.01$, 0.05 , and 0.10 , respectively.

Variable	(1) Per capita GDP	(2) Per capita GDP	(3) Per capita GDP	(4) Per labour GDP
Mean temperature	0.240*** (0.0463)	0.227*** (0.0463)	0.230*** (0.0465)	0.237*** (0.0495)
(Mean temperature) ²	-0.00522*** (0.000970)	-0.00489*** (0.000948)	-0.00502*** (0.000974)	-0.00501*** (0.00103)
Mean precipitation	-0.0109 (0.0112)		-0.00860 (0.0113)	-0.0110 (0.0126)
(Mean precipitation) ²	0.000969 (0.00104)		0.000860 (0.00103)	0.00100 (0.00115)
Extreme precipitation		-0.0113** (0.00564)	-0.0111* (0.00574)	-0.0145** (0.00625)
Lag of GDP per capita	0.842*** (0.0209)	0.843*** (0.0207)	0.841*** (0.0209)	
Lag of GDP per labourer				0.783*** (0.0256)
Population growth rate	-0.800*** (0.258)	-0.830*** (0.258)	-0.826*** (0.258)	
Labour growth rate				-0.853*** (0.101)
Constant	-2.186*** (0.581)	-2.106*** (0.579)	-2.067*** (0.584)	-1.934*** (0.621)
Year fixed effect	Yes	Yes	Yes	Yes
Observations	782	782	782	672
Within R2	0.970	0.970	0.970	0.948
Number of provinces/cities	63	63	63	63

The results show that temperature has a significant, nonlinear effect on GDP per capita at the 1% significance level. The mean temperature impacts economic performance, and the two variables have an inverse U-shape relationship. In columns (3) and (4), the estimated mean temperature coefficient is 0.23, and the squared term coefficient is about -0.005. Provincial income, measured by GDP per capita or labour, peaked at around 23 degrees Celsius and declined when the mean

temperature surpassed this threshold. The nonlinear relationship between economic performance and temperature in the 63 provinces of Vietnam is shown in Figure 1.

