Master's degree in Macroeconomic Policy and Financial Markets

"Burning Growth: Rising Temperatures in a Growth-at-risk Approach. A case study of Colombia"

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ABSTRACT IN ENGLISH:

The rise in global temperatures have been a growing source of concern for policy makers given its potential impact for sustainable economic activity. This paper explores the effects of a temperature shock on the distribution of economic growth in Colombia. Specifically, it focuses on the impact of these shocks on economic risks. The findings suggest the existence of asymmetries on the lower and upper tail of the distribution, indicating that higher temperatures leads to less optimistic outcomes for GDP growth. Also, it is found negative and significant effects of temperature shocks on non-agricultural sectors. The results are obtained using quantile regressions under the Growth-at-risk approach and local projections.

ABSTRACT IN CATALAN/ SPANISH:

Una fuente creciente de preocupación para los hacedores de política es el aumento de las temperaturas globales y su impacto potencial sobre la sostenibilidad de la actividad económica. Este artículo explora los efectos de un choque de temperatura en la distribución del crecimiento en Colombia. Específicamente, analiza el impacto de estos choques sobre los riesgos económicos, a través del uso de regresiones por cuantiles bajo la metodología de Growth-at-risk y proyecciones locales. Los resultados sugieren la existencia de asimetrías en la cola inferior y superior de la distribución, indicando que temperaturas más altas conducen a resultados menos optimistas para el crecimiento del PIB. Asimismo, se encuentran efectos negativos y significativos de choques de temperatura en sectores no agrícolas.

KEYWORDS IN ENGLISH: Growth-at-risk, temperature shocks, climate change

KEYWORDS IN CATALAN/ SPANISH (3): Growth-at-risk, choques de temperature, cambio climático

BARCELONA SCHOOL OF ECONOMICS

Burning Growth:
Rising Temperatures in a Growth-at-risk Approach

A Case study of Colombia

by

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Abstract

The rise in global temperatures have been a growing source of concern for policy makers in the recent years, given its potential impact for sustainable economic activity. This paper contributes to climate literature exploring the effects of a temperature shock on the distribution of economic growth in Colombia. Specifically, it focuses on the impact of these shocks on economic activity risks. The findings suggest the existence of asymmetries on the lower and upper tail of the distribution, indicating that higher temperatures leads to less optimistic outcomes for GDP growth. It is also found negative and significant effects of temperature shocks on non agricultural sectors such as manufacturing, construction and energy. The results are obtained using quantile regresssions under the Growth-at-risk approach and local projections.

Key words: Growth-at-Risk, Quantile Regressions, Local Projections, Temperature shocks, Warming, Environment, Impulse Response Functions

JEL classifications: O44, C21, E27, Q54

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1. Introduction

Average global temperature on Earth has increased by 1.1°C since 1880. This rise has being mainly happening since 1975, at a rate of 0.15°C to 0.20°C per decade [1]. According to some authors (Zhongming et al. (2022); Acevedo et al. (2018)), higher annual average temperatures can be associated with economic damages in climate-exposed sectors such as agriculture, forestry, fishery, energy and tourism, and through outdoor labor productivity and capital accumulation.

Colombia's temperature has increased around 1°C during the last century and, as shown in Figure 1, monthly mean-temperatures are getting higher every decade. Moreover, nearly 30% of the economy relies in climate-exposed sectors - manufacturing, construction, agriculture and energy - which makes the country highly vulnerable to temperature shocks. According to The World Bank Group (2021), temperatures across Colombia are projected to continue rising, with mean monthly temperatures projected to increase 1.88°C by the 2050s, which will have critical consequences for water availability, agricultural output and the operation of the hydroelectric power.

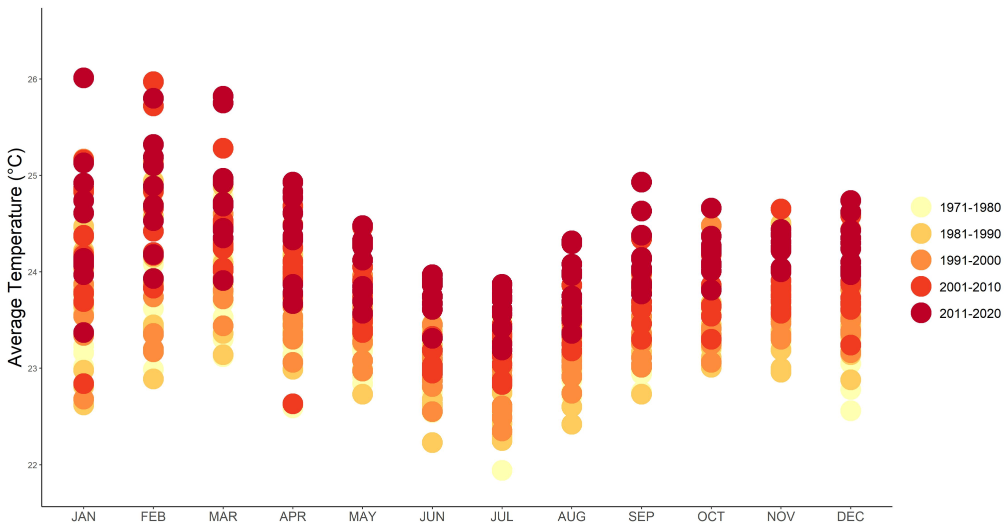

FIGURE 1: Variability and Trends of Mean- Temperature across Seasonal Cycle, 1971-2020
Source: Climate Change Knowledge Portal, The World Bank Group

In Colombia, agriculture represents 7% of GDP and it is an important source of export earnings and food security. The coffee industry, which constitutes the main crop, with around 15% of the agricultural output along with cut flowers, tropical fruits, sugarcane and cattle production are highly vulnerable to rising temperatures and hydrologic events.

[1]NASAS's Goddard Institute for Space Studies (GISS) Surface Temperature Analysis

According to The World Bank Group (2021), rising temperatures, especially daily maximum temperatures, could suppose an increase of heat stress for livestock and could reduce critical crop yield for rural populations. Moreover, rising temperatures are leading to rapid de-glaciations, which are a critical source of water for the country, jeopardizing the quantity and quality of supply for human consumption and agriculture. Additionally, the energy sector is heavily reliant in hydro-power - 86% of the national electricity generation comes from this source of energy- which means that higher temperatures will increase energy demand while reducing water availability, impacting river flow and the hydro-power generating capabilities.

Given that Colombia is one of the most vulnerable and less resilient countries to global warming according to the Climate Economics Index of Swiss Re Institute [2] and the ND-GAIN Country Index [3], this paper aims to analyze the effects of temperature shocks on short-term aggregate and sectoral economic growth in Colombia and the persistence of these effects. Especially, it focuses on how rising temperatures could affect risks (tails of the distribution) to economic activity, and slow the development of the country. According to Kiley (2021), a hotter average temperature could raise the risk of factors that lead to an economic contraction. For this purpose, the paper follows Adrian et al. (2019) growth-at-risk approach and studies how the distribution of contemporaneous and future GDP growth is affected by temperature shocks using the quantile regression method (Koenker, Bassett (1978)). The effects are analyzed up to four quarters ahead by applying the local projection method introduced by Jordà (2005).

