Climate and sovereign risk: the Latin American experience with ENSO events[1]

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Abstract

Using monthly panel data over the period 2007-2019 for seven Latin American countries, we empirically test the impact of climate shocks, here ENSO (*El Niño* Southern Oscillations), on sovereign risk. Local Projections are computed to assess the dynamic response of sovereign spreads to ENSO events. Results show that strong *El Niño* and *La Niña* shocks lead to a significant increase in sovereign spreads, but with different timing. Strong *El Niño* shocks are associated with a significant short-term increase in sovereign spreads, while strong *La Niña* events are associated with a delayed but significant increase in sovereign spreads after a short-term decrease. Thus, our results suggest a potential asymmetry in the effect of these ENSO events on sovereign risk. We also highlight high volatility in the dynamics of sovereign spreads, which may reflect an overreaction of investors faced with the high degree of uncertainty generated by the economic and financial consequences associated with ENSO events. Complementary time-series estimates suggest that Costa Rica and Peru are especially subject to these effects. Overall, our results provide a warning about the fact that, in the case of Latin American countries, weather shocks associated with strong ENSO events have adverse macroeconomic and financial consequences that can lead to an increase in sovereign risk, hinder their government's ability to act as a 'climate rescuer' of last resort, and may be aggravated in the future by climate change.

Keywords: climate macroeconomy; ENSO; climate finance; sovereign spreads; local projections

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I. Introduction

In the last decade, the new climate economy literature, summarized by Dell *et al.* (2014), has emerged to explore the role of climatic variations on various social and economic outcomes (Carleton & Hsiang, 2016). Several studies have found that weather fluctuations (level and variations of temperatures, storms, rainfall, etc.) have important effects on economic performance (Dell *et al.*, 2012; Burke *et al.*, 2015; Kalkuhl & Wenz, 2020; Kotz *et al.*, 2021; Kotz *et al.*, 2022).

ENSO and macroeconomy. A recent literature has more specifically investigated the dynamics of the so-called climate 'teleconnections' and notably the ENSO (*El Niño Southern Oscillation*) phenomenon. ENSO is the leading mode of interannual climate variability in the world and is responsible of a huge number of climate extremes (very high temperatures and excess rainfall and wildfires among others) with highly heterogeneous economic consequences across different regions in the world (Cashin *et al.*, 2017), but more especially for 'teleconnected' countries (Hsiang *et al.*, 2011) and those in South America (Cai *et al.*, 2020).

ENSO may be subdivided into *El Niño* and *La Niña* events, characterized respectively by unusually warm ocean temperatures along the Equatorial Pacific and by unusually cold ocean temperatures. Both ENSO events lead to deviations in normal temperatures, that impact the weather conditions around the globe. ENSO is thus likely to have different direct and indirect impacts on social activity, such as civil conflicts (Hsiang *et al.*, 2011), but also on economic outcomes (Smith & Ubilava, 2017; Generoso *et al.*, 2020). Consequently, depending on their intensity and magnitude, ENSO events are likely to strongly impact the well-being of populations. A better understanding of the ENSO effects on economic and financial activity is thus necessary to protect populations and improve their adaptation to ENSO-induced climate variations. This is particularly important since ENSO is likely to be impacted by the current global warming. Indeed, the frequency and the magnitude of ENSO events are expected to grow in the future (Cai *et al.*, 2014, 2021, 2022; Yeh *et al.*, 2018) and could exacerbate the size of its current detrimental effects on the economy, even though there is no absolute consensus on the direction and magnitude of that response (Callahan *et al.*, 2021).

A brief literature has already empirically investigated the effects of ENSO on the economy. Brunner (2002) estimated a VAR (*Vector AutoRegressive*) model to derive significant effects of ENSO on GDP growth and inflation for the G7 countries over the period 1950-1999. Two other related studies failed to identify clear-cut effects from ENSO on GDP growth. Kozaryn

& Okulicz (2008) did not find any effect for the United States over the period 1894-1999. Taking into account a large number of countries and using Granger causality tests, Laosuthi & Selover (2007) found little evidence of a recurring effect of El Niño on GDP growth, except for South Africa, Australia, the United Kingdom and, to a lesser extent, the Philippines. Using a GVAR (*Global Vector AutoRegressive*) model over the period 1979-2016, Cashin *et al.* (2017) studied the impact of *El Niño* events on economic growth, inflation, energy prices and non-fuel commodity prices accounting for spillover effects between countries. They found evidence of a large but highly heterogeneous impact of ENSO on economic growth and inflation across different regions. Smith & Ubilava (2017) used panel threshold regressions to outline regime-dependent nonlinearity in the GDP growth response to ENSO shocks. Generoso *et al.* (2020) estimated the effects of ENSO on the growth rate of 76 developing countries in relation to heterogeneous local weather conditions. Very recently, Callahan *et al.* (2022) re-examined the effect of El Niño on economic growth and how such effects may change in the future.

