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On the Macro Impact of Extreme Climate Events in Central America: A Higher Frequency Investigation

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ABSTRACT: Central America is one of the world's most vulnerable regions to extreme climate events. The literature estimates the macroeconomic effects of climate events mainly using annual data, which might underestimate the true effects as these extreme events tend to be short-lived and generate government and family support in response. To overcome this limitation, this paper studies Central American countries' macroeconomic impact of climatic disasters using high-frequency (monthly) data over the period 2000-2019. We identify extreme climate events by defining dummy variables related to storm and flood events reported in the EM-DAT (Emergency Events Database) and estimate country-specific VAR and panel VAR. The results suggest that a climatic disaster drops monthly economic activity in most countries in the region of around 0.5 to 1 percentage points on impact, with persistent effects on the level of GDP. We show that even as extreme climate events were relatively less severe under our sample period, quantitative effects are similar or larger than previously estimated for the region. In addition, remittances (transfers from family living abroad) increase for most countries in response to a extreme climate event, acting as a shock absorber. The results are robust to controlling for the severity of the climate events, for which we construct a monthly climate index measuring severity of weather indicators by following the spirit of the Actuaries Climate Index (ACI).

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WORKING PAPERS

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Prepared by Hee Soo Kim, Carlos Chaverri, Emilio Fernandez-Corugedo, and Pedro Juarros [1]

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I. INTRODUCTION

Central America is one of the most vulnerable regions in the world to extreme climatic events such as tropical storms and floods, with sizeable impacts—sometimes devastating—in terms of affected people and economic damages. For instance, the European Commission's 2020 INFORM Climate Change Index[2] identifies all CAPDR countries (Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama, and the Dominican Republic) in the top 30 most vulnerable countries (out of 194), except for Costa Rica (32).[3] Understanding the dynamic macroeconomic effects of extreme climate events in CAPDR countries is key to designing ex-ante and ex-post policy interventions to mitigate such impacts. This paper studies the impact of climatic disasters on economic growth and the role of remittances as a shock absorber in Central American countries using high-frequency data.

Table 1. CAPDR: Summary statistics of reported floods and storms

Table 1a. 1960-2022

	Event 1/				Damages (% of GDP)		
	Floods	Average duration of the event 2/	Storms	Average duration of the event	Average	Median	# Events reported 3/
Honduras	38	0.12	25	0.11	5.45%	0.50%	21
Guatemala	35	0.09	20	0.09	1.04%	0.15%	24
El Salvador	18	0.14	18	0.06	2.75%	1.66%	12
Nicaragua	23	0.36	24	0.08	6.39%	0.23%	12
Dominican Republic	30	0.09	39	0.05	1.11%	0.21%	18
Costa Rica	30	0.15	10	0.10	0.87%	0.30%	15
Panama	40	0.14	8	0.02	0.19%	0.04%	15
Total					**2.54%**	**0.21%**	

Table 1b. 2000-2019

	Floods	Average duration of the event 2/	Storms	Average duration of the event	Average	Median	# Events reported 3/
Honduras	20	0.19	11	0.12	0.43%	0.16%	8
Guatemala	22	0.13	14	0.11	0.18%	0.02%	5
El Salvador	11	0.20	11	0.06	3.20%	3.68%	4
Nicaragua	16	0.46	14	0.07	0.02%	0.02%	3
Dominican Republic	21	0.13	23	0.04	0.22%	0.07%	10
Costa Rica	19	0.19	4	0.16	0.21%	0.26%	4
Panama	25	0.14	2	0.02	0.02%	0.01%	5
Total					**0.97%**	**0.15%**	

1/ EM-DAT as of May, 2022.

2/In months

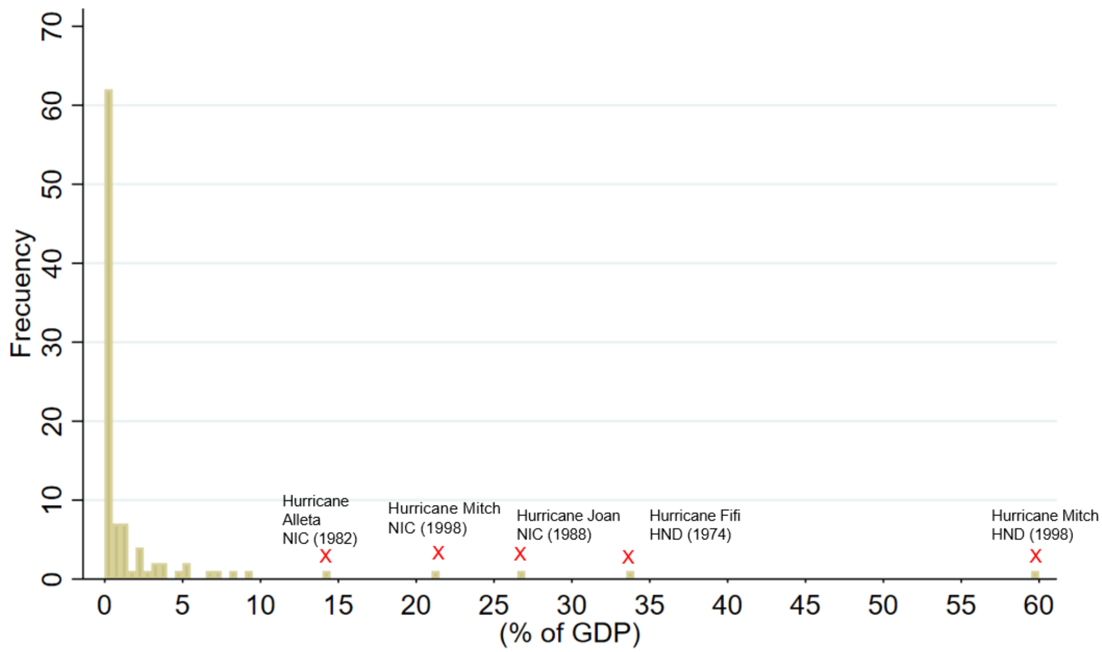
3/Not all recorded events have estimated damages

Source: EM-DAT and IMF staff calculations.

[2] The INFORM Climate Change index analyzes how risks related to climate change under different emission and socio-economic scenarios will evolve.

[3] Relative to the exposure to climate events, the region has a low adaptive capacity, which ceteris paribus makes them more vulnerable with a higher impact on the population given the elevated levels of poverty.

Figure 1. CAPDR: Total damages as % of GDP (1960-2022)



Source: EM-DAT and IMF staff calculations.

Table 1 presents summary statistics of some of the climate-related natural disasters reported in the Emergency Events Database (EM-DAT) [4] comprising the period of 1960-2022. The table focuses only on meteorological and hydrological events such as floods and storms, dominating extreme climate events in these countries.[5] The frequency of these events is significant, with some countries such as the Dominican Republic, experiencing over one climate-related natural disaster event on average per year (69 events in 62 years). Moreover, the events (where damages are reported) tend to be sizeable, with average damages ranging between 0.2 percent of GDP to 6.4 percent.[6] However, these averages mask that some events are truly dramatic, with damages exceeding 10 percent of GDP (Figure 1) in five episodes, including storms Fifi and Mitch which caused damages of 33 percent in Honduras in 1974 and around 60 percent in 1998, respectively.[7] Table 1 (b) shows the number of floods and storms events and the estimated damages by EM-DAT for the our sample period, 2000-2019. As Table 1 shows, the events under analysis due to

[4] The EM-DAT database records natural disasters if they meet at least one of the following criteria and are reported by the authorities: i) 10 or more people are killed; ii) 100 or more people are reported as affected; iii) a state of emergency is declared or iv) if there is a call for international assistance.

[5] The database also reports droughts to which countries in the region have exposure. However, it is often difficult to know when the drought starts and ends in the EM-DAT database and hence not possible to create a dummy variable

[6] EM-DAT database defines total damages as the amount of damage to property, crops, and livestock. For each disaster, the registered figure corresponds to the damage value at the moment of the event. Total damages are available only for about 1/3 of the geological disasters recorded in the database (Bello, 2017).

[7] These large devasting events are not included in our empirical investigation, given the lack of high-frequency economic data at the time of the disaster.

data availability of monthly economic activity (2000-2019) have been less severe in the latest data sample (2.54 vs 0.97 percent of GDP, on average). Despite the fact that the damages are larger as a share of GDP prior to 2000, according to EM-DAT, reported intensity and frequency of climate events in the region according to climate data are larger after the 2000 (see Figure 2 below).

There is a growing body of research quantifying the macroeconomic effects of climate change and of extreme climate events, with different strands depending on the question being addressed. One strand, comprising a large body of literature, has sought to examine the economic effects from *changes* in temperatures or precipitations to identify the overall climate change impact on economic activity (e.g., Akyapi et al., 2022; Khan et al., 2021; Newell et al., 2021; Acevedo et al., 2020; Letta and Tol, 2019; Burke et al., 2015; Bansal and Ochoa, 2011; Barrios et al., 2010). Hsiang (2010) examines effect on annual average temperatures on economic growth and finds that twenty-eight Caribbean-basin countries lose national output by 2.5 percent to 1°C warming. Bansal and Ochoa (2011) find that the adverse effect on GDP growth to an increase in global temperature is larger for countries closer to the Equator. Similarly, Dell, Jones, and Olken (2012) show that 1°C increase in temperature drops GDP per capita growth for poor countries. A second type of literature has focused on extreme climate events to estimate the consequences of climatic disasters using economic losses reported for each event, typically using the EM-DAT database (Yang, 2008; Raddatz, 2009; Mendelsohn et al., 2011; Fomby et al., 2013; Acevedo, 2014, among others).[8] Pertinent to our work given its proximity, IMF (2017) shows that natural disasters are macro-critical for the CAPDR region and estimates from a VAR with annual data over 1950-2016 show that storms and floods reduce real GDP growth by around 1 percentage point. Similar results for CAPDR using annual data were also obtained by Bello (2017). Most of these studies examining extreme events, employ panel estimation at an annual frequency. For example, Raddatz (2009) uses panel autoregressive distributed lags to quantify economic losses from climatic disasters in developing countries. Similarly, Acevedo (2014) studies Caribbean economies using panel VAR with exogenous variables and shows that storms and floods negatively affect GDP growth, with severe disasters having larger effects, although not statistically significant.

However, the literature has important limitations in estimating the impacts of extreme climate events, such as tropical storms and hurricanes, on economic activity using annual data:

- First, these extreme climate events tend to be short-lived, and annual data make it difficult to accurately estimate the event's direct impact. As Table 1 shows, the average duration of climate events (storms and floods) is 0.12 months, while 83.6 percent of the events have an average duration of less than 6 days. Moreover, when a climate event occurs late in the year, its economic impact will likely be reflected in the subsequent

[8] Other literature strands estimate the damages arising from climate events by estimating damage functions. Initial studies include (Hope et al., 1993; Nordhaus and Yang, 1996; Tol, 1997; Christensen et al., 2012).

year. In our sample period 2000-2019, around 40 percent of climate events occurred in the last quarter of the year (25.4 percent in October and 14.3 percent in November-December).

- Second, economic responses to these events, namely reconstruction, insurance payouts, family transfers, or government support to households and businesses affected by the event, could offset the impact of the climate-related natural disaster at an annual frequency (creating a bias due to endogenous policy response, which explains in part why AEs suffer less from climatic events or why these events may even have positive effects on GDP growth (Loayza et al., 2012).[9] Especially, for events that occur early in a calendar year, economic responses may fully offset the impact of the event in subsequent months.[10]

- Thirdly, annual data can also dilute the estimate of climate events. Studies using wind, precipitation, and/or temperature to capture extreme climate events (storms, floods, or heatwaves) may find it challenging to identify these events if, for instance, periods of high precipitation to capture a storm or flood are followed by lower-than-average precipitation in the remainder of the year.

Hence, it is more accurate to employ higher frequency data to better ascertain the economic impact of climate events or find alternative forms to address the shortcomings of using annual data. One promising recent study that seeks to address some of these challenges is Akyapi et al. (2022), who construct over 160 climate variables from high-frequency data and higher spatial resolution to assess their impact on annual economic activity while controlling for other economic events such as the fiscal response. Akyapi et al. (2022) find a larger share of GDP variation explained by weather variation than previously estimated, validating the claim that annual averages of weather variables and economic activity tend to underestimate the impact of climate events. Another approach, complementary to Akyapi et al. (2022), is to exploit higher frequency economic activity data. A recent paper by Kim et al. (2021) incorporates a novel extreme weather climate index (ACI, or Actuaries Climate Index)[11] to assess the impact of severe weather shocks

[9] This is an important observation for CAPDR countries since institutional vulnerability may not mitigate the impact of climate events.