To estimate the effect of temperature shocks on aggregate output and some of the most climate-exposed sectors, it is used quarterly deviations of temperatures levels from a 30-year historical norm. The analysis is focused on risks of the economic activity, this means in the 10th and 90th percentiles of the distribution of GDP growth. As a reference, it is also examined the effects of temperature shocks on the mean and the median of the output growth distribution.

The findings suggest that temperature shocks have a negative and significant effect on the entire distribution of output growth, suggesting that temperatures increases the risks to reach less favorable outcomes in Colombia. However, these effects are asymmetric across the percentiles, exhibiting higher effects on the lower tail of the one-quarter-ahead distribution. Nonetheless,

[2] Colombia ranks 42 out of 48 countries analyzed in the index. The index captures the economic impact estimates, climate risk scores of exposure to severe weather events across geographies and countries' current adaptive capacity to climate change. The index assigns 70% weight to the physical risk space, divided between chronic and acute risk. The chronic risk index that accounts for 30% to chronic risk which ranks countries by size of aggregate negative GDP-impact from climate change. The 30% of the overall index is assigned to a measure of a country's current capacity to cope with the negative impact from climate change

[3] Colombia ranks 92 out of 182. The ND-GAIN Country Index summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience. For the vulnerability dimension the country ranks 84, while in the readiness dimension ranks 108.

these effects vanish immediately in the 10th percentile, while in the upper tail persist up to three quarters ahead. Regarding the climate-exposed economic sectors, it is found that manufacturing is affected only through the upper tail, but this impact is the most persistent when compared to the other sectors. Meanwhile, construction is the most severely affected in the entire distribution, given its high exposure to temperatures. The energy sector is also vulnerable, provided the country reliance on hydro-power for electricity generation. Finally, no effects are found for agriculture in Colombia, which could be associated to the national efforts to reduce its vulnerability to climate change. In order to get a broader understanding of the climate effects on economic growth, it is also considered precipitations as deviations from its historical norm. The results suggest no influence on the GDP growth, neither affecting the mean nor the quantiles of the distribution.

This paper helps to fill up a research gap in Colombia on the impacts of global warming. As identified by the The World Bank Group (2021), it has not been extensively assessed the impacts of rising temperatures on key economic sectors and industries, different from agriculture, contributing on the identification of important spots of risk for economic growth in Colombia. Additionally, this paper contributes to the current climate-related literature by doing the analysis on a quarterly level instead of using annual data. This allows to capture seasonal effects of temperatures and avoids the possibility that two opposite movements in weather compensate each other within the same year. For example, by using annual data, Hsiang (2010) has found that economic response to temperature shocks appears to be only contemporaneous. However, a desegregated analysis through quarters, as in this paper, reveals that there are effects that could show up in future quarters within a year. Finally, the dynamics effects on different percentiles of the distribution of GDP growth are computed, which enables to analyze the impact of temperatures shocks over time.

This document is organized as follows: The first section is this introduction; Section 2 describes the main results of some of the most relevant climate-related literature; Section 3 presents the empirical approach and the identification of the temperature shock; Section 4 introduces the data that is used; Section 5 reports the most relevant findings; and Section 6 concludes and provides some insights about policy implications. The annex provide some details regarding the empirical analysis.

2. Literature Review

Climate literature suggests that increases in temperatures are likely to have a negative effects on economic growth (Acevedo et al. (2018); Dell et al. (2009); Dell et al. (2012)). However, some authors argue that these effects are nonlinear. For example, Acevedo et al. (2018) and Kalkuhl, Wenz (2020) finds that rising temperatures lower per capita output in countries with relatively high annual average temperature, while in cold countries the effect of rises in temperatures does not affect negatively their growth. Dell et al. (2012) suggest that there are large and negative effects of higher temperatures on growth, but only in poor countries. While Burke et al. (2015) finds that productivity declines gradually with warming, and this decline accelerates at higher temperatures.

In warmer economies, the effect is long-lasting and has a higher impact on agricultural output, labor productivity in climate-exposed sectors (Dell et al. (2012)), capital accumulation and human health. Agricultural value added and crop production drop with higher temperatures (Acevedo et al. (2018); Deryugina, Hsiang (2014); Stern, Stern (2007)). Indeed, higher temperatures have slowed agricultural productivity growth over the past 50 years globally. Kalkuhl, Wenz (2020) and Deryugina, Hsiang (2014), also find that there is strong evidence of temperature shocks effects on productivity. Deryugina, Hsiang (2014) obtains that the average productivity of individual days declines roughly linearly by 1,7% for each 1°C increase in daily average temperature beyond 15°C. Dell et al. (2012) identifies that temperature shocks have large effects on industrial output growth in poor countries. According to the authors, this may be caused by a demand-side spillover from the negative effect of temperature on agricultural output, or might reflect labor productivity losses.

In the medium term, Acevedo et al. (2018) suggests that the effects on rises in temperature are persistent. According to the authors, temperature shocks decay slowly, especially in relatively hot locations. Their findings suggest that seven years after a weather shock, per capita output is 1% lower for the median emerging market and 1.5% lower for the median low-income country. Another channel of impact, is that higher temperatures may reduce future labor supply as a result of increase in mortality rates, and other health outcomes (Deryugina, Hsiang (2014)). However, Dell et al. (2012) affirm that the effect of increases in temperatures might attenuate as the economy adapts. Nonetheless, this process of adaptation could harm the potential of the economy to grow in the short-term, by diverting resources from investment in productive capital and innovation (Batten (2018)).

There is not an extensive literature regarding the climate impacts on the entire distribution of output growth, given that the research has focused on the effects of temperature shocks on the conditional mean of GDP growth. However, Kiley (2021) analyzes the contemporaneous link between temperature shocks and the annual growth of real GDP per capita across the distribution of output for 124 countries, using the growth-at-risk approach. He founds that an increase in temperature affects the lower tail in a much more significant degree than the central tendency of the distribution of growth. Compared to Kiley (2021), this paper differs in the frequency used for the data and the analysis of the temperature effects over different horizons. In this case, the analysis is made on a quarterly basis instead of annual, and it is explored the effect of temperatures shocks on contemporaneous and future output growth.

3. Methodology

In order to study the impact of temperature shocks on the GDP growth, it is used the Growth at Risk approach (Adrian et al. (2019)) to analyze the entire distribution and the local projections method to explore the dynamics of the effects (Jordà (2005)). For this aim, temperature shocks are considered as exogenous increases in temperatures in Colombia and are measured as deviations of temperature levels from a 30-year historical norm.