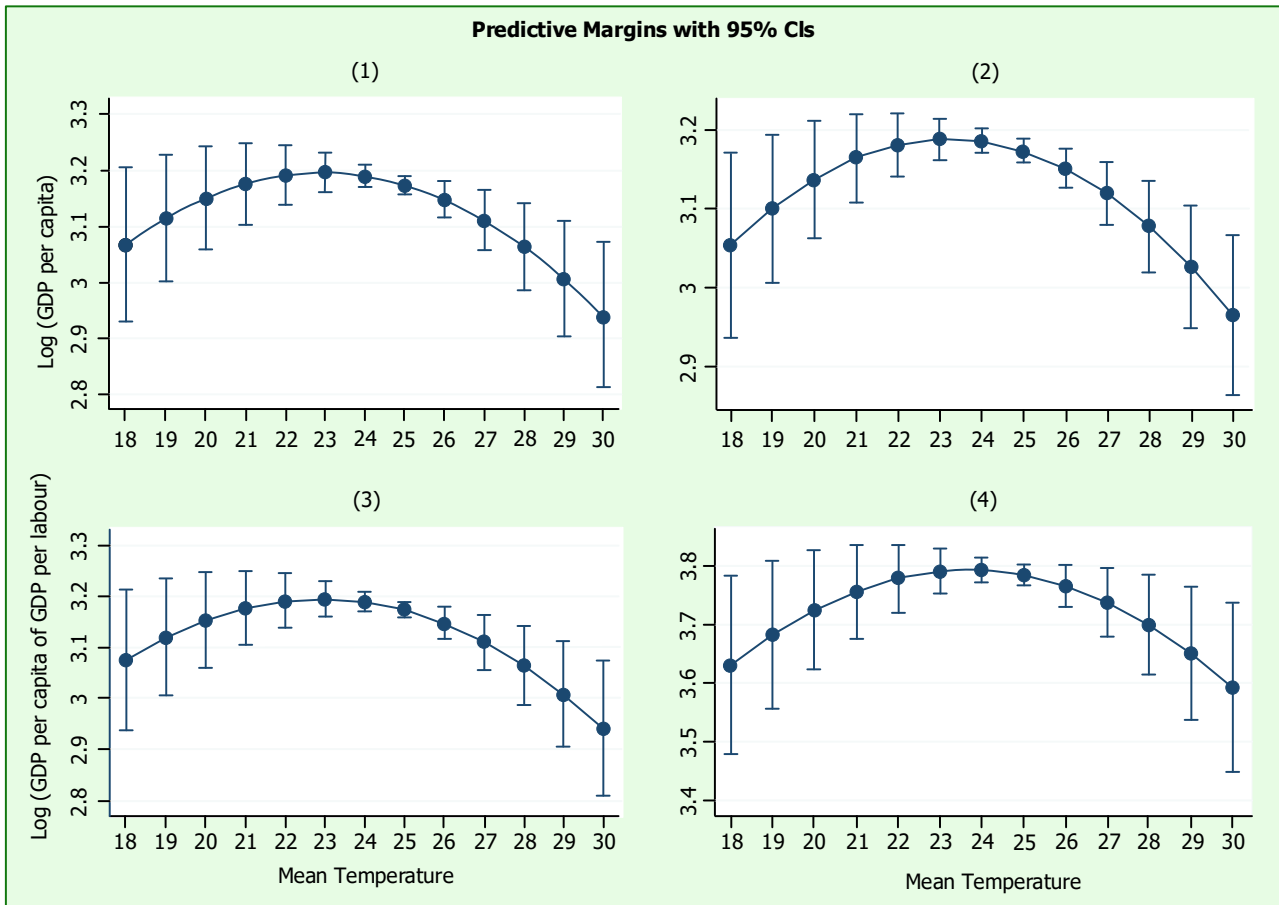


Figure 1. The nonlinear relationship between temperature and economic performance. Note: (1), (2), (3), and (4) correspond to the four columns in Table 5.

In contrast, the estimated coefficient for mean precipitation and its squared term were non-significant in all columns, suggesting that mean precipitation does not significantly impact economic performance. These results are similar to those of Henseler and Schumacher (2019) because rainfall has both positive and negative effects. On the positive side, rain provides water for agricultural and industrial production. On the negative side, rain can lead to flooding or landslides. Combining the above factors results in no significant impact of mean rainfall on GDP per capita or labour. The results of the control variables also align with expectations. The estimated coefficients for lagged GDP per capita or labour were significantly positive, while those for population and labour growth rate were significantly negative.

Robustness of Results

The authors assessed robustness using a dynamic GMM model suitable to manage potential endogeneity issues (Hoeffler, 2002). The results of the GMM model are presented in Tables 6 and 7. The GMM results again showed the negative impact of extreme precipitation on economic performance. They are significant in all four regression models. The regression coefficient was slightly smaller for the GMM than for the FEM. These results are similar to Collalti and Strobl (2022). In Vietnam, extreme precipitation often appears simultaneously with storms and can lead to flooding and landslides if it rains heavily for a long time. Therefore, extreme precipitation can negatively impact GDP per capita and labour in Vietnam.

Table 6. Robustness assessment of the effects of extreme precipitation on economic performance. Note: Standard errors are shown in parentheses. ***, **, and * indicate significance at $p < 0.01$, 0.05, and 0.10, respectively.

Variable	(1) Per capita GDP	(2) Per capita GDP	(3) Per capita GDP	(4) Per labour GDP
Extreme precipitation	-0.00776* (0.00516)	-0.00882* (0.00531)	-0.0116** (0.00586)	-0.0137** (0.00641)
Lag of GDP per capita	0.999*** (0.0147)	1.000*** (0.0147)	0.998*** (0.0147)	
Lag of GDP per labourer				1.007*** (0.0152)
Population growth rate	-0.511 (0.435)	-0.545 (0.429)	-0.494 (0.443)	
Labour growth rate				-0.881*** (0.138)
Constant	0.0470 (0.0503)	0.0877* (0.0450)	0.0479 (0.0506)	0.0261 (0.0641)
Year fixed effect	Yes	Yes	Yes	Yes
Observations	782	782	782	672
Number of provinces/cities	63	63	63	63
AR(1)	7.82×10^{-6}	8.28×10^{-6}	8.38×10^{-6}	1.34×10^{-5}
AR(2)	0.111	0.0956	0.0962	0.109
Hansen	0.224	0.328	0.406	0.339
Number of instruments	61	61	62	53

The authors also used the GMM to examine the nonlinear effect of temperature on economic activity. The GMM regression results in Table 7 again confirm that temperature has a nonlinear effect on economic performance. The effect of temperature on economic performance has an inverted U-shape. The GMM regression coefficients in Table 7 are approximately the same as the FEM regression coefficients in Table 5. These results are similar to those of Kumar and Khanna (2019) and Zhao et al. (2018). Excessively low temperatures will negatively impact agricultural activities. For example, icy weather can damage crops and livestock, especially in the Northern region of Vietnam. In contrast, excessively high temperatures can decrease labour productivity (Al Refaie et al., 2021) and increase electricity consumption due to the need for air conditioning (Zhang et al., 2019). Therefore, a mean temperature of about 23°C is optimal for economic performance in Vietnam.