[10] More than 5 percent of climate events occurred in the first quarter of the year. For Central American countries, Bello (2017) document negative effects of climate disasters on per capita GDP growth on the first year, but positive in the second and third year.

[11] The ACI, computed for the US and Canada, is an aggregate indicator of six weather components denoting frequency change of severe weather and the extent of sea level rise. Further explanations of the index and its construction can be found in the data part of the Appendix.

on monthly economic activity (industrial production, consumer prices, the unemployment rate, and interest rates) on the US economy.[12]

The approach we take in this paper is similar to Kim et al. (2021) in that we exploit the availability of high frequency data in the CAPDR region (monthly GDP, prices, exchange rate and remittances) to better estimate the impact of monthly climate events.[13] To our knowledge, this is the first time that this type of analysis has been done in Central America. To identify extreme climate events, we exploit information from the EM-DAT database which identifies the dates of tropical storms and floods. Like other studies (e.g., Noy, 2009; Raddatz, 2009) we create a dummy variable identifying 1 as incidence of a certain event and 0 otherwise. We then estimate a Vector Autoregression (VAR) at a monthly frequency, typically comprising the period of 2000-2019, including these climate dummies, domestic activity variables, and controlling for US activity and oil prices. We find that climate events in Central American countries decrease year-over-year GDP growth by about 0.5-1 percentage points. These estimates are in line or higher than previously estimated for the region using annual data over a sample period that includes much larger reported damages (Bello (2017); IMF (2017)). This implies that it is important to use high-frequency data to analyze the economic impact of climate events.[14]

We also contribute to the literature analyzing the impact of remittances in mitigating the impact of natural disasters, more specifically for climate-related natural disasters. The literature largely finds that remittances tend to increase in response to natural disasters in low- and middle-income countries (e.g., Babii et al. (2022), Balli and Balli, (2011), Beaton et al. (2017), Ebeke and Combes (2013), Bettin, G. and Zazzaro (2018), Yang (2008)). Again, this literature typically uses annual data and panel methods. We also find that remittances or transfers from nationals living abroad increase by more than 3 percentage points in response to an extreme climate event in Central American countries. This evidence is consistent with remittances acting as a shock absorber or as a private insurance mechanism.

A potential limitation of this approach is that creating dummy variables assigns the same weight to all disaster types, which may lead to ignoring the heterogenous magnitude of each disaster event. To better quantify the intensity of each event in a higher frequency and without measurement issues, we construct an extreme weather index following the spirit of the Actuaries Climate (ACI) Index and test the robustness of our results. Among CAPDR regions, this index is created for Honduras and Guatemala, where there exists a long time series of daily (and thus

[12] Using a smooth transition VAR estimated over 1963-2019, they find that increases in the climate index over the past decades, capturing increased occurrence of severe weather, adversely affect industrial production, which drops by 0.12 percentage points on impact, while consumer prices and unemployment increase.

[13] Fiscal data and interest rate data are not long enough for many of the countries in the region, so it was not included in the estimates.

[14] Based on reported damages in the EM-DAT database, the largest reported damages occur prior to 2000, around 3 percent of GDP in the CAPDR region vs around 1 percent of GDP since 2000.

monthly) weather data for temperature, wind, and precipitation.[15] The construction of this index represents the second contribution of this paper. Using this index to control for the severity of each climate events, we show that our results are robust. This implies that, on average, the climate event dummies capture the average intensity of extreme events relatively well. Future work should explore further the non-linearities of these extreme climate events exploiting the newly constructed ACI index.

The rest of the paper is organized as follows. Section 2 describes the data and empirical model. Section 3 provides results, and Section 4 concludes. The Appendix contains further information about the climate index and additional results.

II. DATA AND EMPIRICAL MODEL

Our empirical work focuses on seven countries: Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama and the Dominican Republic. These countries are characterized as middle-income countries, with the exception of Nicaragua (low-income country), where agriculture, construction, manufacturing and tourism tend to be important growth drivers. Northern triangle countries (Guatemala, Honduras, El Salvador and Nicaragua), and the Dominican Republic have a significant share of their population living abroad, namely the US, with remittances being on average around 16 percent of GDP in 2019 (similar to total government expenditures).

Economic Data

The macroeconomic variables used in our analysis are the monthly index of economic activity (IMAE), the bilateral exchange rate with the US dollar (for those countries with floating exchange rates), the consumer price index, and remittances. We use seasonally unadjusted data to avoid the seasonally adjustment from mitigating typical seasonal factors that may be weather related and thus consider year-over-year growth rates for all variables.[16]

Our data covers the period from 2001 to 2019. We exclude 2020 despite the presence of two important storms in the region (Eta and Iota) given that the economies in CAPDR were being affected by the Covid pandemic. Availability of monthly GDP is a key factor for why it is not possible to extend the sample period (an exception is Costa Rica which has an IMAE series going back to 1991).[17]

[15] Data for the other CAPDR countries except Honduras and Guatemala is available, although not many, but is interpolated from neighboring weather stations. Such interpolations reduce the quality of the reported data.

[16] A caveat of using year on year rates is that the initial impact from climate events may be dampened as discussed in the Introduction.

[17] Quarterly data is also not available over a long time period in the region. The relatively short sample period does not lend itself to examine the impact of climate change. This is an advantage since we can detract from looking at climate trends, see e.g., Akyapi et al. (2022) for more on this issue.

As noted above, we consider the importance of remittances in the transmission mechanism of extreme climate events. Hence all VAR estimates, other than Costa Rica and Panama (who send more remittances than they receive and do not have data at the monthly frequency) include remittances. This allows us to examine their responses to better understand whether remittances play a key supporting role.[18] Likewise, all VAR estimates excluding El Salvador and Panama, countries with fixed exchange rates, include the bilateral exchange rate to capture the importance of the open economy channel.

In addition to the aforementioned macroeconomic variables, two exogenous variables are included to control for external factors: namely monthly US GDP[19] (which can affect exports from Central American countries as well as remittances), and brent oil prices (to capture increases in domestic inflation driven by increases in commodity prices).

Climate Events Data

We consider two alternative measures of extreme climate events. First, we create monthly dummy variables of flood and storm within each CAPDR country using the EM-DAT database, assigning a 1 to a reported tropical storm or flood.[20] As noted above, to improve the fact that the dummy variable approach provides an equal weight to each climate event, we construct a monthly climate index based on the ACI that provides information about severe weather conditions (Appendix 1).[21] Among CAPDR countries, the index is constructed for Honduras and Guatemala, the two available countries in terms of data availability and quality. Each country's index is an aggregation of 5 weather components (high temperatures, low temperatures, heavy rainfall, drought, and high wind) where each component is standardized relative to the reference period (1961-1990).[22,23]

In Figure 2, the left panel plots the monthly values of the index for Honduras from 1973 to 2017 and the right panel plots the monthly values of the index for Guatemala from 1973 to 2018.[24] Red lines indicate positive values and blue lines indicate negative values. As the index is standardized based on the reference period, positive (red) values imply that weather has become more extreme since 1990 (see Appendix 1 for more details). Despite the greater intensity of climate events since 2000, reported damages are lower compared to 1960-2000 events.[25]

[18] These countries also tend to experience sizeable labor migration to the US in response to climate events. However, detailed migration data does not exist.

[19] Monthly GDP is constructed by S&P based on the construction of NIPA quarterly national accounts data. We have also considered monthly measures of industrial production and the results do not change significantly.

[20] More specifically, we record as 1 each event so that in months where more than one event occurs, the value of the dummy can be greater than 1 (e.g., if a storm and a flood occur in the same month, the dummy records the value 2).

[21] An alternative approach would be to use each of the weather components as well as define additional variables in line with the methodology proposed by Akyapi et al. (2022).

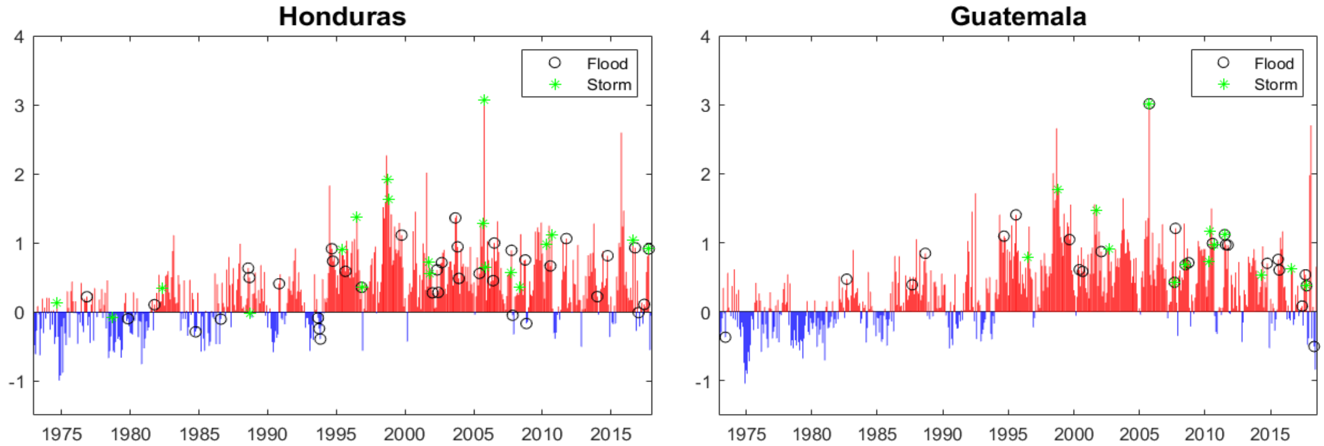
[22] The reference period is set by construction of some indices collected from Climdex (https://www.climdex.org/). Also, the ACI is based on the same reference period. Further information can be found in the Appendix A.

[23] Each of the series underlying the index are presented in the Appendix A.

[24] The ending period of each of the two series is due to unreliable data quality afterwards.

[25] Bello (2017) report similar results for Latin America and the Caribbean.

Figure 2. Constructed monthly climate index



Source: Climdex and IMF staff calculations.

As can be seen from each panel, red bars start to dominate from mid-1990 indicating that extreme weather has increased over time. It is noticeable that the climate index seems to largely correspond to reported climate events in EMDAT such as storms (green star) and floods (black circle).

EMPIRICAL MODEL

Our benchmark econometric model[26] is a country-specific vector autoregression with exogenous variables (VARX):

$$\boldsymbol{y}_t = \boldsymbol{c} + \boldsymbol{\Phi}_1 \boldsymbol{y}_{t-1} + \cdots + \boldsymbol{\Phi}_p \boldsymbol{y}_{t-p} + \boldsymbol{\Gamma}_0 \boldsymbol{z}_t + \boldsymbol{\Gamma}_1 \boldsymbol{z}_{t-1} + \cdots + \boldsymbol{\Gamma}_p \boldsymbol{z}_{t-p} + \boldsymbol{B\varepsilon}_t$$

Where $\boldsymbol{y}_t$ is a vector of five endogenous variables including the climate variable (i.e., either dummy variable or climate index times the dummy) and domestic economic variables, such as year-over-year: IMAE growth, inflation, exchange rate and remittances, and $\boldsymbol{z}_t$ is a vector of two exogenous variables (US GDP growth and oil prices). p and q represent lag lengths for the endogenous variables and the exogenous variables, respectively. For the former, we use lag length criteria tests and for the latter we include either the first or second lag depending on which one has the most explanatory power.[27]

Identification is achieved by zero contemporaneous restrictions (i.e., Cholesky decomposition) which assumes $\boldsymbol{B}$ as a lower triangular matrix. We order first in $\boldsymbol{y}_t$ the climate dummy and the climate index time the dummy We also impose restrictions in the matrices $\boldsymbol{\Phi}_1, \dots, \boldsymbol{\Phi}_p$ such that all

[26] We also try panel estimates but set country-specific VAR as our benchmark to see differences between the countries. We show panel results as a robustness analysis.