It is first assessed the effects of temperature on the conditional mean of output growth using Ordinary Least Squares (OLS), as shown in equation (1).

$$GDPgrowth_{t+h} = \alpha_{t+h} + \lambda_{t+h} Shock_{t+h} + \phi_{t+h} X_{t+h} + \epsilon_{t+h} \tag{1}$$

Where $GDPgrowth_{t+h}$ is the growth rate of GDP at $t + h$. $Shock_{t+h}$ is the deviation of temperatures from a 30-year historical norm and X_{t+h} include a set of control variables that will be defined in the next section.

Quantile regressions are used to estimate how the distribution of GDP growth changes with temperature shocks. This method minimizes the sum of absolute errors, rather than the sum of squared errors, and put differential weights depending on whether the error term is above or below a particular quantile.

According to Das et al. (2021), another advantage of this method is its robustness to outliers. Therefore, the coefficients estimates are computed as:

$$\hat{\beta}_\tau = argmin \sum_{t=1}^{T-h} (\tau \cdot 1_{(GDPgrowth_{t+h} \geq X_t \beta)} |GDPgrowth_{t+h} - X_t \beta_\tau| + (1-\tau) \cdot 1_{(GDPgrowth_{t+h} < X_t \beta)} |GDPgrowth_{t+h} - X_t \beta_\tau|) \quad (2)$$

Where X_t is the set of predictors and τ refers to the quantile. Then, the predicted value from that regression is:

$$\hat{Q}_{GDPgrowth_{t+h}|X_t}(\tau|X_t) = X_t \hat{\beta}_\tau \quad (3)$$

Where $\hat{Q}_{GDPgrowth_{t+h}|X_t}(\tau|X_t)$ is a consistent estimator of the quantile function, as shown by Koenker, Bassett (1978). Given that the focus of the paper is to evaluate how temperature shocks affects risks (tails of the distribution) to economic activity, the percentiles used are 10th, 50th and 90th (Kiley (2021); Das et al. (2021)). For robustness, the model was also estimated for the percentiles 5th, 15th, 85th and 95th. The relationship between temperature shocks and output growth distribution is computed contemporaneously and one-quarter ahead, while the dynamics of the different GDP growth quantiles are estimated using local projections following Jordà (2005). This method will allow to trace out the response of GDP growth at different horizons to a temperature shock at time t, as in equation (4). According to Li et al. (2020) firms do not take costly adaptive actions in response to short-run temperature shocks. Therefore, in order to minimize the potential effects of adaptation, it is considered a short-term horizon, defined as four quarters ahead.

$$GDPgrowth_{\tau,t+h} = \alpha_{\tau,h} + \lambda_{\tau,h} Shock_{\tau,t} + \phi_{\tau,t} X_{\tau,t} + \epsilon_{\tau,t+h} \quad (4)$$

Where $h = 0, ..., 4$. $GDPgrowth_{\tau,t+h}$ is the GDP growth at period $t+h$ for the τth quantiles and X is a vector of control variables that will be explained in the next section. The response of $GDPgrowth_\tau$ at time $t+h$ to a temperature shock at time t is given by $\lambda_{\tau,h}$. The impulse-response functions are estimated as a sequence of $\lambda_{\tau,h}$ for each horizon. 90% confidence bands are computed using bootstraping for the standard errors.

4. Data

To estimate how the distribution of GDP growth changes with temperature shocks, it is used the inter-annual GDP growth [4] for Colombia as the dependent variable. The series used as controls, X_{t+h}, are: i) lagged GDP growth; ii) the Financial Condition Index (FCI) estimated by the International Monetary Fund (IMF) [5] ; iii) El Niño Southern Oscilation Index (ENSO) computed by the National Oceanic and Atmospheric Administration (NOAA),[6] and; iv) a dummy variable that takes a value of 1 during a period of economic crisis and 0 otherwise. The first two controls are included following Adrian et al. (2019) growth-at-risk approach. ENSO index, which is the primary predictor for global climate disruptions (Physical Sciences Laboratory (NOAA) (2022)), intends to clean the effects of temperatures on economic growth, while the dummy variable controls for the housing market crisis in Colombia (1998-2001).

The sample goes from the first quarter of 1994 until the third quarter of 2016, constrained by the availability of the Financial Condition Index. All the series have been adjusted by seasonal and calendar effects. The data is used on a quarterly basis in order to analyze fluctuations of temperatures within a year. This approach avoids the risk of compensating opposite effects within the same year period.

4.1. Temperature Shock

The shock was obtained as the deviation of the mean of temperature levels from a historical norm, which is a 30-year Moving Average. This 30-year window corresponds to the climatological standard norms established by the World Metereological Organization (WMO). As shown in Figure 2, the distribution of the historical norm of the temperature for Colombia has shifted to the right. This shows that years are becoming hotter and more intense temperatures are occurring more frequently (Climate Change Knowledge Portal, The World Bank Group).

[4]This refer to the growth rate of a quarter with respect to the same quarter in the previous year. The GDP series had to be spliced given that the original data were segregated into three different base years.

[5]According to the IMF, this variable is constructed using a set of 10 indicators, which includes corporate spreads, term spreads, interbank spreads, sovereign spreads, the change in long-term interest rates, equity and house price returns, equity return volatility, the change in the market share of the financial sector, and credit growth. This computation is based on Koop, Korobilis (2014) and build on the estimation of Del Negro, Primiceri (2015) time-varying parameter vector autoregression Doz et al. (2011). This approach has two advantages: first, it can purge financial conditions of (current) macroeconomic conditions; second, it allows for a dynamic interaction between the FCIs and macroeconomic conditions, which can also evolve over time.

[6]El Niño is a periodic variation in sea surface temperature and the air pressure of the overlying atmosphere (Southern Oscillation) throughout the equatorial Pacific Ocean, according to the National Centers for Environmental Information (NCI)