Climate and sovereign risk literature. In parallel, a new emerging 'climate finance' literature (Hong *et al.*, 2020) has investigated the links between climatic factors and financial markets. Recent papers have shown that extreme climate events are likely to impact sovereign risks. Kling *et al.* (2018) conducted the first study on the impact of climate change on the cost of sovereign capital. They showed that countries with high vulnerability to climate change face a risk premium on their sovereign debt, which reduces their fiscal capacity for investing in climate adaptation and resilience. Similarly, Cevik & Jalles (2022) used an OLS model with fixed effects to regress the sovereign bond spread of 98 advanced and developing countries between 1995 and 2017 against climate vulnerability and resilience indicators. They found that vulnerability and resilience to climate change have a substantial impact on sovereign bond spreads. Specifically, countries with higher resilience to climate change experience lower sovereign bond spreads than countries with greater vulnerability to climate change risks. Furthermore, the consequences of climate change are more significant in developing countries that have limited capacity to adapt and mitigate the effects of climate change. Similarly, using a structural panel VAR approach on a sample of 40 developed and emerging economies, Volz *et al.* (2020) found that countries with higher climate risk vulnerability experience significant increases in yield bonds. The impulse response function analysis shows that shocks affecting climate vulnerability and resilience have lasting effects on bond yields after 12 quarters, and that countries with higher exposure to climate risks experience greater permanent effects on yields than countries with lower exposure.

Another set of studies has focused on sovereign ratings as an alternative indicator of sovereign risk. Cevik *et al.* (2020) conducted an initial analysis of the influence of climate change on sovereign credit ratings. Using multinomial ordered models on 67 countries over the period 1995–2017, they found that sovereign credit ratings are negatively impacted by climate change vulnerability. Similarly to Cevik & Jalles (2022), Cevik *et al.* (2020) found that countries with high vulnerability or low adaptability to the impacts of climate change have lower credit ratings. Klusak *et al.* (2021) used machine learning methods to develop a model that estimates climate-adjusted sovereign credit ratings for 108 countries. They found that under various warming scenarios, climate change is linked to a decline in sovereign debt ratings starting in 2030. This negative impact is amplified as the scenario becomes more pessimistic. For example, the annual interest payment on sovereign debt increases by US$ 137-205 billion under the RCP 8.5 scenario across the sample due to climate change. Finally, Zenios (2022) proposed connecting integrated assessment models (IAMs) with stochastic debt sustainability analysis (DSA) to enhance the comprehension of sovereign debt dynamics related to climate risks and evaluated the fiscal capacity to support climate policies. He showed that climate change raises the cost of debt due to higher sovereign credit ratings. This could hinder the state's fiscal capacity to conduct mitigation and transition climate change policies. Furthermore, if the debt dynamics increase with the intensity of climate change, this could further limit the state's fiscal capacity.

Climate and sovereign risk patterns. The natural disasters induced by climatic events such as ENSO can impact the agricultural and tourism sectors and, by contagion, can have adverse consequences on the real economy, especially on public deficits and debt. Thus, a climate event can ultimately impact sovereign credit risk and thus the evaluation of sovereign debt by rating agencies. For instance, Moody's reports (2016a, 2020b) show that natural disasters have been important determinants of sovereign debt risk for many countries in the past.[2] Beyond the effects of climatic oscillations on sovereign risk through adverse consequences on the real economy, there are financial spillover effects through international contagion mechanisms (Bissoondoyal-Bheenick *et al.*, 2014). For example, the downgrading of a 'benchmark' country

[2] Historically, small countries vulnerable to natural disasters have been the most negatively impacted (Cantelmo *et al.*, 2019). These countries have exhibited higher public debt levels compared to countries that are less exposed to natural disasters (Cabezon *et al.*, 2015; Munevar, 2018), sometimes leading to a default situation (Moody's 2016a, 2020b). For instance, in August 1999, Ecuador announced suspension of payment of its Brady bonds due to damage caused by flooding as a result of the extreme El Nino event in 1997-1998. Combined with a high public debt of about 100% of GDP, the weakness of the banking system, an expansionary monetary policy, the lack of commitment to reforms and an unstable political situation, it became increasingly difficult to service its debt, forcing the government to default (Trebesch *et al.*, 2012).