[27] Results are available on request.

economic variables do not have an impact on the climate variable.[28] This implies that the economic variables do not have contemporaneous effects on the climate variable, which is a reasonable assumption in the short-term.[29] Therefore, a climate shock in the system is entirely exogenous. Still, we allow the climate disaster variable to interact with a lag with economic variables and country characteristics, for example, if major disasters lead to political changes with economic growth consequences (i.e., Nicaragua due to Hurricane in 1998).

III. RESULTS

This section presents results of impulse response functions (IRFs) to a one-time climate shock. We first show our baseline results of country-specific VAR with dummy-based climate variable. We then show panel estimates of the climate dummies and country-specific VAR augmented with the climate index constructed for Honduras and Guatemala as a robustness analysis. Throughout the impulse response figures, we show 68 percent bootstrap confidence interval.

3.1. Baseline results VAR estimates using climate dummies

As a baseline specification, we run country-specific VARs using the "dummy based" climate variable. The dummy variable adds storm and flood events since some countries have few storm events and thus not enough to identify the aftermath of climate shocks. The response of the dummy variable is normalized to 1 on impact so that we interpret the rest of the responses as an impact to a climate event. We focus on the results of IMAE growth and remittance growth and relegate the full results for each country to Appendix B.1.

In Figure 3, we present responses of IMAE (year-over-year) growth to an occurrence of a climate event obtained from each country-specific VAR. The largest effect on impact occurs in the Dominican Republic and El Salvador, where economic growth (proxied by IMAE), contracts by around 0.5 of a percentage point and 1 percentage point, respectively. For the case of Honduras and Costa Rica, monthly economic activity also declines (by around 0.75 percentage points) around three to five months after an event. These results suggest that while output growth returns to its long-run average, there is no return to the pre-climate shock trend.[30] Output also declines in the case of Nicaragua, however, the impact is not statistically significant. The same is true for Panama, although in this case output increases on impact. The insignificant impact in Nicaragua

[28] In the first row of each matrix, all coefficients apart from that of the lagged climate event are set equal to zero. This implies no impact from any of the economic variables on the climate variable.

[29] We also consider estimation of this system using the local projections methods of Jordà (2005). The results are robust to this methodology and are available on request.

[30] These persistent level effects are also found in Hsiang and Jina (2014) and Akyapi et al. (2022) among others.

and Panama is partly due to relatively small climate events during our estimation period as measured by damages in the EM-DAT database (Table 1b).

Figure 3. Country-specific responses of IMAE growth using climate dummies

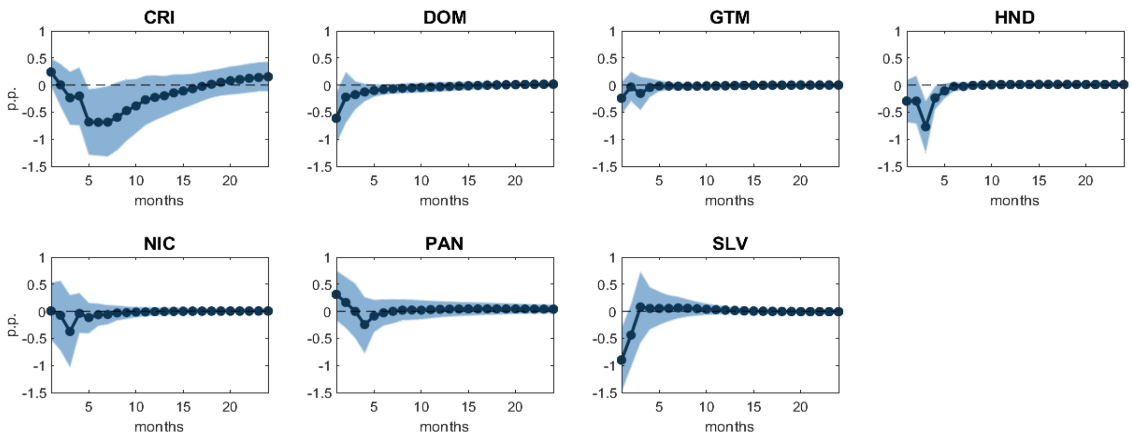


Figure 4 examines the impact of climate events on remittances, an important driver of economic activity in the region, especially countries in the Northern Triangle (Beaton et al., 2017). As mentioned earlier, remittances play a crucial role in northern triangle economies. In the case of Costa Rica and Panama, these countries send more remittances than they receive. The results show that remittances increase by around 3 and 8 percentage points in response to extreme climate events in Honduras and Guatemala, respectively.[31] In the Dominican Republic, El Salvador and Nicaragua, responses are not statistically significant. For Nicaragua, the results partly reflect the lack of sizable climate events over the estimation period, a lower stock of migrants relative to other central American countries (Babii et al., 2022) and that many of the migrants have either been living in the United States for a long period or were born in the United States (also the case for El Salvador and the Dominican Republic).[32]

The increase in remittances in Honduras and Guatemala is consistent with a mitigation role of remittances, as they act as private insurance mechanism supporting consumption smoothing when families are hit by a climate disaster (Beaton et al., 2017).[33] The response points to a compassionate effect, as immigrant workers in the US send more transfers to their home country to cushion the impact and support their families from an extreme climate event. A key reason for

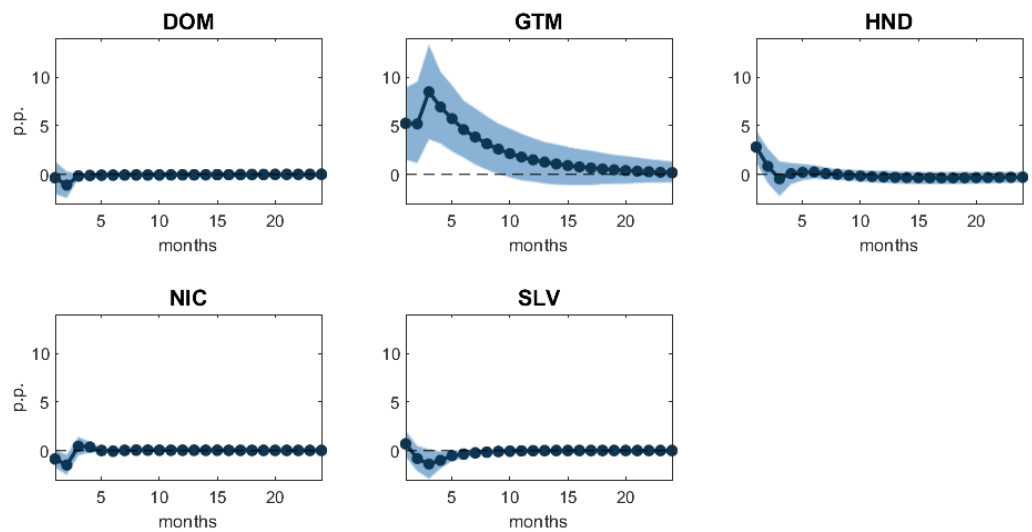
[31] While the increase in remittances in Honduras is less than that of Guatemala, it is worth noticing that remittances comprise a larger share of GDP in Honduras than Guatemala (24 percent of GDP vs 16 percent).

[32] While the stock of migrants for the Dominican Republic in the United States is larger compared to other central American countries (Babii and others, 2022), most migrants have been living in the United States for a prolonged period. According to the Pew institute, by 2017 around 43% of foreign-born Dominicans had been in the US for at least 20 years and 53% where US nationals (https://www.pewresearch.org/hispanic/fact-sheet/u-s-hispanics-facts-on-dominican-origin-latinos/). Similarly for Nicaraguans (and Salvadorians), 64% (44%) had been living in the US for over 20 years and 61% (33%) were US citizens.

[33] In the VAR estimates, we considered the impact of an exogenous remittances shock. We find that the impact on economic activity is positive and statistically significant in all cases.

the statistically positive response is that Hondurans and Guatemalans are more recent migrants into the US, relative to the other northern triangle countries and the Dominican Republic. Moreover, the larger response in Guatemala than Honduras highlights that migration is a relatively more recent phenomenon in Guatemala than Honduras and thus, there are more of first-generation Guatemalan immigrants than Honduran in the US, likely with stronger ties to their home country (IADB, 2013; Sanchez-Ancochea and Martí, 2014; Ambler, 2019).

Figure 4. Country-specific responses of remittance growth using climate dummies



In the Appendix, we show that for most countries climate events lead to a statistically increase in inflation by 0.2- ½ p.p., with a peak impact 2 to 5 months after the shock, consistent with the destruction of agricultural production. However, the results for the exchange rate point to an appreciation that received sizable remittances inflows (Honduras and Guatemala) but insignificant otherwise.

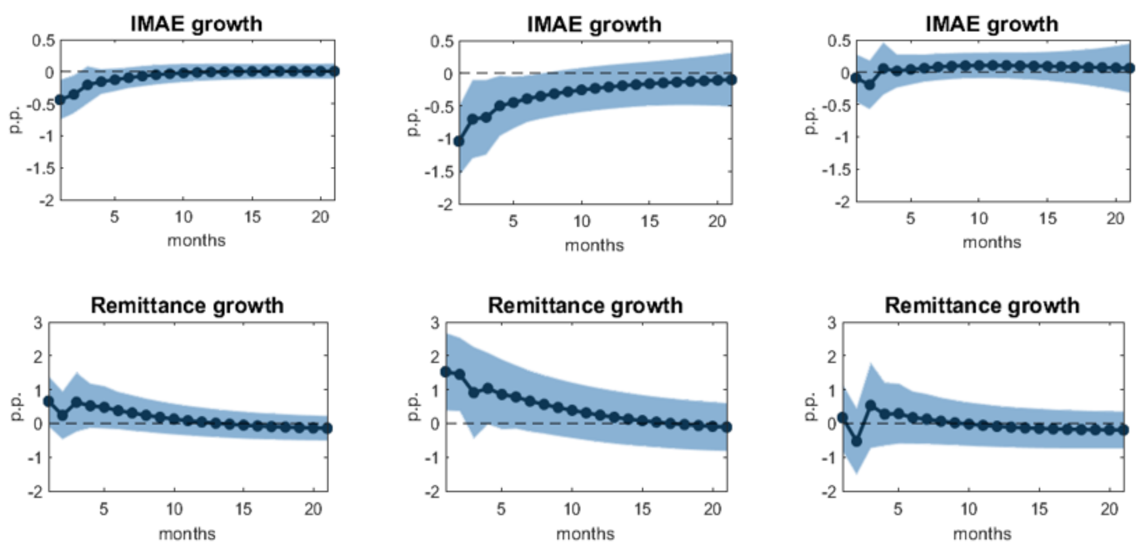
3.2. Robustness

Our results so far point to important economic activity impact from extreme climate events, though less clear impact on remittances. We now conduct further robustness and estimate the impact of different climate events.

3.2.1. Panel estimates

We run panel VAR; a method popularly used in literature. Figure 5 first shows results from the sum of storm and flood dummies, comparable with the results presented thus far. Furthermore, as we get more observations for each event by stacking several countries,[34] we break down the sum and show results for each storm and flood separately. Since we are interested in estimating the impact of climate events on remittances, we consider five countries (Dominican Republic, El Salvador, Honduras, Nicaragua, and Guatemala) controlling for the response of remittances, the exchange rate and inflation rate. The overall results are qualitatively similar to the country-specific results.[35] On impact, year-over-year IMAE growth declines between 0.2 and 0.6 pp, while year-over-year remittances increase by more than 1.5 pp. As expected, the impact from storms—which typically have more destruction than floods in the EMDAT database—is greater than the impact from floods, both on economic activity and remittances. Also, the estimated impact of IMAE growth tends to be longer lasting from storms, having a peak response after two months of the event. The full results can be found in Appendix B.2. The impact on remittances is the largest on impact.[36]

Figure 5. Panel estimates using climate dummies



(a) Storm + Flood (b) Storm (c) Flood

Annualizing the estimated economic activity (IMAE) impacts from extreme storm events for the region, our high-frequency monthly panel estimation implies a decrease of 0.6 percentage points in output, in line or higher than previously estimated in the literature using annual data. For instance, IMF (2017) find that storms and floods contract GDP growth by around 1 p.p. over the sample 1950-2016 which includes truly extreme events as shown in Figure 1 above. Similarly,

[34] This is appropriate given the relative similarities of the economies in the countries of interest.

[35] To facilitate the comparison with specific country-VAR in Figure 3 and 4, we normalize the climate shock.

[36] The stronger impact of storms vs other climate effects on output was also found in IMF (2017) and Bello (2017).