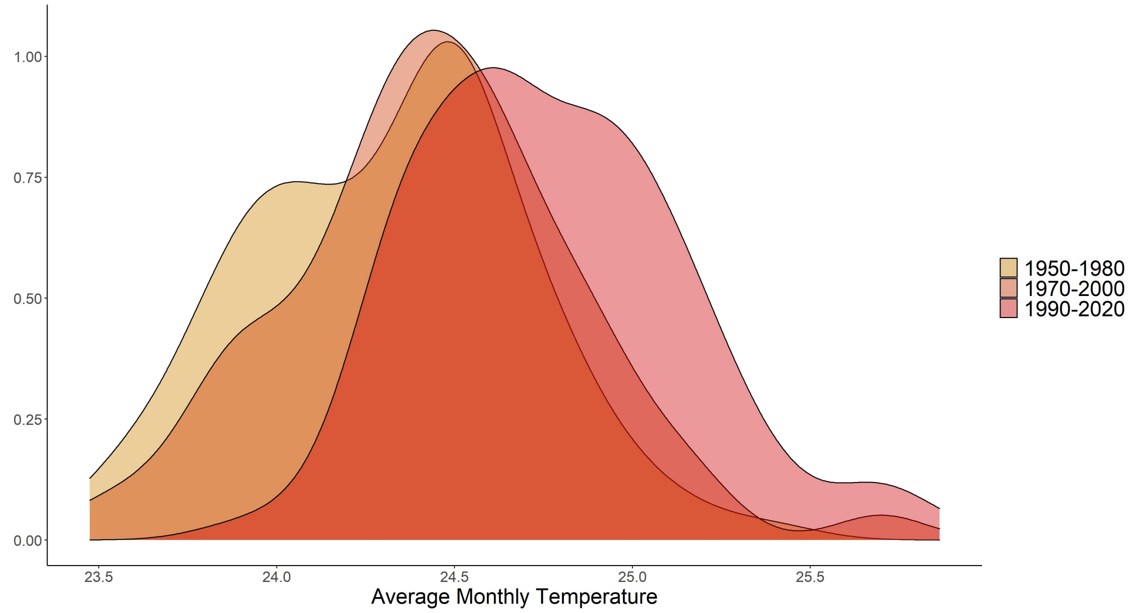

FIGURE 2: Change of distribution of mean-temperature in Colombia, 1951-2020
Source: Climate Change Knowledge Portal, The World Bank Group

Given that rising temperatures is a global phenomenon, it is assumed that the shock is exogenous. Hence, Colombia cannot be the cause of rising temperatures. As seen in Figure 3, Colombia is a minor contributor to global C02 and Greenhouse emissions.

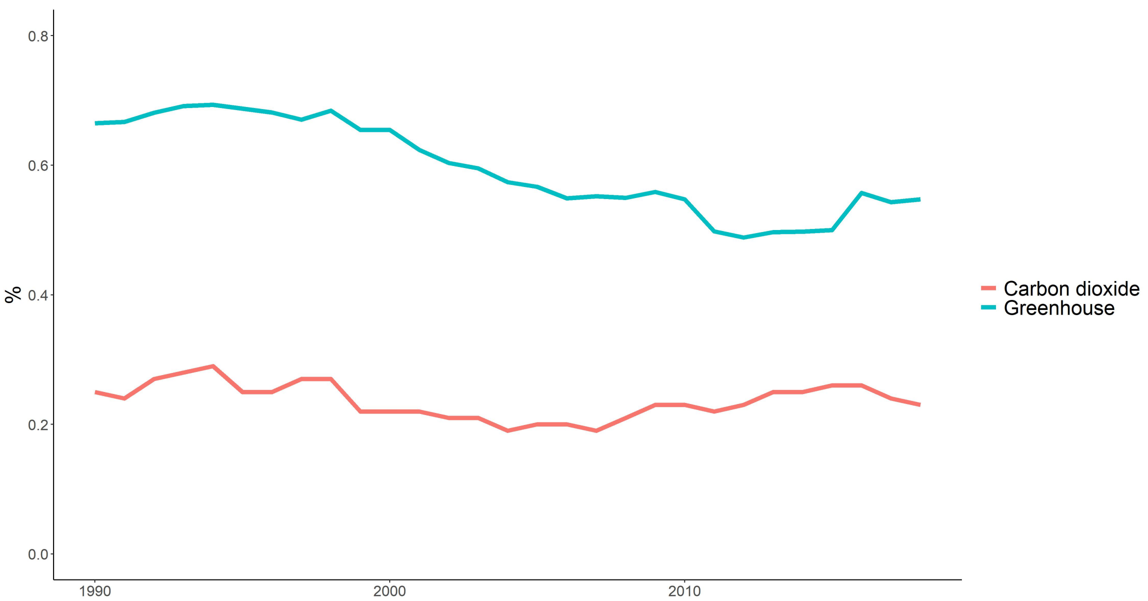

FIGURE 3: Colombia contribution to global CO2 and Greenhouse emissions
Source: Our World in data and World Bank databases

In order to rule out the possibility of reverse causality, the shock was regressed using contemporaneous and lagged values of GDP growth as independent variables.

$$Shock_t = \alpha_t + \sum_{i=0}^{5} \gamma_{ti} GDPgrowth_{t-h} \tag{5}$$

Different combinations of up to five lags of GDP growth were tested and the coefficients were not significant (Annex A). These results suggest that there is no evidence that Colombian GDP growth causes temperature. Additionally, using the Augmented Dickey-Fuller Test, it was checked that the shock is stationary (Annex B). Figure 4 shows the temperature shock.

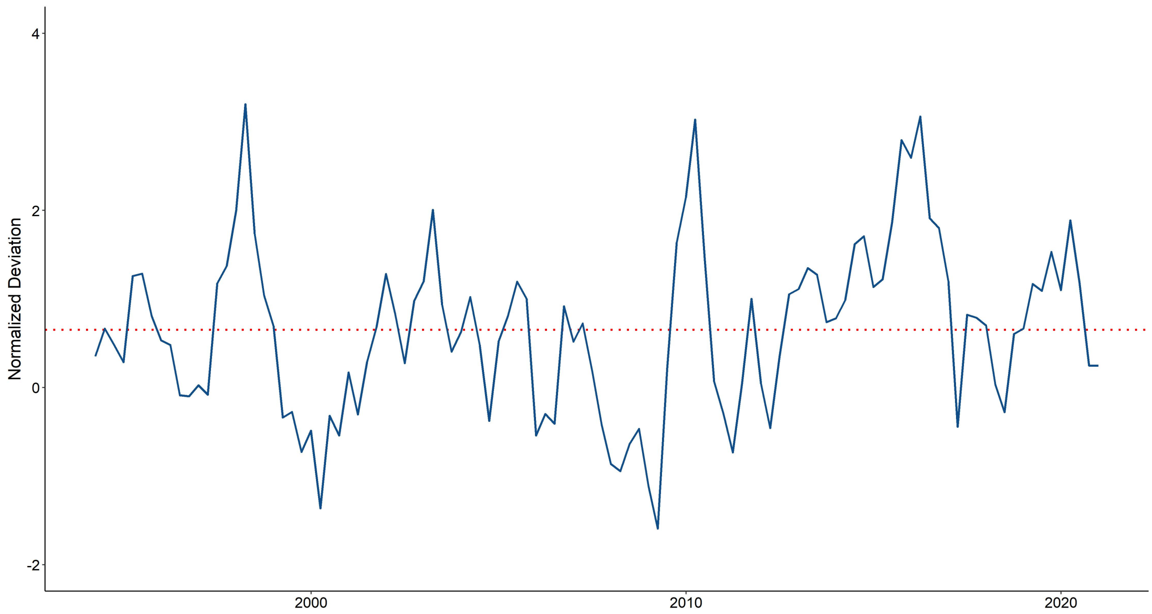

FIGURE 4: Temperature shock

5. Results

To analyze the effects of temperature shocks on contemporaneous and one-quarter ahead economic growth, the first attempt is done through Ordinary Least Squares (OLS). It is assessed how the mean of the GDP growth distribution is affected by a warmer weather. In this sense, Table 1 contains the results for the contemporaneous effects of temperature shocks, along with the control variables, on economic growth. In line with the literature, it was found that temperatures shocks have a negative and significant effect for the conditional mean of GDP growth.