in a given regional area (Chile and Mexico in Latin America, for instance) can impact most of the neighboring countries (Batten *et al.*, 2017). Finally, investors' preferences and expectations are likely to change according to different transmission channels, such as asset valuation and volatility, portfolio management and capital flows, in response to extreme climatic shocks due to an ENSO event. For example, globalization has led to an increase in foreign capital inflows in Latin America and an appetite for emerging sovereign debts. The increase in capital inflows has recently accelerated due to near-zero interest rates linked to the unconventional monetary policy pursued by most of central banks following the subprime crisis, which has, in turn, led to an intensive search for positive yields by international investors. This increasing appetite for the sovereign debt of emerging countries is likely to reduce yields and favor the debt acquisition. However, the huge capital inflows from the rest of the world make the emerging countries very dependent on external financing, which can increase the sovereign risk premiums in view of their higher financial vulnerability (especially in the event of a drastic reduction of foreign capital inflows). Consequently, the effect associated with foreign capital inflows is complex, since it leads to two opposite effects: a downward pressure linked to the increase in demand (the demand effect), and an upward pressure reflecting the greater probability of default (the vulnerability effect), with the overall impact being the net effect of these two.

Contribution. All in all, it is necessary to assess how an ENSO event can impact sovereign risk in order to obtain a better understanding of the role played by weather shocks on the financial vulnerability of countries highly exposed to climate-related anomalies. As a result, this paper focuses on the impact of climatic factors on the sovereign bond spreads of Latin American countries that face a double vulnerability (from climate and finance). Considering ENSO for the first time – the previous literature is mostly based on Notre-Dame climate vulnerability index data – to study the impact of climatic factors on financial markets has some key advantages. First, ENSO is one of the most important climate phenomena on Earth and it plays a fundamental role in climate science. Indeed, as a common factor, ENSO has a global influence on local meteorological conditions such as temperature and tropical/non-tropical rainfall (Timmermann *et al.*, 2018). Second, ENSO can be considered as a quasi-natural experiment. It thus has good exogenous properties for empirically assessing the dynamic impact of climate shocks on sovereign risks in Latin American countries. Third, ENSO has a very strong impact on the local climate conditions of most of the Latin American countries studied in this paper. It can be considered as a proxy for the study of climate change and future relationships between climate and finance.

We chose Latin American countries as a suitable case study because they display a 'double vulnerability': 1) they are particularly 'teleconnected' to ENSO and 2) they are dependent to external financing and capital inflows. Indeed, most of these countries are financially vulnerable due to frequent exposure to financial crises and strong dependence of both firms and states on international financial market conditions for their external sources of financing (BIS, 1999).[3] In other words, these Latin American countries face a sovereign risk, i.e., they are likely to be unable to refund their debt in response to an adverse macroeconomic or financial shock (Remolana *et al.*, 2007) and are thus associated with high risk premium levels.

Due to data availability, seven countries were selected over the 2007-2019 period: *Brazil, Chile, Columbia, Costa Rica, Mexico, Panama* and *Peru.* In contrast to the previous literature, we used high-frequency time series data that have been collected at a monthly frequency country by country using the Bloomberg database. This enabled us to study the dynamics of the reaction of sovereign risk to the climatic shocks using Local Projections. All in all, the focus of this paper on ENSO shocks is especially relevant for better understanding both the present and the future consequences of climate change on financial markets and financial stability through the sovereign risk, and for preparing the population's adaptation to the growing climatic shocks. Indeed, it is now well known that climate change will have more negative effects on the most vulnerable (in terms of climate and finance) countries, such as those in Latin America. If the magnitude and frequency of climatic shocks increase due to climate change and increasingly frequent extreme weather events (Cai *et al.*, 2021), these countries will face to further financial fragility due to their greater difficulty in obtaining external financing. This will limit their ability to use counter-cyclical policy to mitigate the immediate consequences of climate shocks, as well as to mobilize the necessary financing to protect against them and to adapt to future shocks.