Bello (2017) finds an impact on per capita GDP growth of around ¾ p.p. on impact from storms and around ¼ for other climate events. This is one of the contributions of our paper. Crucially, that our results are similar to those of Bello (2017) and IMF (2017), whose sample period include 1970 to 2000 and hence larger damages of GDP (see Figure 1 and Table 1), suggests that the impact of extreme climate effects might have been underestimated using annual data in the earlier time period.

3.2.2 Augmented results using the monthly climate index

Our work thus far has explored the economic impact of extreme weather events with dummy variables constructed from the EMDAT database. In this subsection, we utilize the constructed monthly climate index for Honduras and Guatemala, where there exist long and continuous time series of underlying weather data, to better quantify the weights imposed to each climate event. The advantages of utilizing an index like ACI include: First, it is measured with physical and meteorological observations, which could alleviate the well-known measurement problems. Second, it is of higher frequency aggregated from daily to monthly observations in line with our economic data to avoid underestimating the true impact of severe weather shocks under low frequency. Third, it allows us to measure the severity of the weather conditions related to the identified events.

To test the robustness of our results, we combine the information from climate events from the EMDAT database (dummies) with that from the climate index. Thus, we multiply the climate index with the dummy variable to approximate the intensity of each disaster and thus provide more accurate estimates of extreme climate events on economic activity.

Figures 7 and 8 show the results of our variables of interest to a one standard deviation shock in the intensity of the extreme climatic event in Honduras and Guatemala, respectively. Consistently with our previous estimates, the results suggest significant increase in remittance growth and decrease in IMAE growth[37] as a response to extreme climatic shocks. The full results are delegated to Appendix B.3.

[37] To understand the effects on IMAE growth better, we dig deeper by disaggregating IMAE into three subsectors: primary (agriculture and mining), secondary (manufacturing and construction), tertiary (services and all the residuals). The findings indicate that decrease in aggregate IMAE growth is mainly driven by primary sector which drops about 1 percentage points. The response of secondary sector is not clear for the first few months right after the shock but barely drops and significant after 5 months. Tertiary sector increases on impact which could be due to an increase in health expenditures or government supports to recover from losses or damages after extreme climate events.

Figure 6. Augmented results using the climate index (Honduras)

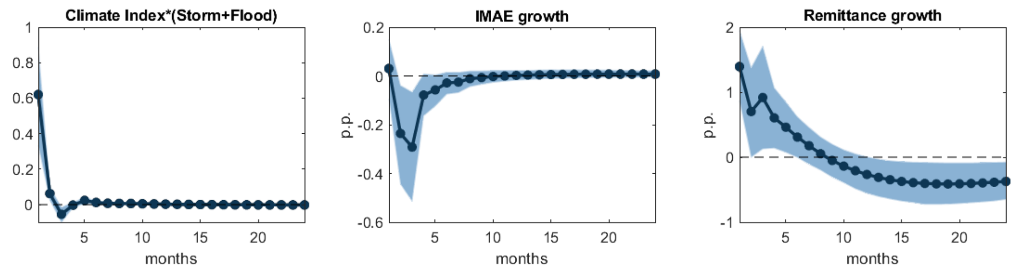
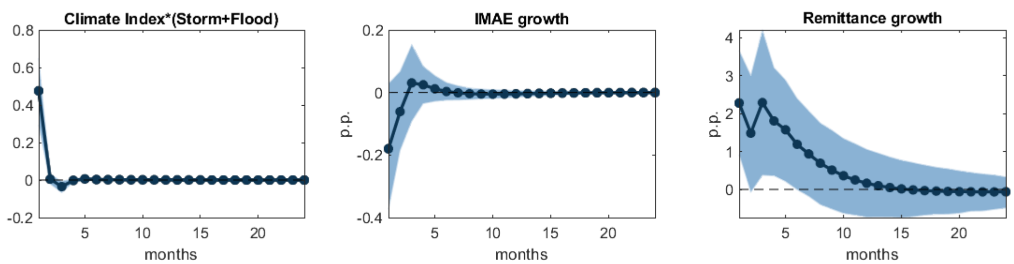


Figure 7. Augmented results using the climate index (Guatemala)

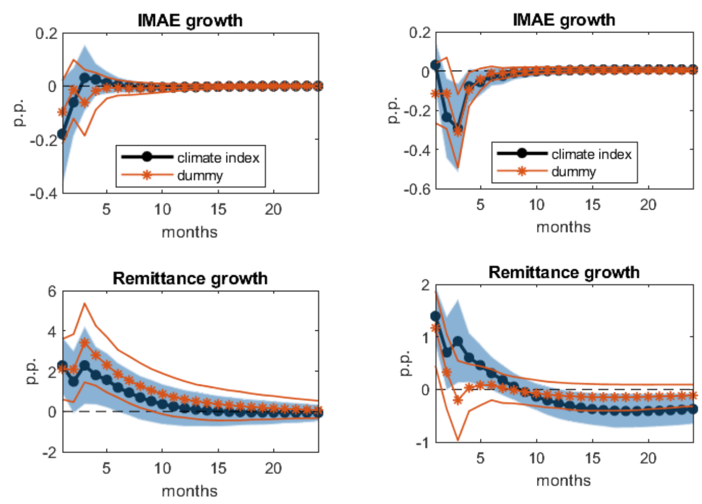


To closely compare the country-specific VAR estimates using dummies (Figures 3 and 4) with the augmented dummies using the ACI index, we plot the two responses for IMAE growth and remittance growth in Figure 9.[38] The overall dynamics of the responses are similar, with a somewhat larger and more significant effects with the augmented specification, especially for Honduras. Although the two specifications are not qualitatively different, the contribution of the augmented approach is to provide a better estimate of the outcomes associated with climate events.

Lastly, using the estimates of IMAE growth from the climate index specification, we convert the monthly impact to annual growth impact which we get -0.6 percentage points for Honduras and -0.2 percentage points for Guatemala. This implies that the annual effect on economic growth is roughly equal to or twice as severe as the monthly effect.

[38] For comparison, we did not normalize the responses from the dummy.

Figure 8. Comparison of IRFs between two specifications of climate variable



(a) Guatemala (b) Honduras

IV. Final Remarks

In this paper, we estimated the impact of extreme climate events using high-frequency data for seven Central American countries highly exposed to climate change risks (Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama, and the Dominican Republic). To our knowledge, this is the first analysis that employs high-frequency estimates for CAP-DR countries and complements existing literature studying the consequences of climatic disasters that mainly have done panel estimation at an annual frequency, some using the EM-DAT database. Our high-frequency analysis seeks to overcome limitations from previous work using annual data. First, using lower frequency data might underestimate the true effects of the extreme climate events as these may be short-lived. Second, reconstruction or external/government support to economic agents could offset the direct impact of the disasters within the year. Thus, in our analysis, we exploit monthly dummy variables to better estimate the effects of the climatic shocks. We estimate country-specific VAR and panel VAR with exogenous variables, covering the period from 2000 to 2019. Overall, the findings indicate that climate events result in statistically significant macroeconomic impact in most Central American countries, with monthly year-over-year economic activity decreasing by around 0.5-1 percentage points and increasing remittances by more than 3 percentage points on impact in the case of Guatemala and Honduras. Despite excluding important extreme climate events between 1970 and 2000, our results are comparable to studies using annual data in the region (IMF, 2017 and Bello, 2017). These results suggest that estimates using annual data are likely to be underestimated.

While dummy variables are popularly used in work ascertaining the impact of extreme climate events, such method does not exploit the heterogeneity of different events since dummies assign the same weight to different climate events. To address this point, we construct a monthly extreme climate index for Honduras and Guatemala following the spirit of the Actuaries Climate Index (ACI), which aggregates six weather components measuring the frequency change of severe weather and the extent of sea level change. Creating the index for the two countries allows us to incorporate both higher frequency investigation and heterogenous magnitude of each disaster, thus addressing the aforementioned limitations. Hence, we multiply this index with a dummy variable so that each event could be weighted differently. We find qualitatively similar results with our estimates with dummy variables. Future work should explore further the non-linearities of these extreme climate events exploiting the newly constructed ACI index.

Our results have both important direct and indirect policy implications. A direct implication of our results is that more accurate estimates of the impact of climate effects is key for policy makers to better design good policies. These would include ensuring the availability of sufficient resources to respond to each climate event[39] or the design of adaptation policies to mitigate their impact in the future.[40] On the latter, most countries in the region have and are implementing national adaptation plans, as well as introducing climate risk analysis into their fiscal frameworks. With limited fiscal resources and competing needs (e.g., poverty reduction), it is crucial for CAPDR countries to carefully allocate resources and to consider the distributional effects of climate adaptation policies, with cost-benefit analysis (CBA) being an integral tool for their evaluation (Bellon and Massetti, 2022). In that sense our estimates can support for more accurate CBA to evaluate CAPDR countries' adaptation plans.

[39] This requires that climate risks be incorporated in macro-fiscal frameworks through, for instance, relevant climate scenarios that incorporate temporary weather disasters, such that the scenarios determine the "adequate size of buffers and risk-reduction strategies" (Aligishiev and others, 2022).

[40] This requires the design of plans to evaluate the impact, vulnerability, and quantification of existing (and future) risks. Moreover, these plans should be carefully implemented and monitored to maximize their impact.

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Appendix

A. Climate index construction

This section descries the construction of the climate index for Honduras and Guatemala, the two countries providing long enough and continuous underlying data. To create the index, we closely follow Actuaries Climate Index (ACI) developed by the actuaries' association for the United States and Canada as a monitoring tool for a climate change. The index aggregates the following six weather components:

1. T90 (extreme high temperature): frequency change of temperatures above the 90th percentile relative to the reference period of 1961 to 1990.
2. T10 (extreme low temperature): frequency change of temperatures below the 10th percentile relative to the reference period of 1961 to 1990.
3. Rx5days (heavy precipitation): maximum five-day rainfall in the month
4. CDD (drought): maximum number of consecutive days with less than 1mm of daily precipitation
5. W (high wind): frequency change of daily wind power above the 90th percentile relative to the reference period of 1961 to 1990.
6. S (sea level): change in the sea level

In order to aggregate different measures of the components, each of the variable is standardized relative to the reference period. The ACI is then defined as a simple average of the standardized components.[41] Overall, an increased value of the index indicates that the incidence of severe weather has increased.[42]

Now, constructing an index for Honduras and Guatemala, we collected data on temperatures and precipitations from Climdex,[43] the same data source used by ACI. Moreover, we collect daily wind speed data from IOWA Environmental Mesonet (IEM)[44] and convert it to the same standardized high wind variable as defined in the ACI. Lastly, although few data sources for the sea level are available, there are many missing observations and thus we drop the component. Thus, the index is an aggregation of five weather indicators.

[41] In ACI, standardized T10 enters with negative sign when averaging to reflect decreasing trend of severe cold weather due to the recent warming in temperatures in the US and Canada. However, when we looked at the same component for Honduras and Guatemala, the variable showed increasing and cyclical trend after mid-1980s, which could be due to impacts of El Nino and La Nina in Central America regions. To properly reflect the fact for the two countries, we change the negative sign to positive sign so that an increase of cold extremes increases the aggregated index.