In particular, a 1°C increase in temperatures reduce year-on-year economic growth in 1.69 percentage points in Colombia, after controlling for past values of GDP, financial conditions, the intensity of El Niño y La Niña phenomenon and a dummy for the housing market crisis.

	Estimate	Std. Error	P-value
Intercept	1.2694	0.4204	0.0034
GDP_{t-1}	0.7573	0.0805	1.41e-14
FCI_t	-0.3537	0.2387	0.1423
$Temperature_t$	-1.6989	0.6579	0.0116
$ENSO_t$	0.2075	0.1262	0.1039
$Crisis_t$	-0.0038	0.6282	0.9951

Table 1: OLS regressions for contemporaneous effects on GDP growth

The size of the effects for Colombia seems to lie on the range suggested by climate literature. In fact, Kiley (2021) found that the mean of economic growth falls about 1.3 percentage points after a 1°C increase in average temperature in a hot country, while Hsiang (2010) estimates a decrease of 2.5 percentage points on output growth in response to a 1°C increase in temperature in the Caribbean and Central America.

	Estimate	Std. Error	P-value
Intercept	2.7153	0.5467	3.85e-06
GDP_{t-1}	0.4062	0.1043	0.0002
FCI_t	-1.0785	0.2962	0.0005
$Temperature_t$	-2.5845	0.8627	0.0036
$ENSO_t$	0.4039	0.1648	0.0165
$Crisis_t$	0.1613	0.8624	0.8521

Table 2: OLS regressions for effects of temperature shocks on GDP growth one quarter ahead

Looking forward, when the effect of temperature is evaluated on the conditional mean of one-quarter ahead GDP growth, it is also found a negative and significant impact. In Table 2, it can be seen that this effect is higher than what was captured contemporaneously. In this case, year-on-year economic growth is reduced by 2.6 percentage points after a 1°C increase in temperatures. These results suggest that there are additional channels that could be operating in the short-term, before the possible process of adaptation takes place.

5.1. Asymmetries of temperature shocks on GDP growth distribution

The evidence for the conditional mean of GDP growth presented before could be ignoring possible asymmetric effects of temperature shocks on the tails of the distribution, and therefore not considering how temperatures could affect risks to economic activity. This means that these estimates could be optimistic, and rising temperatures could be worsening economic downturns and/or limiting economic expansions. To test this statement, it is computed the effect of temperature shocks on three key percentiles of the contemporaneous and one-quarter-ahead output growth distribution, 10th, 50th and 90th percentiles, through quantile regressions.

The results presented in Table 3 suggest that, contemporaneously, temperature shocks are not significant at 5% confidence level for the median or the tails of the output growth distribution. Nonetheless, the impact on the one quarter ahead GDP growth appear to be significant for the entire distribution. In fact, the median and both tails present a statistically significant negative result, suggesting that an increase in temperatures reduce the more optimists and pessimists expected outcomes in Colombia. Therefore, a hotter weather leads to more severe economic contractions and to smaller economic booms. Thus, the evidence found for the conditional mean could be underestimating the overall effects of temperature shocks. A warmer weather not only reduces average economic growth but increases the vulnerability of the economy by making the expected outcomes less favorable in Colombia.

Quantile	Contemporaneous			One quarter ahead		
	Estimate	Std. Error	P-value	Estimate	Std. Error	P-value
10th	-1.01126	0.82409	0.22337	-4.16289	1.69030	0.01596
50th	-0.85141	0.75932	0.26552	-2.93677	1.37088	0.03525
90th	-1.52152	0.84081	0.07412	-2.77908	0.69693	0.00015

Table 3: Quantile coefficients of temperature shocks (deviation from mean temperature levels) on the distribution of GDP growth contemporaneous and one-quarter ahead for the 10th, 50th and 90th percentiles

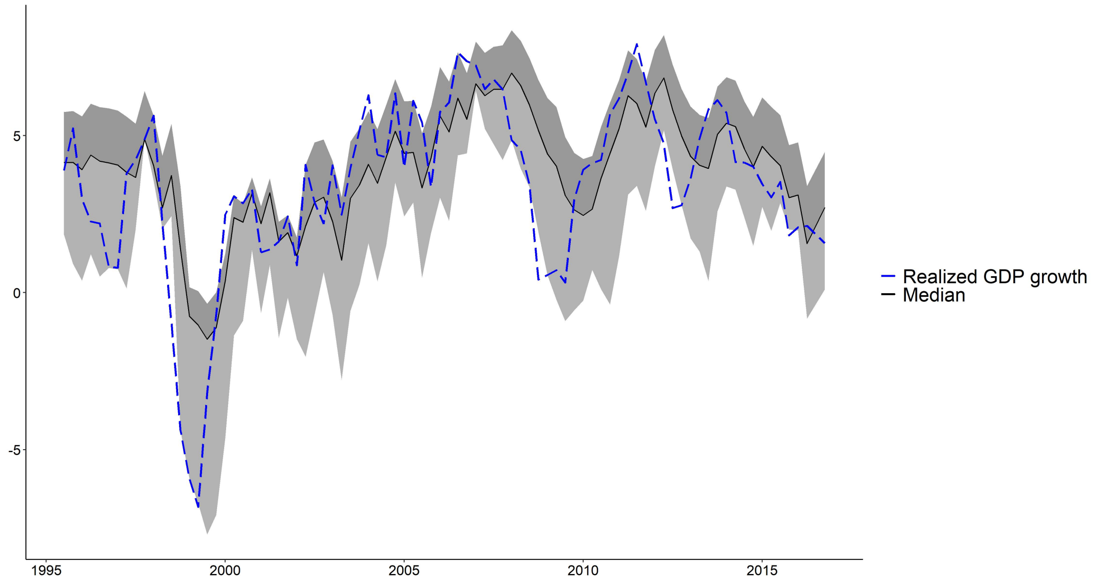

FIGURE 5: Predicted distribution of Colombia GDP growth one-quarter ahead for the 10th, 50th and 90th percentiles

However, the fact that the size of the effect in the 10th percentile is much higher than in the 90th percentile, could be implying that there are asymmetries between the upper and lower tail of the output growth distribution. For instance, when it is computed the evolution of the predicted distribution of GDP growth one-quarter-ahead, it can be inferred that the lower tail presents more variability over time (Figure 5). These findings suggest that temperatures are more informative on the lower tail of the one-quarter-ahead output growth distribution than in the upper tail.