As a result, in this paper, we empirically test for the first time how the sovereign spreads of a sample of seven Latin American countries observed at monthly frequency over the period 2007-2019 are impacted by weather shocks arising from ENSO events. Using Local Projections, we find that strong *El Niño* and *La Niña* shocks lead to a significant increase in sovereign spreads, but with a different timing. Strong *El Niño* shocks are associated with a significant short-term increase in sovereign spreads, while strong *La Niña* shocks are associated with a delayed but significant increase in sovereign spreads. More generally, our results show that weather shocks

[3] In contrast to Asian countries (for example), for which, external sources of financing are more related to banking intermediation.

generated by ENSO events have real macroeconomic consequences (*physical risks*) that can also have financial consequences leading to increasing sovereign spreads (*financial risks*). However, in line with recent studies dealing with the impact of ENSO on GDP growth (Generoso *et al.*, 2020), our estimates suggest a potential asymmetry in the effect of these ENSO events – *El Niño* versus *La Niña* – on sovereign risk.

The rest of the paper is organized as follows. In section II, we discuss the potential economic and financial mechanisms that could explain how ENSO might influence sovereign risk in Latin American countries. Data and stylized facts are presented in section III. The econometric methodology is detailed in section IV, while section V presents and discusses our main results. Section VI checks the robustness of our findings, and section VII concludes the paper.

II. From ENSO events to sovereign risk: economic and financial mechanisms

In this section, in relation to the existing climate-economy literature, we describe the different potential economic and financial mechanisms linking climate-related disasters associated with ENSO events to sovereign risk.

2.1. Direct fiscal effects

ENSO and related extreme weather events are likely to directly increase the fiscal imbalance of teleconnected countries through a surge in the public expenditures and/or a reduction in fiscal revenues (IMF, 2018).

Increased public expenditure. ENSO events are likely to increase public expenditure in several situations.[4]

- Increased public expenditure can be the result of the needs of financing for reconstruction and investments in new public infrastructure and new physical assets stemming from damage and disasters caused by ENSO events, such as floods, tropical storms and wild fires (Mitchell *et al.*, 2014; Hochrainer-Stigler *et al.*, 2018; Schuler *et al.*, 2019). For example,

[4] Public expenditures destined for the private sector covers public-private partnerships or state-owned enterprises (for example, in the case of Costa Rica, infrastructure such as hydraulic dams, electricity networks, ports, etc.). Damage to capital, loss of revenues or increased business costs need to be offset by increased public spending or by issuing sovereign debt. For Costa Rica, the government has an explicit obligation (by law) to compensate for losses, either through the emergency fund or a temporary increase in public spending.

Caramanica *et al.* (2020) noted that the cost of reconstruction rises after each ENSO event in Peru.

- Increased public expenditure can also come from the bailout of uninsured public or private companies that experience significant losses in response to natural disasters caused by ENSO events. Indeed, these disasters can damage or destroy private property and require state support to households and businesses to rebuild homes and the physical capital of businesses.

- Since damage associated with natural disasters caused by ENSO events is likely to lead to greater financial instability and stock prices volatility, due to investors' more pessimistic expectations about future economic and financial conditions in countries experiencing these shocks, governments may be forced to bail out certain companies and financial institutions in order to reduce uncertainty on financial markets.

- In addition, these existing effects can be amplified for vulnerable countries. As stressed by Melecky & Raddatz (2011), the impact of extreme risks and disasters is 15% higher for countries where the insurance sector has a low penetration rate, whereas there is no significant change for countries in which the insurance sector is well developed. In 2015, the penetration rate of the insurance sector, taken from OECD Insurance Statistics, was 11.1 % in the USA, 8.5% on average in the OECD countries, but only 1.9% in Costa Rica, 2.7% in Colombia, 4.6% in Chile, 1.9% in Peru, 3.1% in Brazil and 2.1% in Mexico.

A decrease in fiscal revenues. The reduction of fiscal revenues is directly linked to the economic downturn caused by the adverse effects of climate shocks on firms' production, which in turn entail a decrease in GDP that automatically leads to a fall in fiscal revenues (Schuler *et al.*, 2019; Bova *et al.*, 2019).

Therefore, by worsening fiscal balance, ENSO events may contribute to an increase in sovereign risk.