Table 7. Robustness assessment of the nonlinear effects of climatic variables on economic performance. Note: Standard errors are shown in parentheses. ***, **, and * indicate significance at $p < 0.01$, 0.05, and 0.10, respectively.

Variable	(1) Per capita GDP	(2) Per capita GDP	(3) Per capita GDP	(4) Per labour GDP
Mean temperature	0.242*** (0.0683)	0.240*** (0.0699)	0.240*** (0.0684)	0.240*** (0.0756)
(Mean temperature) ²	-0.00505*** (0.00141)	-0.00500*** (0.00144)	-0.00500*** (0.00141)	-0.00504*** (0.00157)
Mean precipitation	-0.0324 (0.0284)		-0.0314 (0.0286)	-0.0490 (0.0337)
(Mean precipitation) ²	0.00326 (0.00310)		0.00320 (0.00309)	0.00483 (0.00349)
Extreme precipitation		-0.00659 (0.00560)	-0.00467 (0.00603)	-0.00738 (0.00642)
Lag of GDP per capita	0.988*** (0.0186)	0.991*** (0.0171)	0.988*** (0.0186)	
Lag of GDP per labourer				0.990*** (0.0172)
Population growth rate	-0.379 (0.551)	-0.286 (0.519)	-0.375 (0.553)	
Labour growth rate				-0.884*** (0.157)
Constant	-2.664*** (0.807)	-2.723*** (0.828)	-2.634*** (0.805)	-2.614*** (0.863)
Year fixed effect	Yes	Yes	Yes	Yes
Observations	782	782	782	672
Number of provinces/cities	63	63	63	63
AR(1)	9.14e-06	8.33e-06	9.32e-06	2.50e-05
AR(2)	0.127	0.105	0.126	0.208
Hansen	0.662	0.702	0.702	0.624
Number of instruments	61	61	62	56

DISCUSSION

The findings of this study provide robust evidence on the economic impacts of temperature and extreme precipitation in Vietnam, emphasising both nonlinear and adverse effects. While previous research has extensively examined the relationship between climatic variables and economic performance, this study contributes by utilising daily precipitation thresholds as a proxy for extreme weather events, offering a more precise measure of their economic consequences.

The nonlinear relationship between temperature and economic performance observed in this study is consistent with Burke et al. (2015), who found that temperature increases beyond an optimal threshold reduce macroeconomic productivity. Their study estimated an ideal annual mean temperature for economic growth at 13.6 degrees Celsius globally, whereas this study identifies 23 degrees Celsius as the optimal temperature for Vietnam. This difference is expected, as Vietnam's tropical climate means that economic activities, especially labour-intensive sectors, are more adapted to higher temperatures. Zhao et al. (2018) also found a nonlinear relationship between temperature and economic output, where developing countries experienced sharper economic declines when temperatures exceeded optimal levels. Similarly, Kumar and Khanna (2019) identified temperature-related productivity losses in labour-intensive economies, reinforcing this study's results. The inverse U-shaped relationship found here suggests that moderate warming may boost economic performance, but excessive heat reduces productivity, increases energy demand, and negatively impacts agricultural yields.

This study also underscores the adverse effects of extreme precipitation on economic performance, a finding that aligns with previous research. Damania et al. (2020) demonstrated a concave relationship between rainfall and GDP growth in developing economies, indicating that excessive precipitation disrupts agriculture and infrastructure-dependent industries. Likewise, Barrios et al. (2010) found that rainfall variability was a key driver of economic stagnation in Sub-Saharan Africa, where economies heavily rely on agriculture. However, in contrast to studies such as Dell et al. (2012), which found minimal precipitation effects on economic output in high-income nations, this study reveals significant economic consequences of extreme precipitation in Vietnam. The results suggest that heavy rainfall disrupts transportation, reduces labour productivity, and damages agricultural output, leading to overall economic slowdowns.