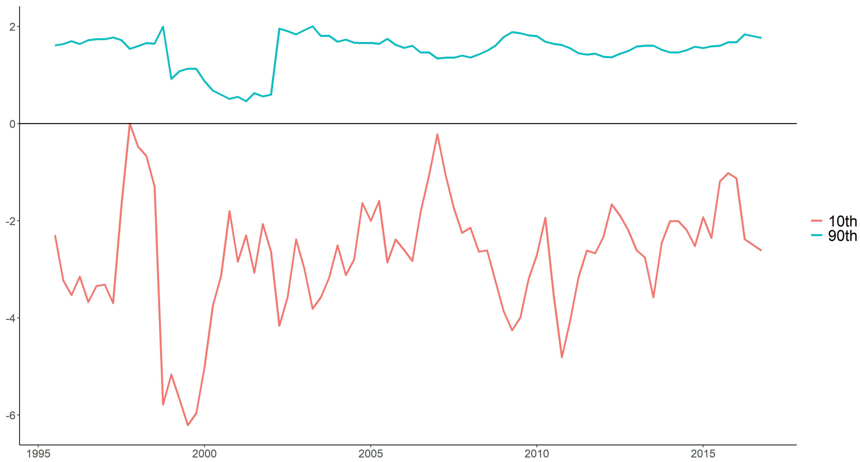

FIGURE 6: 10th and 90th percentiles deviations from the median for predicted distribution of one-quarter ahead Colombia GDP growth

These findings are corroborated in Figure 6, which shows the lower and the upper tail as deviations from the median of the distribution. Clearly, the 90th percentile is more stable over time than the 10th percentile, reflecting the asymmetric effects of temperature shocks on the output growth distribution.

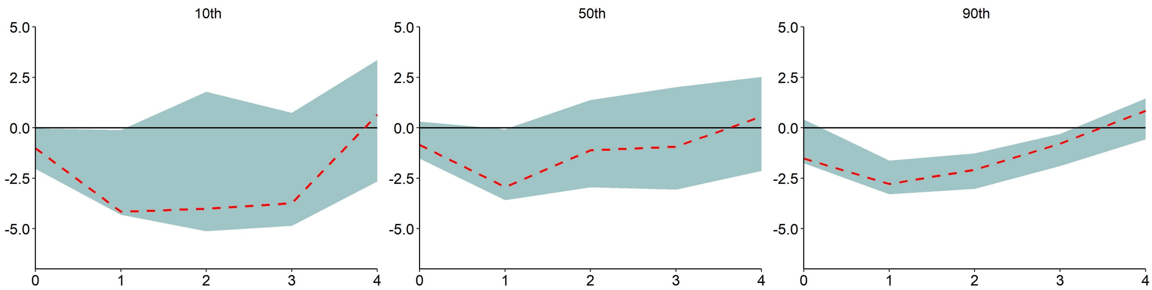

FIGURE 7: IRF of a temperature shock over the GDP Growth for the 10th, 50th and 90th percentiles

To evaluate the effects of temperature shocks on the short-term, considered as four quarters ahead, local projections are used. From the results presented in Figure 7 in the form of impulse response functions, it could be inferred that the adverse effects of temperature shocks on the median and the lower tail are no longer significant after one-quarter ahead. However, for the upper tail, a temperature shock seems to be more persistent, as it has a negative and significant effect up to three quarters ahead. Therefore, beyond the first quarter, the stronger effect of temperatures goes through leading to less optimistic forecasts of GDP growth.

5.2. Driving economic sectors of climate-related impacts

The effects found in the previous section are not expected to be the same across different economic sectors. As mentioned before, agriculture, construction, forestry, fishing, mining and manufacturing are the sectors with higher vulnerability to temperatures. According to climate-related literature (Dell et al. (2009); Acevedo et al. (2018); The World Bank Group (2021);Kalkuhl, Wenz (2020)) the impact of temperature shocks on GDP growth are mainly driven by two channels: i) crop losses in the agricultural sector, and ii) the effects of heat stress on labor productivity, which impacts to a higher extent sectors such as manufacturing and construction.

In order to analyse and understand how the distribution of GDP growth could be affected by temperature shocks on a sectoral level in Colombia, impulse response functions for construction, manufacturing and agriculture are computed. Additionally, it is evaluated the effect of these shocks on the energy sector given that the electricity generation in Colombia relies mainly in hydro-power. It is worth mentioning that these sectors account for the 30% of total GDP in the country.

For manufacturing, temperature shocks affect significantly the activity only in the upper tail, while the median and the 10th percentile do not seem to be affected (Figure 8). This could be reflecting the fact that manufacturing is one of the most resilient sectors within the climate-exposed ones. In fact, many manufacturing activities can be done indoors so the heat stress on labor is diminished, leading to less productivity losses. In contrast, the construction sector

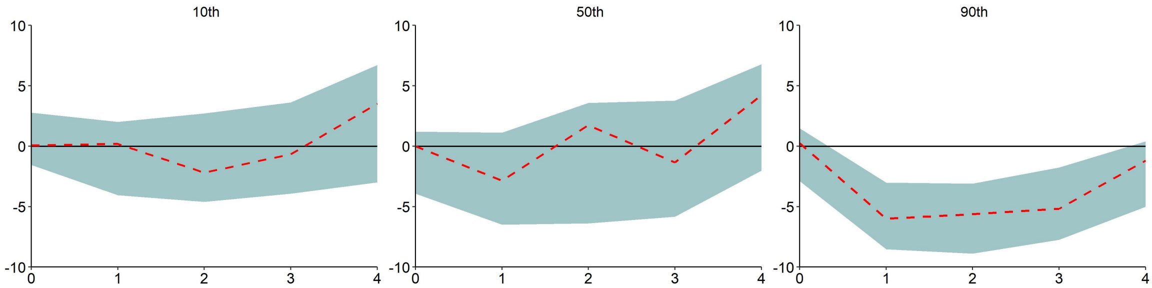

FIGURE 8: IRF of a temperature shock over the Manufacturing Sector GDP Growth for the 10th, 50th and 90th percentiles

cannot easily avoid the exposure to temperatures, so their impact on productivity could be larger. The results confirm that temperature shocks affect the whole distribution of the output growth. As shown in Figure 9, the central tendency and the tails decreases significantly after an increase in temperatures. In particular, the effects are higher and more persistent in the lower tail. In this case, the high magnitude of the response of the construction sector can be explained by its high volatility on year-on-year growth rates. In the last five years of the sample, the construction sector presented growth rates that went from -4% to 24% in inter-annual terms.