2.2. Indirect fiscal mechanisms

2.2.1. Adverse effects on local economic conditions

Supply effects. An extensive literature has highlighted the adverse impact of natural disasters on economic growth (Batten *et al.*, 2020; Klomp & Valckx, 2014). In the case of ENSO, Smith & Ubilava (2017) and Generoso *et al.* (2020) have found detrimental effects of ENSO – both *El Niño* and *La Niña* events – on GDP growth. This result has, however, been challenged by

Laosuthi & Selover (2007) who found that the net global effects of *El Niño* on GDP growth and inflation of 22 countries are relatively weak. This finding is especially true for large economies with a high degree of economic diversification and highly varied local weather conditions or even climatic regimes. More precisely, the effects of natural disasters on economic growth can be conveyed through the adverse consequences on the level of productivity and production in the agricultural and fishing sectors (Pécastaing & Salavarriga, 2022). Brown & Funk (2008) and Battisti & Naylor (2009) and Naylor & Mastrandrea (2010) show that climate shocks, by reducing agricultural production, threaten the food security of developing countries. Adams *et al.* (1999) show that strong ENSO events lead to losses in the US agricultural sector. Hsiang & Meng (2015) confirm the negative and significant effect of *El Niño* on agricultural value added and yields for a panel of tropical countries. As a result, the negative impact of ENSO on GDP is expected to be high in developing and emerging countries, since they are characterized by strong dependence on the agricultural sector and have a low level of diversification of their production.[5] Moreover, temperature anomalies can lead to substantial impacts on labor markets by significantly decreasing labor supply and productivity (Burke *et al.* 2015; Day *et al.* 2019; Letta & Tol, 2019). Finally, the tourism sector may also be adversely affected by climate shocks. Oduber & Ridderstaat (2017) find a significant negative effect of ENSO on tourism demand in the USA, Venezuela, and more surprisingly, the Netherlands.

Demand effects. Batten *et al.* (2020) show that extreme weather events are likely to reduce household revenues, especially those of agricultural and fishing workers through, for instance, a decrease in crop yields or an increase in unemployment, which in turn reduce private consumption. In addition, the adverse effects of climate shocks on firms' physical capital reduces the asset value of private companies, leading to potential financial losses and reduction in investments. However, these negative consequences can be mitigated by a well-functioning banking system that is able to provide external sources of financing for firms experiencing a decrease in their production. On the other hand, as mentioned above, climate-related shocks will have major adverse consequences if the losses experienced by private companies are not covered by insurance contracts.

Ultimately, both transitory supply and demand climate-related shocks are likely to have persistent negative effects on economic growth (Acevedo, 2014; Klomp & Valckx, 2014; Botzen *et al.*, 2019) and public finances. The effects of these shocks are function of their

[5] The magnitude of the effects of ENSO on agricultural outcomes also depends on the synchronization between the interannual period at which ENSO events occurred and countries' harvesting seasonality.

intensity and length, as well as their degree of ENSO teleconnection. In addition, climate change is likely to increase the frequency and magnitude of ENSO events in the future (Cai *et al.*, 2014, 2021, 2022; Yeh *et al*., 2018), depending on the occurrence of tipping points and the energy transition policies implemented.

As a result, supply and demand effects caused by ENSO events are associated with a decrease in domestic macroeconomic fundamentals that can harm public finances and lead to a rise in sovereign risk.

2.2.2. International trade effects

Extreme weather events can damage transport infrastructure, resulting in major perturbations to the supply chain. For example, railway lines, roads and waterways, may be temporarily closed due to floods or storms. More generally, climatic oscillations due to ENSO events may reduce the stock of productive capital and physical infrastructure on which the exporting sector depends.

In addition, ENSO events, by hitting the primary sectors in particular, are likely to lead to a decline in agricultural and fishing production (Pécastaing & Salavarriga, 2022), which in turn reduces exports and increases imports at the same time due to a potential substitution effect. Previous studies, such as Gassebner *et al.* (2010), Oh & Reuveny (2010), Felbermayr & Gröschl (2013), El Hadri *et al.* (2019) and Osberghaus (2019) suggest that natural disasters reduce exports, but have ambiguous effects on imports. Curtin (2019) warned about major disruption to container shipping, due to rising sea levels and the increase in the frequency and intensity of storms.

Thus, due to their adverse effects on exports and trade balance, ENSO events may negatively impact external macroeconomic fundamentals, which may result in a worsening of public finances and an increase in sovereign risk.

2.2.3. Financial factors

FDI and capital inflows. Latin American countries are highly dependent on international capital flows since they are characterized by low levels of domestic savings compared to investment (Goncalves 2018). In these countries, over the period 2000–2017, investment and savings were respectively 4 and 6.5 percentage points of GDP lower than the average of other emerging countries (IMF, 2019). This shortfall forces Latin American countries to rely on foreign investment, through international capital inflows. However, David (2011) showed that the FDI inflows following natural disasters are not able to offset the negative economic effects resulting from climate shocks and may even amplify the economic downturn. Escaleras & Register (2011) showed that natural disasters may also lead to a decrease in FDI inflows.