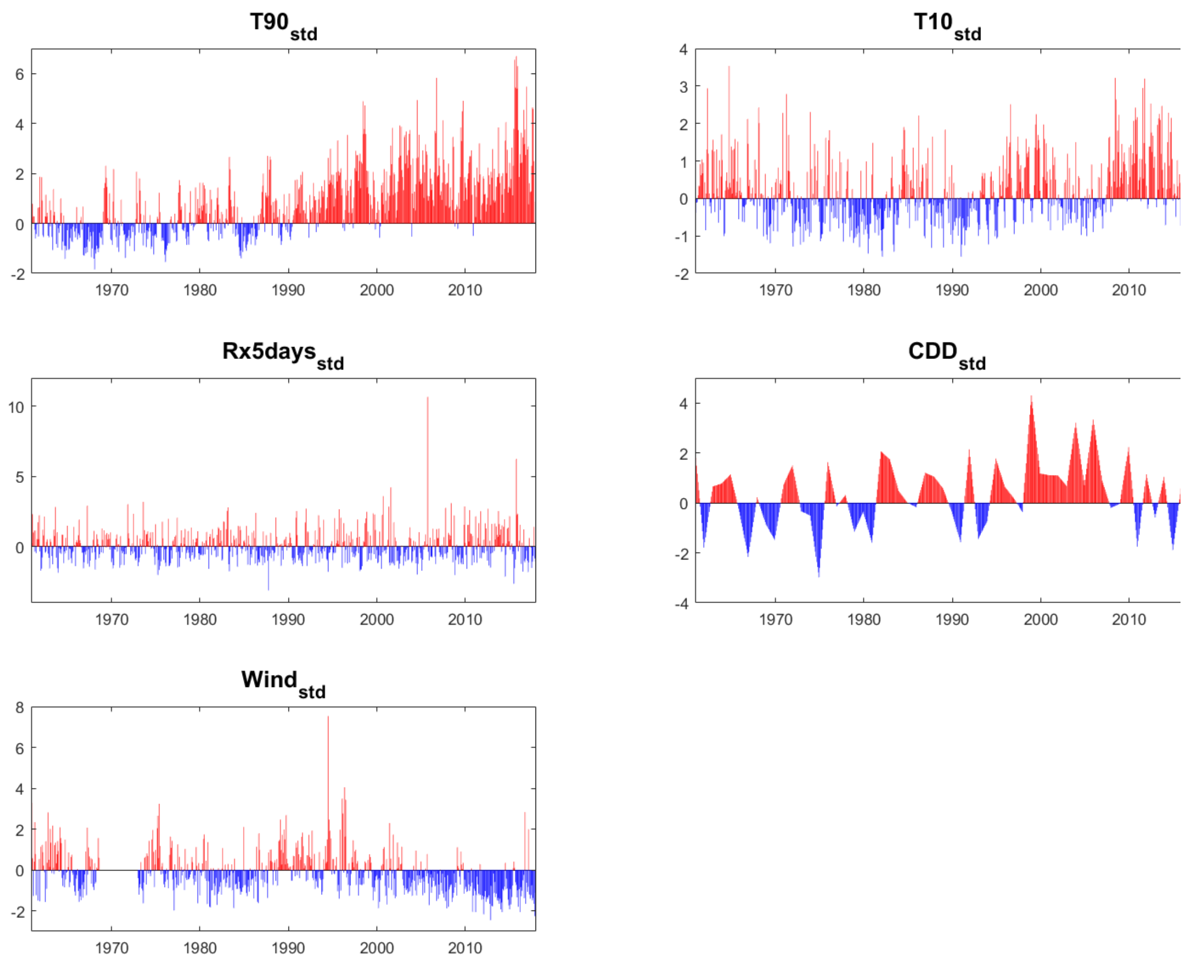
[42] For further information, reader may refer to https://actuariesclimateindex.org/about/.

[43] Climdex (https://www.climdex.org/) provides 27 different weather indices describing temperatures and precipitations. From here, we collect T90, T10, P and D.

[44] https://mesonet.agron.iastate.edu/request/download.phtml?network=HN__ASOS

Figure A1 shows each component plot for Honduras, and the aggregated index is presented in Figure 2 in the main text. In each panel, the bar plots monthly values of the index.[45] [46] Figure A2 and Figure 3 in the main text show the corresponding results for Guatemala.

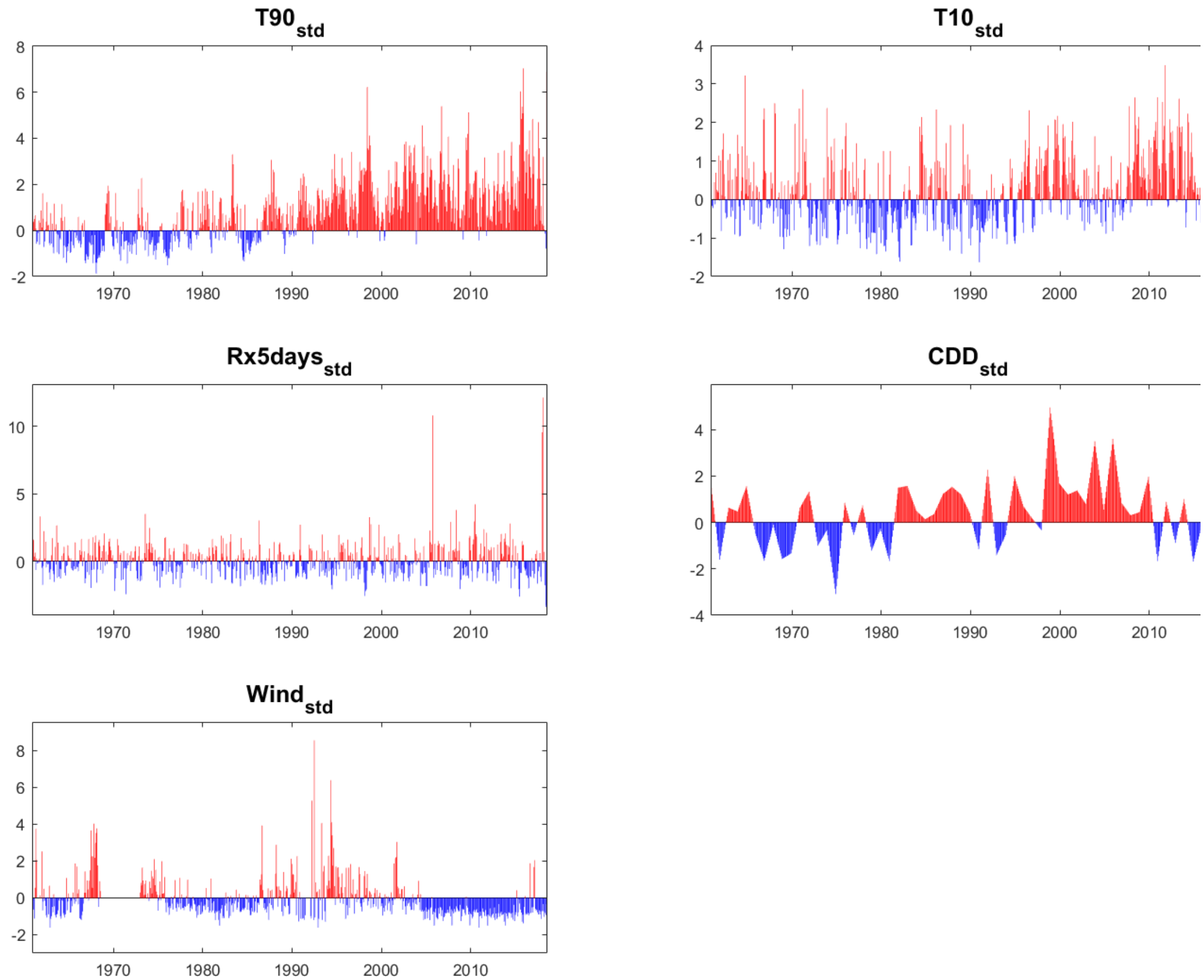
Figure A1. Climate index component plots (Honduras)



[45] Red lines indicate positive values and blue lines indicate negative values. As the index is standardized based on the reference period, positive values implies that the weather component became more frequent relate to the reference period.

[46] In the plot of high wind component, there is a blank period from late 1960s to early 1970s when daily wind speed was not recorded.

Figure A2. Climate index component plots (Guatemala)