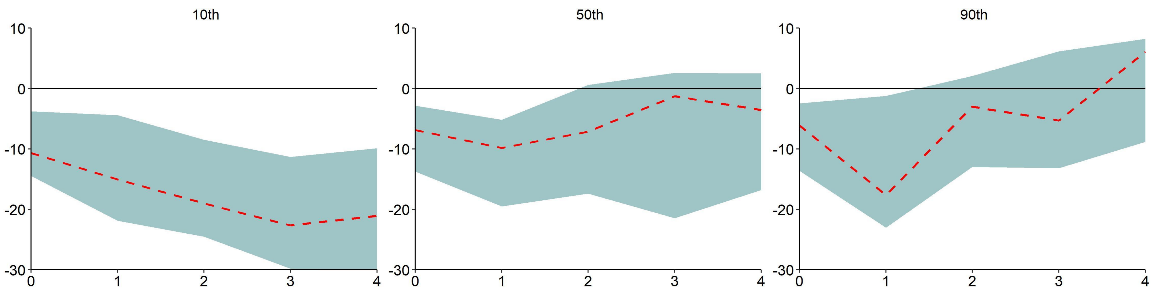

FIGURE 9: IRF of a temperature shock over the Construction Sector GDP Growth for the 10th, 50th and 90th percentiles

For the energy sector, the results also suggest a negative effect of temperature shocks. On impact, effects seems to be significant only for the median of the distribution, while the reaction of the tails takes longer to become relevant.

The use of hydro-power in Colombia could be behind these findings, given that warmer temperatures are associated with greater evaporation and thus surface drying, which increase the intensity and duration of droughts Trenberth (2011).

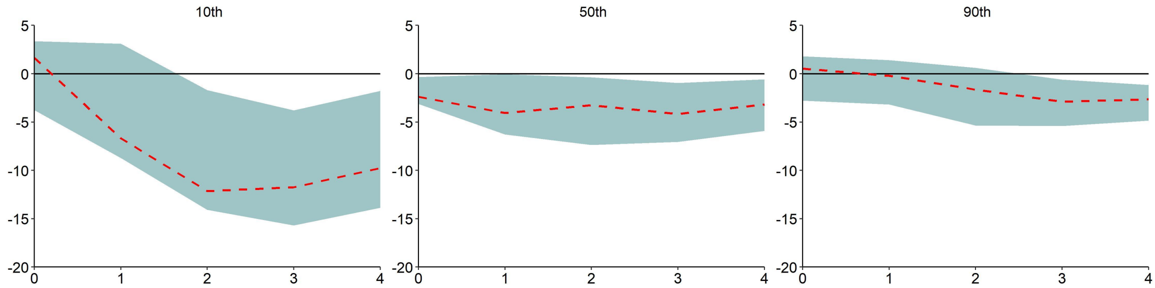

FIGURE 10: IRF of a temperature shock over the Energy Sector GDP Growth for the 10th, 50th and 90th percentiles

Regarding the agricultural sector, the results indicate that temperature shocks do not have significant impact on GDP growth (Figure 11). These results could be associated to two main developments in the agricultural sector in Colombia: i) the National Adaptation Program that was launched in 2012, which aims to reduce the vulnerability of the country and increase its response capacity to the threats and impacts of climate change/global warming; and ii) the large investment made by the Government to the coffee industry since 2010. In Colombia, coffee is the most important crop, accounting for 15% of the agricultural output. Since 2010 the Government has implemented a strategy to improve its productivity by incorporating new varieties that are more adapted to temperature shocks, new markets and crop renewal. However, to support this hypothesis further analysis are required.

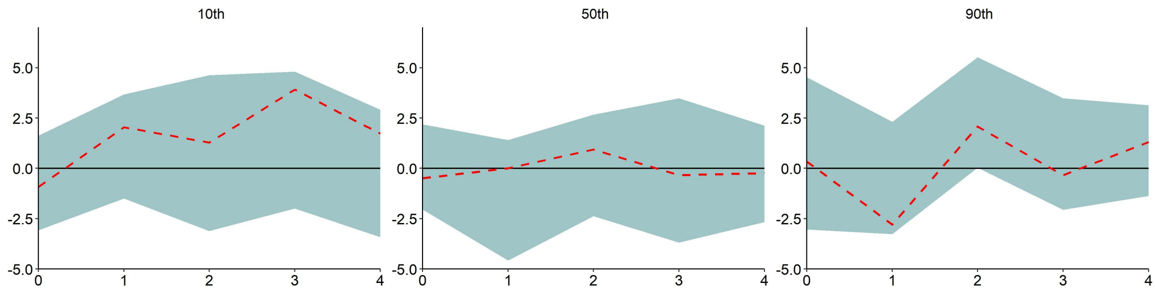

FIGURE 11: IRF of a temperature shock over the Agricultural Sector GDP Growth for the 10th, 50th and 90th percentiles

The previous results for the economic sectors in Colombia go in line with the findings of Hsiang (2010) who suggests that it is implausible for agricultural temperature responses to drive the overall responses of the economy to temperature shocks. Moreover, he indicates that non-agricultural industries suffer large and robust reductions when temperatures increase, which supports the hypothesis that the main driver of the impact of temperatures is the reduction in productivity labor when workers are exposed to thermal stress.

Given the evidence found for temperatures, it is also analyzed the effects of precipitation on the distribution of GDP growth. Nonetheless, results are not significant either contemporaneously nor in the short term in any of the percentiles (Annex C). As mentioned in Acevedo et al. (2018) and Auffhammer et al. (2011), the absence of robust relationship between rainfalls and economic activity could be capturing potentially large measurement errors in the precipitation variable.

6. Robustness

For robustness checks, it is computed the effects of a temperature shock on other percentiles of the GDP growth distribution. Hence, the definition of the lower tail is changed to be the 5th and the 15th percentile. Respectively, the upper tail is redefined as the 85th and 95th percentile.

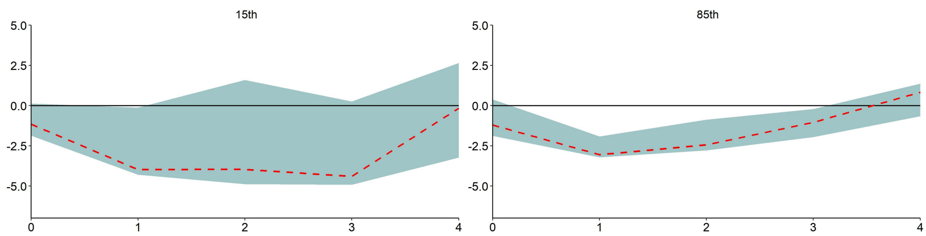

FIGURE 12: IRF of a temperature shock over the GDP Growth for the 15th, and 85th percentiles

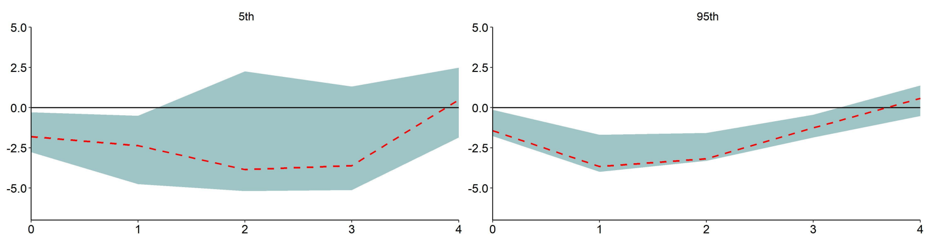

FIGURE 13: IRF of a temperature shock over the GDP Growth for the 5th, and 95th percentiles

Results are consistent with the previous findings, as seen in Figures 12 and 13. For instance, effects on the lower tail are significant up to one quarter ahead. Nonetheless, there is not much evidence that its significance remains for longer periods. On the upper tail, effects are more persistent. This way, a 1°C increase in temperature significantly affects the 85th and 95th percentile up to three quarters ahead.