Asset (mis)valuation. Although to our knowledge there are no studies on this particular topic, it is likely that an ENSO shock will lead to a misvaluation of assets. Because ENSO oscillations and the associated climatic events are difficult to forecast, investors face considerable uncertainty regarding the probability of climate shocks and can only have backward-looking expectations based on the available information on previous ENSO events. For example, investors in 2023 have information about strong past ENSO events, such as 1982/1983, 1997/1998 or 2015/2016, and their impact on the economies of Latin American countries. However, each ENSO event is different, because its effects on temperatures and rainfall are time-varying. As a result, due to this high uncertainty regarding ENSO events, investors may wrongly price financial assets associated with Latin American firms or governments. This may lead to greater asset price volatility and misvaluation, since investors are expected to under- or over-react to an ENSO shock, depending on their own expectations regarding the magnitude and length of the shock and its potential consequences on economic fundamentals.

Credit rating. Countries are assigned an individual sovereign debt rating based on economic, social and political factors. On the one hand, countries with a debt rating equal to or higher than BBB- (according to S&P and Fitch) or Baa3 (according to Moody's) are considered as investment grade and are thus subject to low credit risk. Thus, the risk premiums in these countries are low for firms and governments, thereby fostering capital inflows and investment. On the other hand, countries with a lower sovereign rating are considered as non-investment grade or speculative grade (in the case of payment default). Since an adverse ENSO shock can increase public debt through direct and indirect fiscal effects, this may lead to a sovereign credit rating downgrade that is likely to amplify the initial fiscal impact of the climate shock. Indeed, the negative consequences of an ENSO shock on the economy can lead to an increase in public debt, due to lower fiscal revenues and higher public spending. This may raise doubts in the financial community about the sustainability of the current level of public debt and leads rating agencies to downgrade sovereign bonds associated with countries experiencing such climate shocks, which in turn translates into higher sovereign spreads for these countries. This effect may be reinforced if investors over-react to an ENSO shock, amplifying financial volatility and the surge in sovereign spread.

Consequently, ENSO events can adversely impact capital inflows, asset prices and sovereign credit ratings, which in turn may increase sovereign risk.

2.2.4. Political instability and conflicts

Finally, additional political and social factors are likely to amplify the effects of ENSO events on sovereign risk. Hsiang *et al.* (2011) highlight the relationship between ENSO and increased civil conflicts. More generally, climate change is associated with higher conflict rates (Buhaug, 2016; Gleick, 2018; Nevitt, 2020), although the relationship between the two is still much debated in the literature. Volz *et al.* (2020) discuss the potential political instability resulting from economic downturns, especially regarding the inability of governments to repay their debts. In this regard, Clark (1997) showed that political instability can potentially increase the risk of sovereign default. In the same vein, Cuadra & Sapriza (2008) find that countries with a high degree of political instability and polarization are associated with higher sovereign default rates, resulting in higher risk premiums in the financial markets.

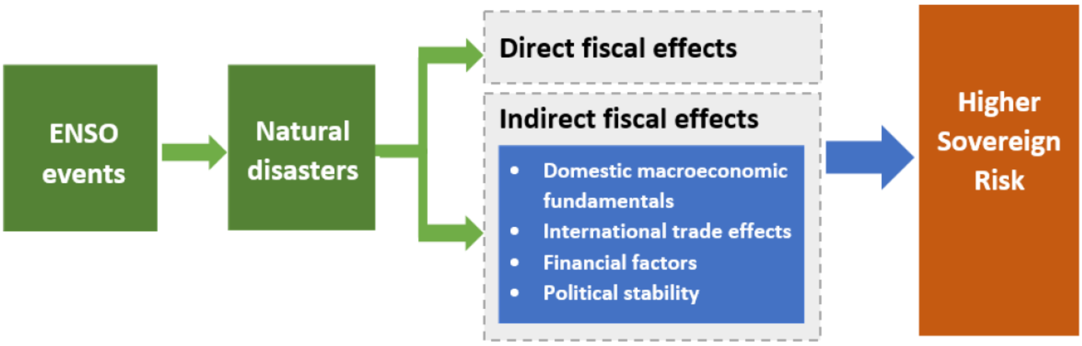
As a result, political and social unrest arising from the adverse economic consequences associated with climate shocks may be additional factors linking ENSO events to increased sovereign risk.