CONCLUSIONS

This study examined the impact of climatic factors, such as temperature and precipitation, on economic productivity. Most previous studies have used mean temperature and precipitation as a proxy for climatic conditions. In addition to mean temperature and precipitation, the study created an extreme precipitation variable to represent extreme weather, which the authors defined as daily precipitation exceeding the 99.95th percentile of daily precipitation within each region. The study examined the impact of climatic factors on economic productivity using panel data from 63 provinces and cities in Vietnam. Climate data were obtained from NASA (2021), while economic data were obtained from the GSO (2021). The study used FEMs for the primary estimations and then used the GMM to assess their robustness.

The findings indicate that extreme precipitation negatively impacts GDP per capita and labour. Provinces and cities that experience a higher frequency of extreme precipitation have lower economic performance. The provinces and cities in the CEC region of Vietnam experience the highest frequency of extreme precipitation and have the lowest GDP per capita. However, the study did not find a linear or nonlinear relationship between mean precipitation and economic performance. Regarding temperature, the authors found an inverse U-shaped relationship between mean temperature and economic performance. The optimal mean temperature for economic activities in Vietnam is 23 degrees Celsius. When the temperature is low, temperature rises lead to better economic performance. Nonetheless, higher temperatures are associated with lower GDP per capita or labour if the temperature exceeds the ideal temperature.

The results provide empirical evidence of the negative effects of extreme weather on economic productivity in a developing country within a tropical region. However, this study has several limitations. Firstly, data was collected and analysed only for Vietnam, limiting the generalisability of the findings to other Southeast Asian countries. Secondly, the analysis focused exclusively on the impact of extreme precipitation and did not consider other extreme weather events, such as extremely low rainfall or extreme temperature events. Additionally, the data analysed covers the period from 2005 to 2018, prior to the COVID-19 pandemic. Thus, the study excludes the period during and after COVID-19, when economic performance was severely disrupted and subsequently in recovery. In future research, the authors plan to expand the scope of the study by collecting data from other countries with economic characteristics similar to Vietnam, such as Thailand, Malaysia, and Laos. Furthermore, future studies should incorporate data spanning the COVID-19 pandemic period and the subsequent recovery phase. Additionally, the authors intend to broaden the analysis to include other types of extreme weather

events, such as extremely low rainfall or extremely high temperatures. Incorporating data from multiple countries will enhance the value and generalisability of the research findings.

ADDITIONAL INFORMATION

AUTHOR CONTRIBUTIONS

All authors have contributed equally.

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CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest.

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ВПЛИВ ТЕМПЕРАТУРИ ТА ЕКСТРЕМАЛЬНИХ ОПАДІВ НА ЕКОНОМІЧНІ ПОКАЗНИКИ: ПРИКЛАД В'ЄТНАМУ

У статті досліджено вплив температури та екстремальних опадів на економічні показники. Дослідження, що вивчають вплив екстремальних погодних умов на економічне зростання, часто використовували частоту стихійних лих або рівень шкоди, завданої стихійними лихами, як показник екстремальних погодних умов. Це дослідження є одним із перших, яке використовує поріг добової кількості опадів як показник екстремальних погодних умов, тим самим фіксуючи більш точні та часті зміни погоди, які традиційні заходи можуть не помічати. Використовуючи детальні панельні дані, зібрані з 63 провінцій і міст В'єтнаму за період із 2005 по 2018 рік, автори провели систематичний аналіз того, як погодні коливання впливають на регіональні економічні показники. Для основних емпіричних оцінок у дослідженні використана модель фіксованих ефектів (FEM) для контролю неспостережуваних, інваріантних у часі провінційних характеристик. Щоб іще більше посилити надійність висновків, застосовано узагальнений метод моментів (GMM), який розв'язує потенційні проблеми ендогенності та серійної кореляції в наборі даних. Його результати свідчать, що екстремальні опади негативно впливають на економічні показники. Провінції з більш екстремальними опадами мають нижчий ВВП на душу населення та робочу силу. Температура має нелінійний вплив на економічні показники. Дві змінні демонструють обернену U-подібну залежність, і оптимальна температура для економічних показників у В'єтнамі становить 23 градуси за Цельсієм. Цей результат дає критично важливі висновки для політиків під час розгляду стратегій регіонального розвитку в контексті зміни клімату.

Ключові слова: зміна клімату, економічні показники, екстремальні опади, FEM, ВВП на робочу силу, ВВП на душу населення, GMM, температура, В'єтнам, погода

JEL Класифікація: O12, O40, Q54, R11