B. Detailed country specific results

B.1. Baseline results

Figure B1. Country-specific VAR estimates with dummy variable: Honduras

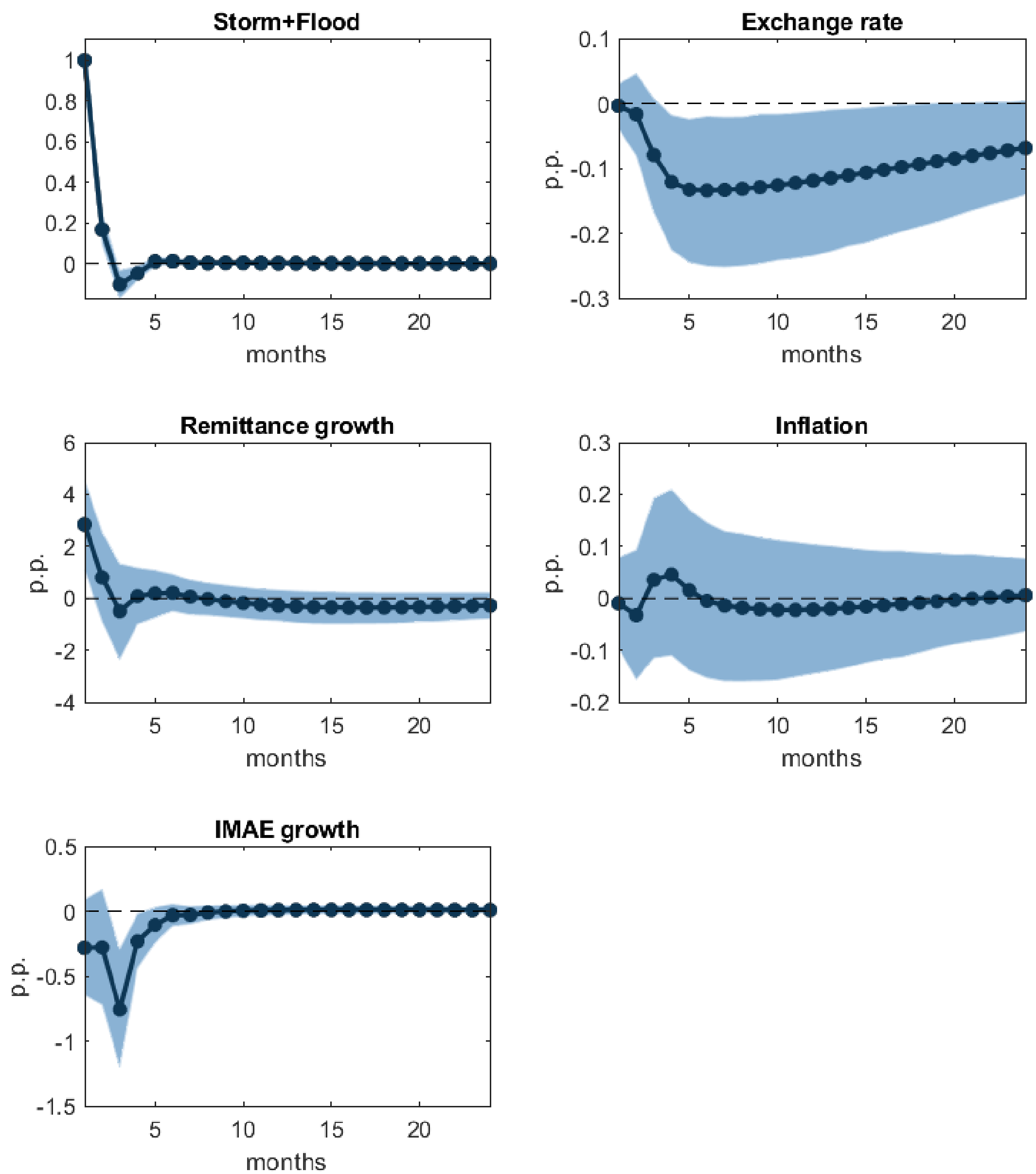


Figure B2. Country-specific VAR estimates with dummy variable: Guatemala

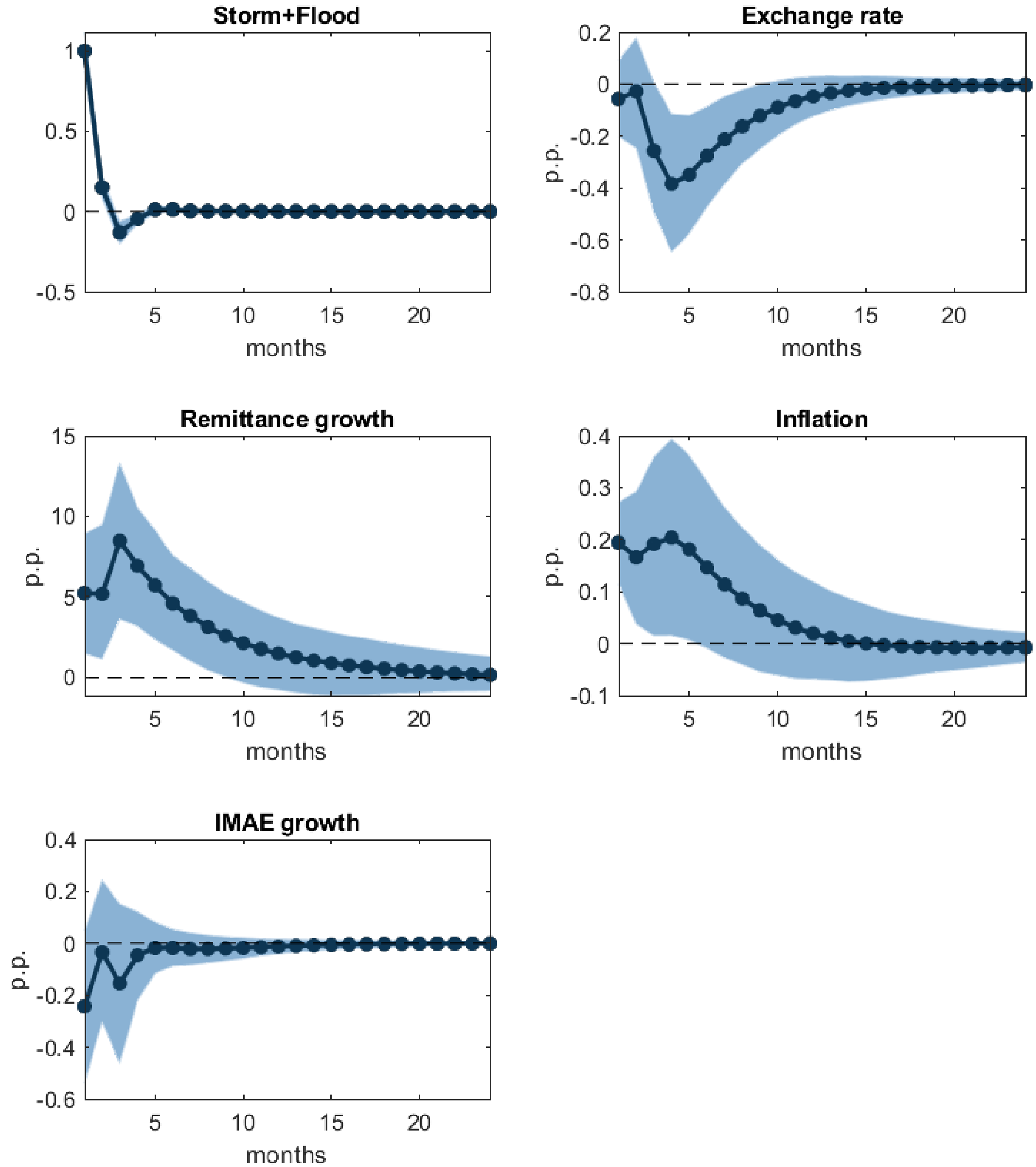


Figure B3. Country-specific VAR estimates with dummy variable: Dominican Republic