2.2.5. Summary of the main channels

Figure 1 below provides a summary of the main channels from ENSO to physical and then sovereign risks. Overall, ENSO events are likely to contribute to an increase in sovereign risk through several channels.

- Direct fiscal channels by worsening the fiscal balance and public finances;
- Indirect fiscal channels associated with a decrease in domestic and external macroeconomic fundamentals that can harm public finance;
- Adverse effects on capital inflows, asset prices and sovereign credit ratings;
- Political and social instability resulting from the adverse economic consequences associated with climate shocks.

Figure 1. Summary of the main channels



3. Data and stylized facts

Data used in this paper are based on climatic and financial risk indicators observed at a country level and monthly frequency from April 2007 to December 2019. The monthly frequency is more reliable than lower frequency data for conducting robust estimates of the ENSO effects on the sovereign spreads. Because of the relative scarcity of financial data for a number of Latin American countries over a sufficient period of time to study the dynamic impact of ENSO events on sovereign spreads, seven countries have been included in our panel, namely Brazil, Chile, Colombia, Costa Rica, Mexico, Panama and Peru. Apart from data availability, our choice of these countries was also motivated by their level of exposure to ENSO, since they are known to be significantly impacted by ENSO events, especially in terms of adverse effects on their economies (Cashin *et al.*, 2017).

3.1. ENSO data and classification of ENSO events

In line with the existing literature, the *Oceanic Niño Index* (ONI) is used as the best proxy for ENSO events. We use the ONI proxy since it corresponds to the operational definition used by the National Oceanic and Atmospheric Administration (Generoso *et al.*, 2020). Moreover, this index has a strong correlation (more than 90%) with other commonly used indicators such as the *Niño 3.4* index and the surface atmospheric pressure-based *Southern Oscillation Index* (SOI) (Bamston et al., 1997).

Regarding the phases associated with ENSO, *El Niño* events are characterized by abnormal warming, while *La Niña* events are characterized by periods of abnormal cooling. The ONI index enables us to visualize the *El Niño* (warm) and *La Niña* (cold) periods in the Tropical Pacific zone using anomalies in average sea surface temperatures (SST) computed as a moving average over a three-month rolling window for the *Niño 3.4* region (see for instance Yang *et al.*, 2021).

(a) *Identification of an El Niño or La Niña event*: an ENSO event is defined as *El Niño* or *La Niña* when we observe five consecutive months of ONI (computed as a moving average over a three-month window) equal to or above +0.5 (*El Niño* event) and equal to or below -0.5 (*La Niña* event).

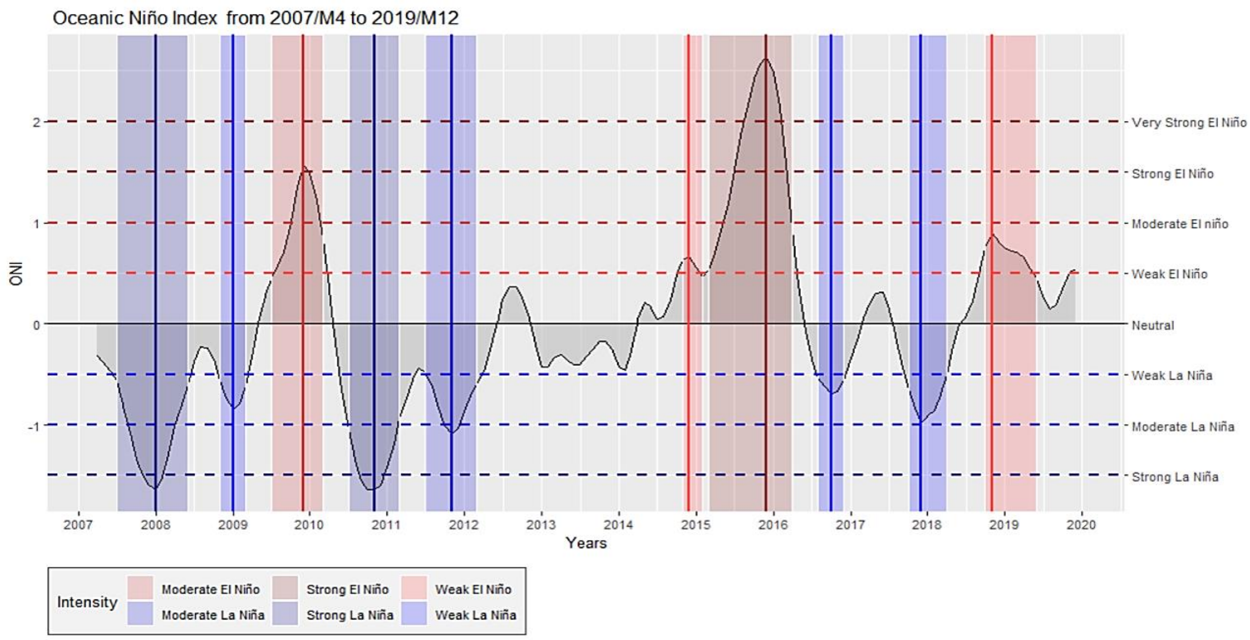
(b) *Identification of a weak ENSO event*: a weak *El Niño* (*La Niña*) event is associated with five consecutive months of ONI lying between 0.5 and 0.9 (-0.5 and -0.9).