7. Conclusions and policy implications

This paper asssess the effects and the short-term dynamics of temperature shocks on the distribution of economic growth in Colombia, using quantile regression (Koenker, Bassett (1978)) and the local projection method (Jordà (2005)). The results suggest that temperature shocks have negative and significant effects on the lower and upper tail of the distribution of GDP growth, indicating the existence of asymmetries. For instance, there is a higher effect on the 10th percentile of the one-quarter-ahead distribution of GDP growth. Nonetheless, this effect is no longer significant for future periods. Meanwhile, temperature shocks are important for the upper tail up to three quarters ahead.

The analysis of the effects of temperature shocks on climate-exposed sectors suggest that several components of GDP are affected by increased heating. For instance, manufacturing activity seems to be negatively affected after a temperature shock, specially on the upper tail. Additionally, the entire distribution of construction shows a strong response to temperature shocks, suggesting that labour productivity could be severely affected by heat stress in this sector. Also, the generation of electricity by hydro-powers in Colombia could be explaining the negative effects on energy sector after an increase in temperatures. Finally, it is not found statistically significant results for agriculture, possibly capturing the national attempt to increase resilience of this sector in Colombia.

In fact, Colombia has taken some steps in the mitigation and adaptation of its economy to rising temperatures. Especially, it has adopted the National Adaptation Program, whose principal objective is to reduce the country's vulnerability and increase its response capacity to the impacts of global warming on economic growth, especially for the agricultural sector. The findings for this sector and the mitigating measures adopted suggest that these efforts could reduce the country's vulnerability to rising temperatures. However, the country should take complementary strategies with a broader scope of sectors such as energy and construction, that appear to be more vulnerable to warming. For example, in the energy sector some of the adaptation measures that could be taken are optimization of the conventional energies and improvement of efficiency and diversification of energy sources and promotion of renewal energy.

Further analysis about the channels and causes of the effects of temperature shocks on GDP growth could be done for a regional level. The heterogeneity on temperature levels and on the reliance on climate-exposed sectors across different regions in Colombia could imply differential effects depending the geographical area analyzed.

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Appendices

A. Reverse Causality of the Temperature Shock

In order to analyze if there is any reverse causality, in the sense of GDP Growth causing the temperature shock, the regression defined in *Equation 5* has been used to model this relation. The following tables show the results for a contemporaneous, two-quarters ahead and up to a year relation.

	Estimate	Std. Error	P-value
Intercept	0.229262	0.046225	2.83e-06
GDP_t	0.006472	0.010175	0.526

TABLE A1: OLS regressions for effects of GDP growth on temperature shocks (No lags)

	Estimate	Std. Error	P-value
Intercept	0.25970	0.05096	1.69e-06
GDP_t	0.02892	0.01691	0.0904
GDP_{t-1}	-0.02092	0.02091	0.3196
GDP_{t-2}	-0.01263	0.01586	0.4279

TABLE A2: OLS regressions for effects of GDP growth on temperature shocks (Up to 2 lags)

	Estimate	Std. Error	P-value
Intercept	0.24833	0.06189	0.000121
GDP_t	0.04244	0.02711	0.120828
GDP_{t-1}	-0.02531	0.03344	0.450966
GDP_{t-2}	0.00504	0.02114	0.812058
GDP_{t-3}	-0.01239	0.02081	0.552958
GDP_{t-4}	-0.01454	0.01604	0.367085

TABLE A3: OLS regressions for effects of GDP growth on temperature shocks (Up to 4 lags)

B. Augmented Dickey-Fuller Test

The Augmented Dickey-Fuller Test has been used to check the stationarity of the temperature shock. This method tests the null hypothesis that a unit root is present in a time series sample. Therefore, the hypothesis is:

$$H_0 : \text{The series is not stationary (Presence of Unit Root)}$$

$$H_1 : \text{The series is stationary (No Presence of Unit Root)}$$

The optimal number of lags for this test have being stated as four. This should give a reliable result given that the data is quarterly. Other order of lags have been checked. The following table gathers the results.

	ADF statistic,	P-value
1 Lag	-4.4992	< 0.01
2 Lag	-4.6751	< 0.01
3 Lag	-4.2299	< 0.01
4 Lag	-3.808	0.02113
5 Lag	-4.1251	< 0.01
6 Lag	-4.0657	< 0.01

Table A4: Augmented Dickey-Fuller test results for multiple lags

C. Precipitation shocks

	Estimate	Std. Error	P-value
Intercept	1.24754	1.10237	0.261
GDP_{t-1}	0.63690	0.09316	1.46e-09
FCI_t	-1.81943	1.13736	0.114
$Precipitations_t$	-0.04476	0.02985	0.138
$ENSO_t$	0.18492	0.48334	0.703
$Crisis_t$	1.64312	3.47258	0.637

TABLE A5: OLS regressions for contemporaneous effects of precipitation shocks on GDP growth

	Estimate	Std. Error	P-value
Intercept	1.31943	1.29120	0.30997
GDP_{t-1}	0.50598	0.10587	8e-06
FCI_t	-3.35195	1.23252	0.00803
$Precipitations_t$	-0.05091	0.03357	0.13333
$ENSO_t$	0.67620	0.52472	0.20127
$Crisis_t$	5.14747	4.12152	0.21538

TABLE A6: OLS regressions for effects of precipitation shocks on GDP growth one quarter ahead

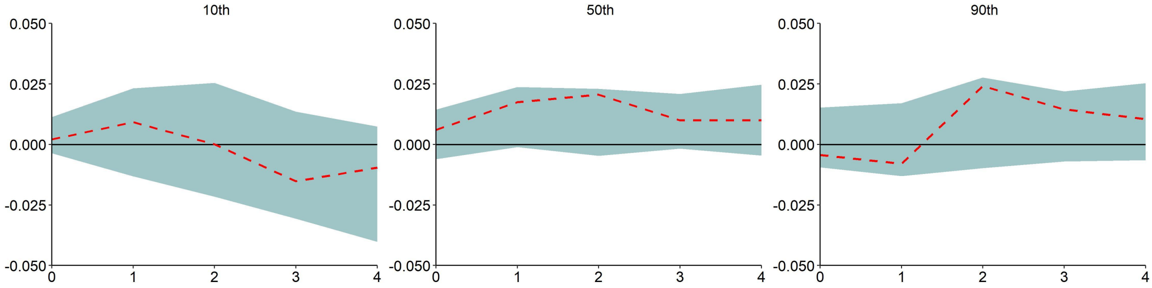

FIGURE A1: IRF of a precipitation shock over the GDP Growth for the 10th, 50th and 90th percentiles