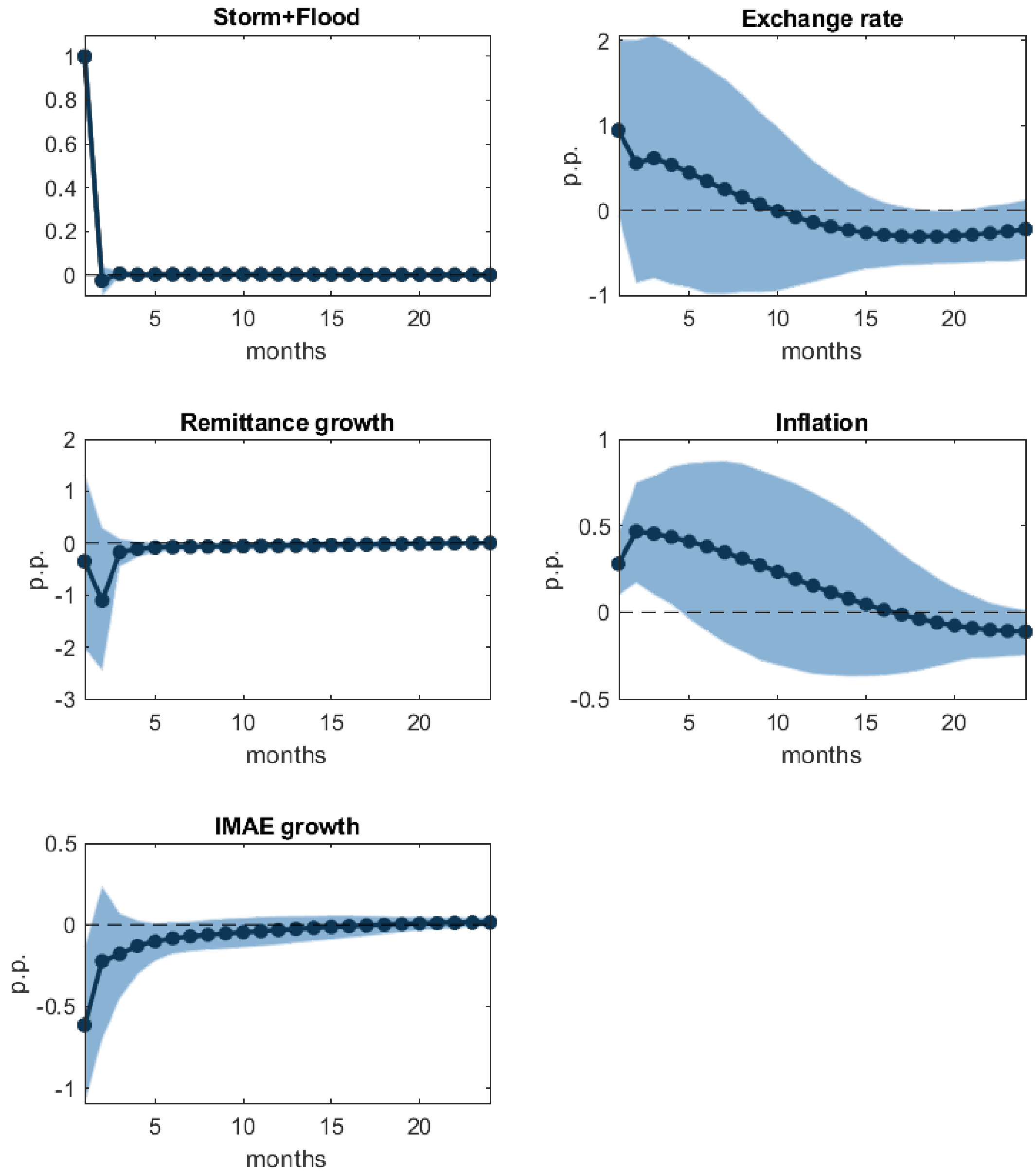


Figure B4. Country-specific VAR estimates with dummy variable: Nicaragua

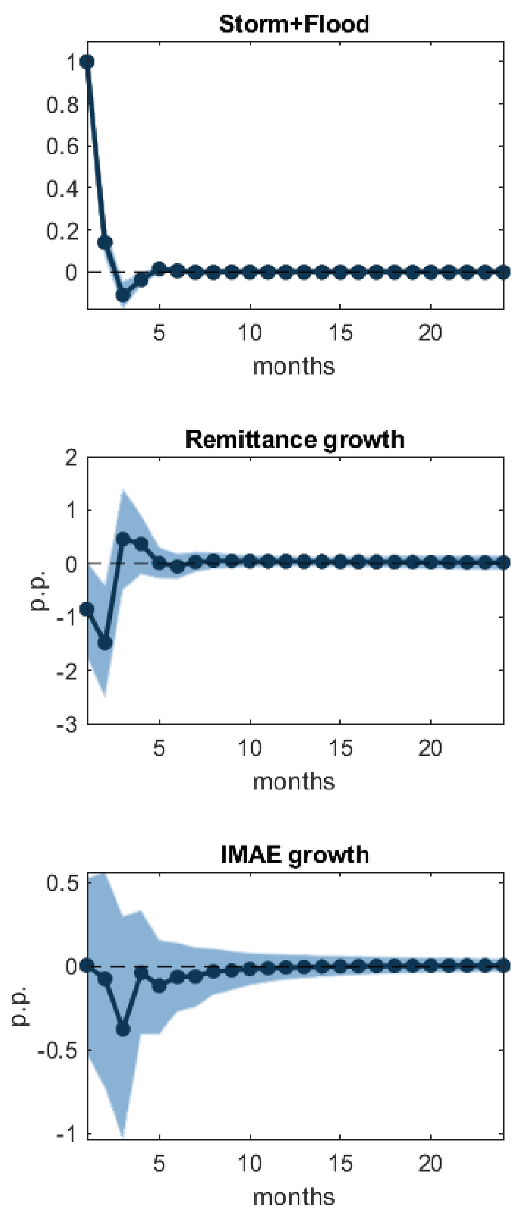


Figure B5. Country-specific VAR estimates with dummy variable: El Salvador

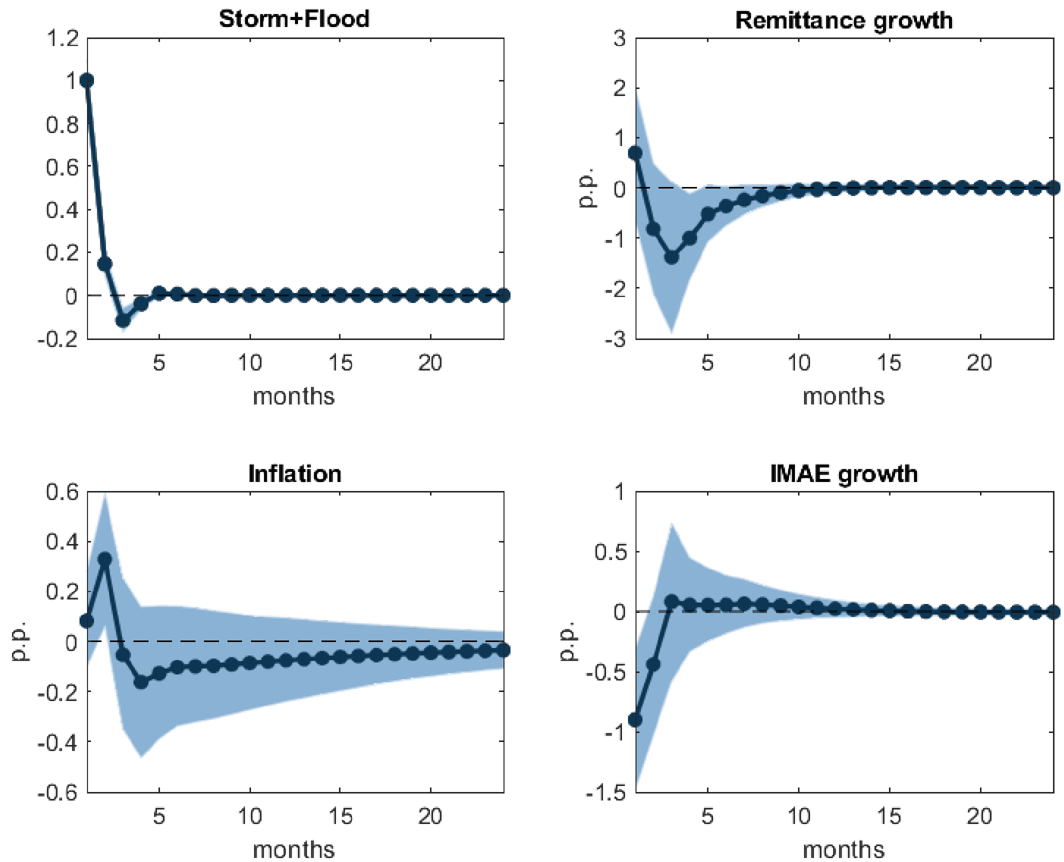


Figure B6. Country-specific VAR estimates with dummy variable: Costa Rica

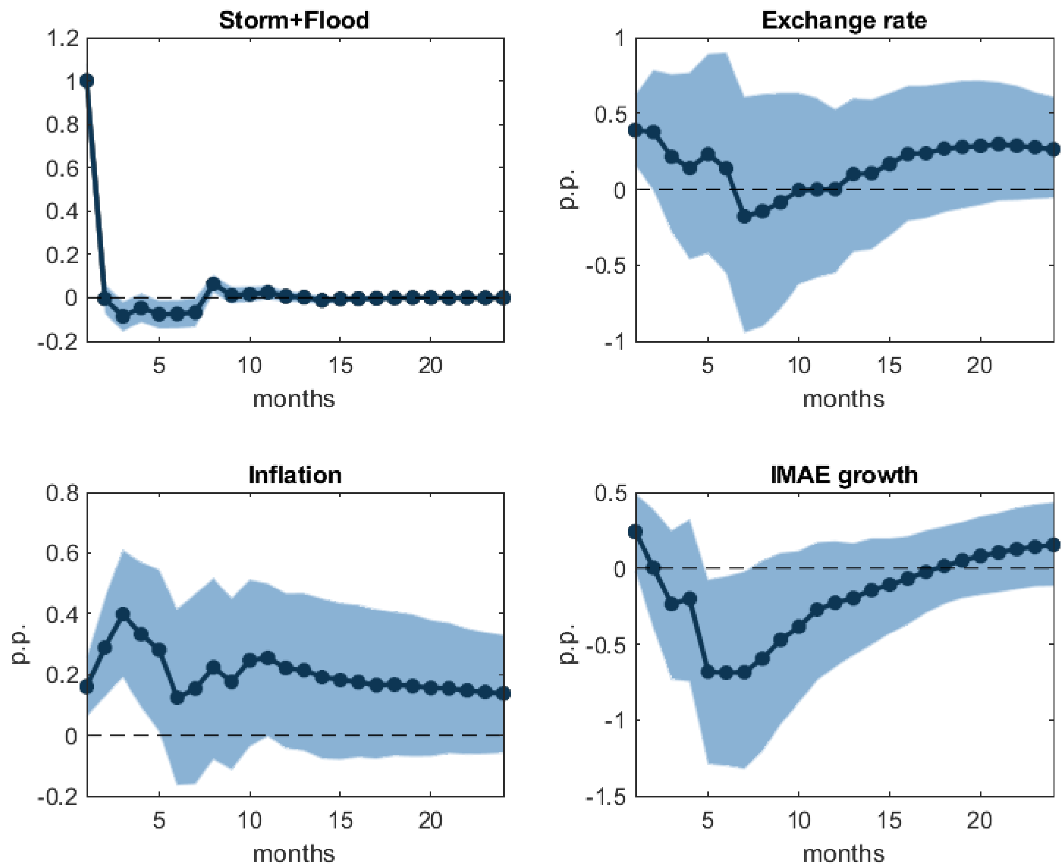
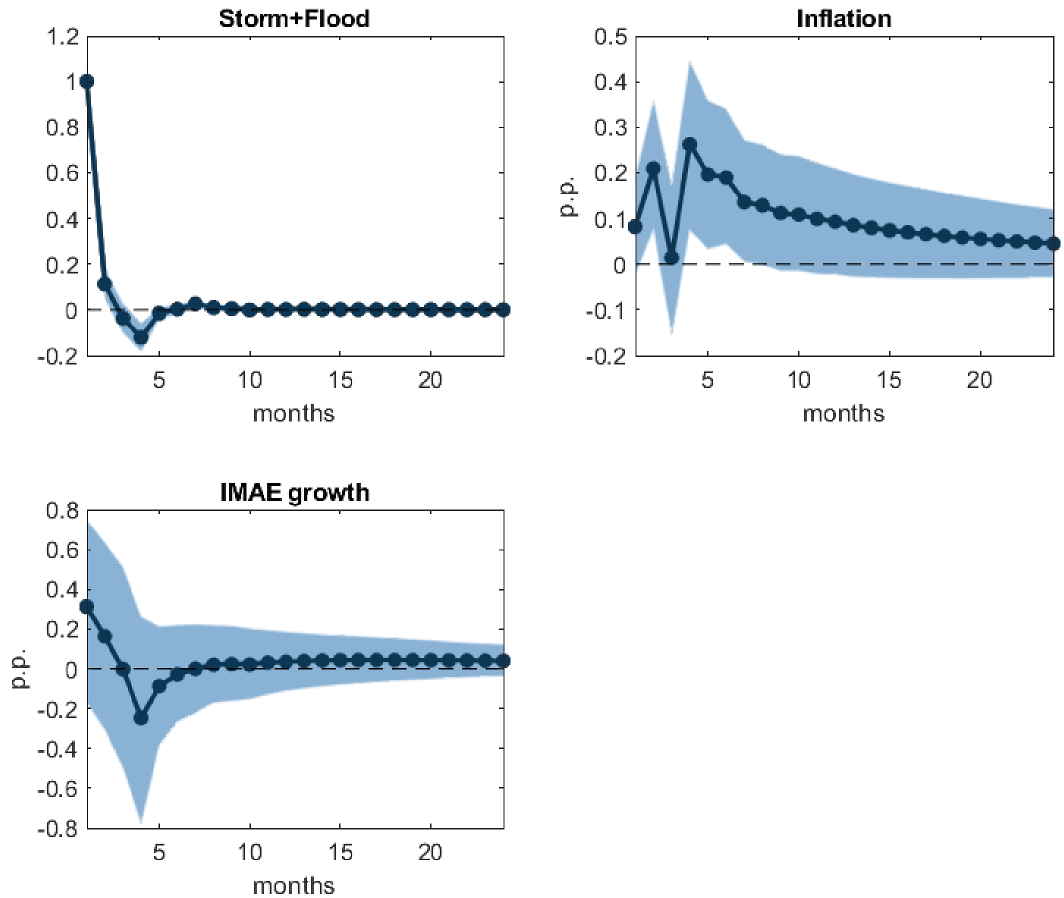


Figure B7. Country-specific VAR estimates with dummy variable: Panama



B.2. Panel VAR

Figure B8. Panel estimates using 'Storm+Flood' dummy

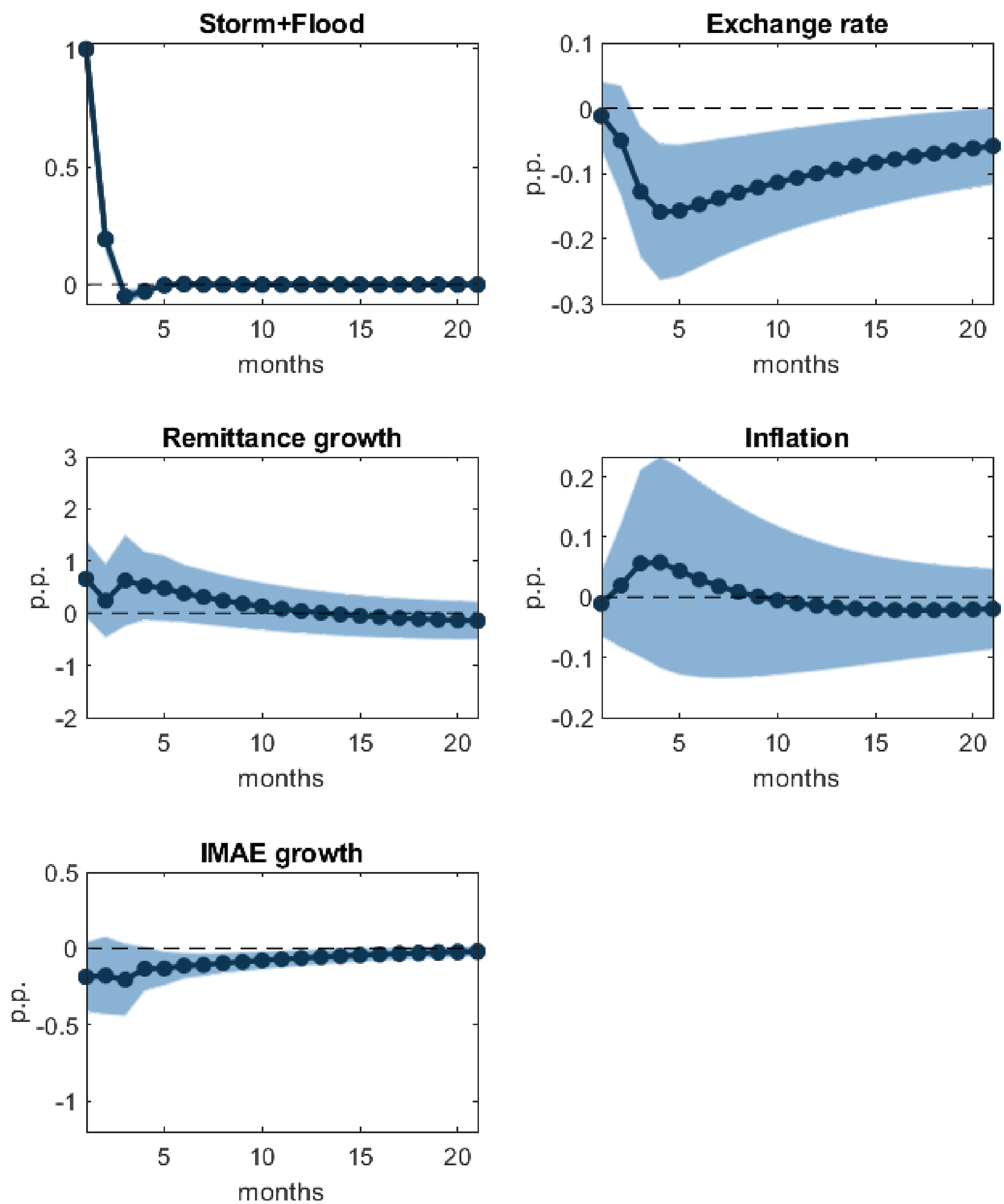


Figure B9. Panel estimates using 'Storm' dummy

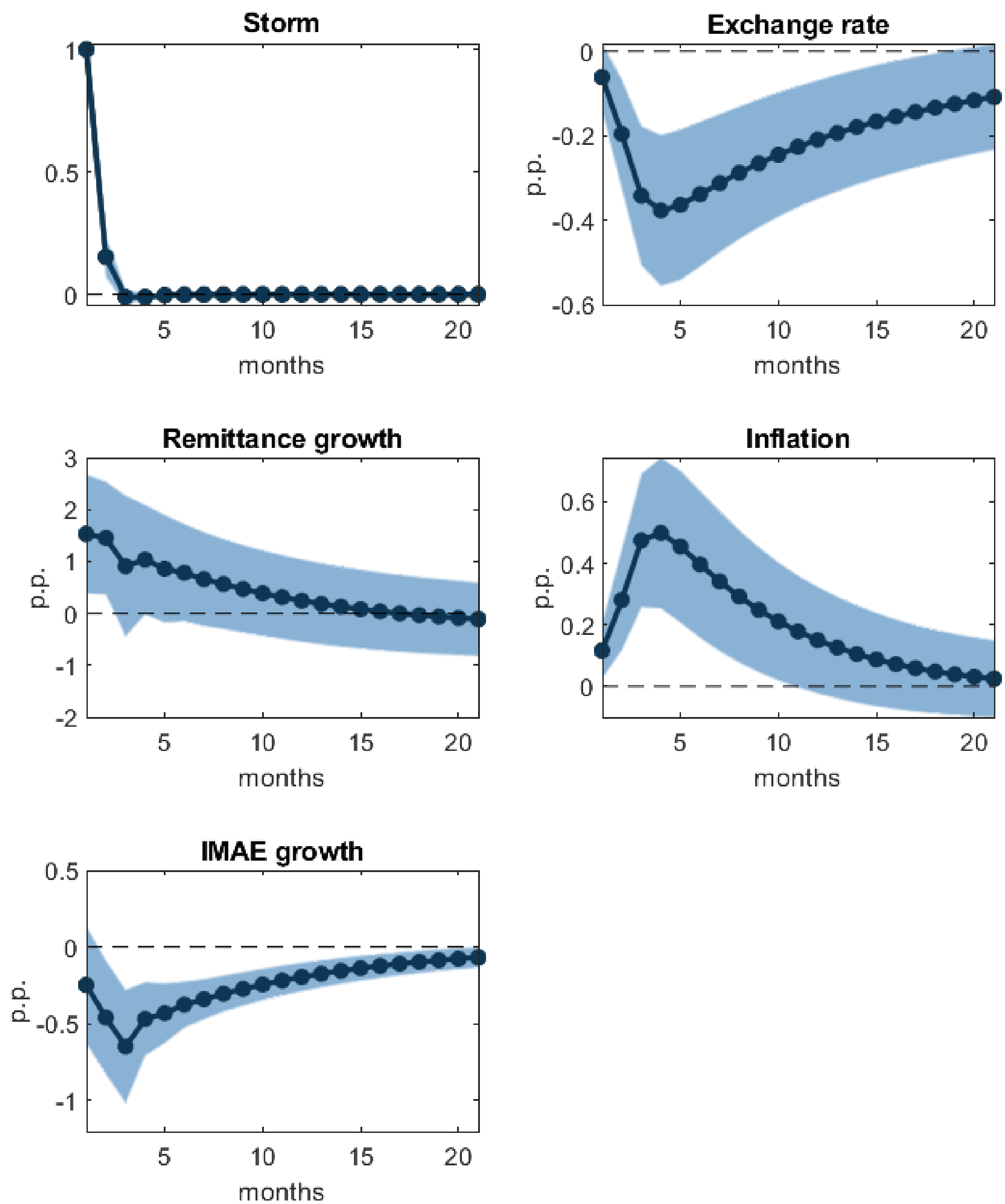
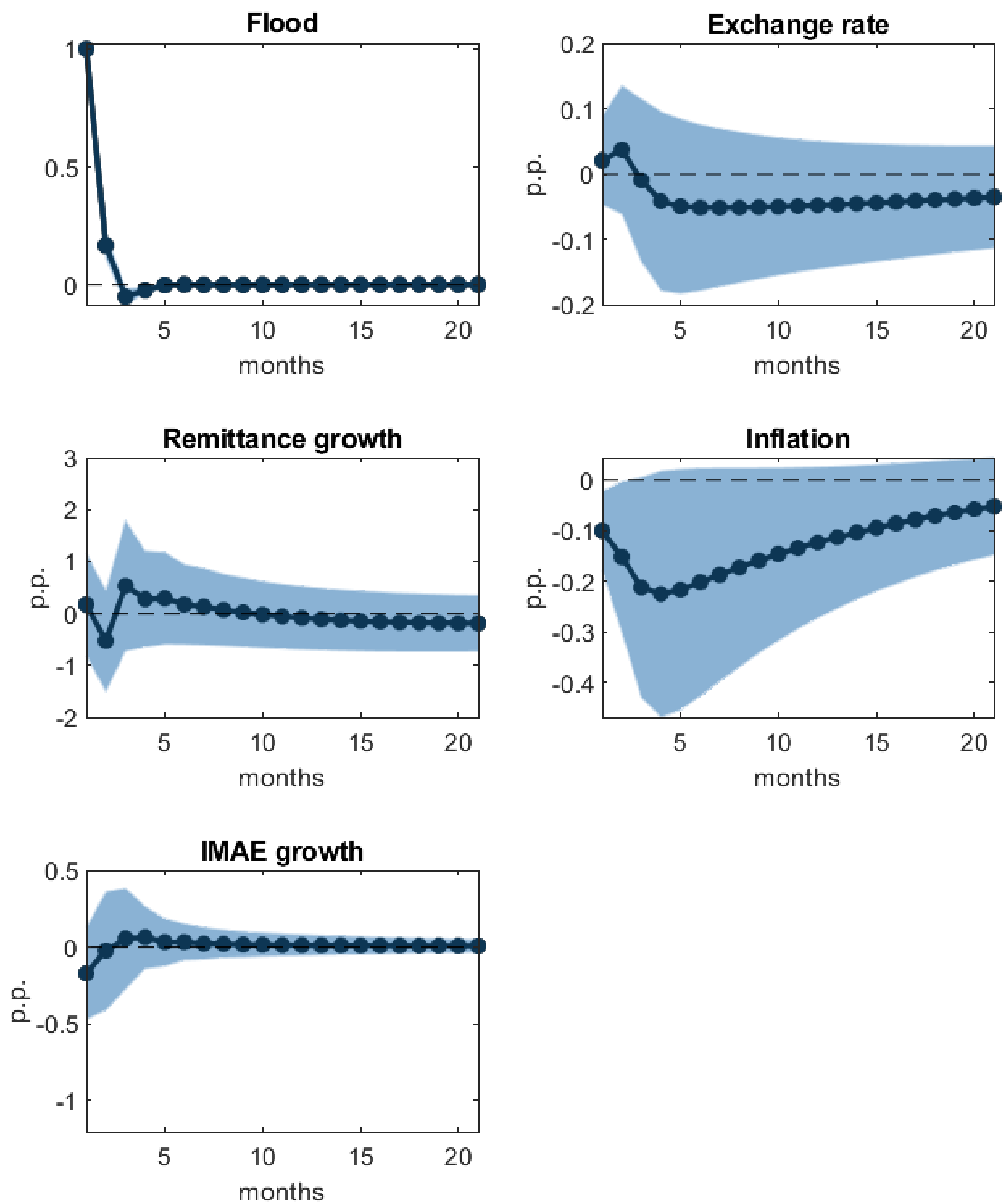


Figure B10. Panel estimates using 'Flood' dummy



B.3. Augmented results using the monthly climate index

Figure B11. Full results of Honduras

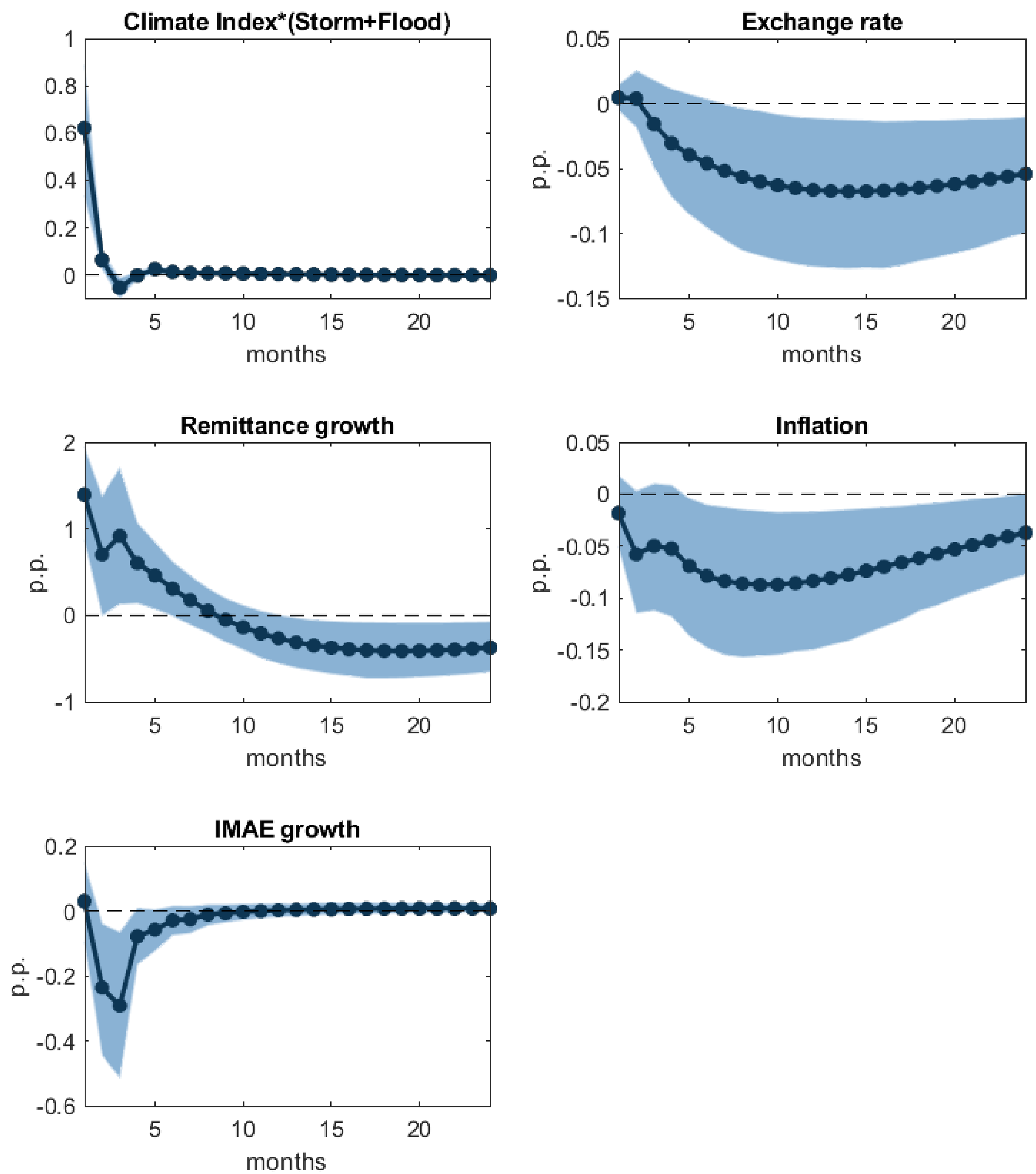
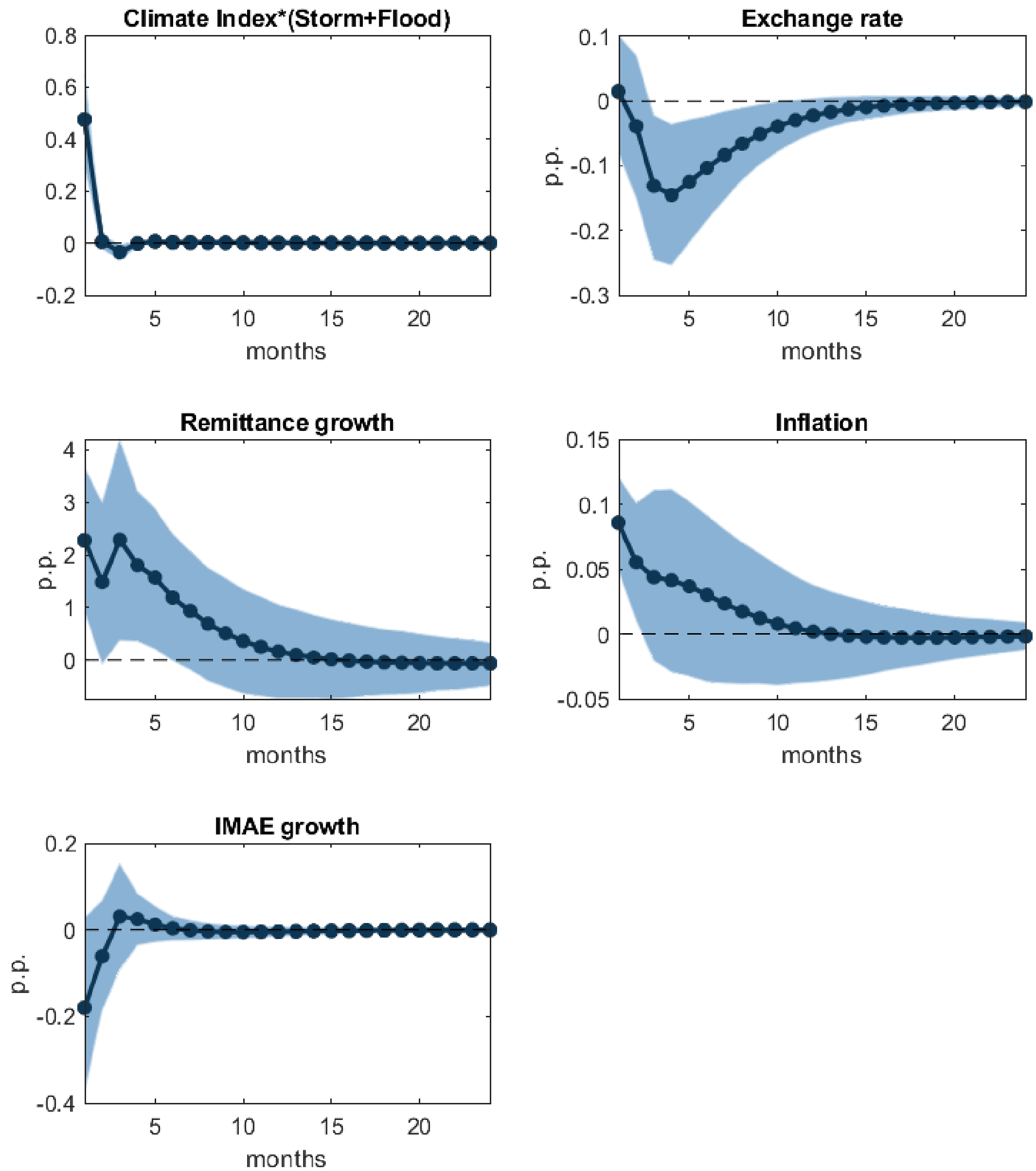


Figure B12. Full results of Guatemala



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