(c) *Identification of a moderate ENSO event*: a moderate *El Niño* (*La Niña*) event is associated with five consecutive months of ONI lying between 1.0 and 1.4 (-1.0 and -1.4).

(d) *Identification of strong ENSO event*: a strong *El Niño* (*La Niña*) event is associated with five consecutive months of ONI equal to or above to 1.5 (equal to or below -1.5).

Figure 2 displays at monthly frequency the dynamics of ENSO events proxy through the ONI indicator and the associated *El Niño* and *La Niña* events over the study period.[6] From 2007 to 2019, two strong *La Niña* events and one very strong *El Niño* event have been identified. Note also that our classification of ENSO events is in line with the previous literature (Santoso *et al.*, 2017; Cai *et al.*, 2020; Timmermann *et al.*, 2018).

Figure 2. Dynamics and phases of the Oceanic Niño Index (ONI)



[6] Appendix 1, Table A1 details the classification of ENSO events used in this paper.

The strongest *El Niño* event (classified as very strong) occurred in 2015. Although this event shares common features with previous strong *El Niño* events, such as those in 1983 and 1998, it exhibits different patterns, however: 1) the record-breaking warm anomaly was in the central Pacific, in contrast to previous *El Niño* events for which SST anomalies peaked toward the far eastern Pacific; 2) there is a difference in its propagation mode, since the 1982/1983 and 1997/1998 *El Niño* events had an apparent eastward propagation signature.

Recent climate literature on the variability of extreme ENSO events (Cai *et al.*, 2014; Yeh *et al.*, 2018; Ham, 2018) suggests that the 2015-2016 event was the first occurrence of an extreme *El Niño* shock in the 21st century. Thus, a classification into two subtypes of ENSO events has been proposed, depending on whether the maximum warming in the tropical Pacific SST is located in the Eastern Pacific (EP) or in the Central Pacific (CP) (Capotondi *et al.*, 2015). This classification explains the frequency and variability of severe natural disasters that occurred in different parts of Latin America following *El Niño* or *La Niña* events. *La Niña CP* events are stronger than *La Niña EP* events, whereas *El Niño EP* events generally have a stronger impact than *El Niño CP* events. In addition, we note that the impact of ENSO events on local weather conditions and thus on macroeconomic outcomes can vary in terms both of the magnitude and the nature or timing of the ENSO event. Finally, there are no absolute laws about ENSO effects: indeed, some moderate events are likely to generate more damage than stronger ones. ENSO is characterized by diversity and asymmetry (Cai *et al.*, 2021).

There are numerous weather anomalies and natural disasters potentially caused by ENSO events. In Appendix 2 (Table A2.1 and A2.2), we present an exhaustive summary of the weather anomalies and natural disasters potentially caused by the strong *El Niño* and *La Niña* events over the period 2007-2019 for the seven countries in our sample. To this end, we focus on five major ENSO-related natural disasters, namely droughts, cold spells, flooding, tropical cyclones, and marine heat waves.[7] In the following two paragraphs, we briefly summarize the main natural disasters related to the strong ENSO events that occurred in our sample, differentiating between *El Niño* and *La Niña* events.

[7] The data we use come from the following sources: ***Bulletin of the American Meteorological Society***, "State of the climate", annual reports from 2007 to 2019, Aon Benfield's "Annual Globe Climate and Catastrophe" reports from 2010 to 2017, Emergency Events Database (EM-DAT), as well as complementary reports from the OECD, World Bank and national governments. Natural disasters classification follows the criteria used in EM-DAT.

3.1.1. El Niño-related natural disasters

For the 2015-2016 extreme *El Niño* event, our sample countries were strongly impacted by droughts and extreme temperatures. Those countries around the Amazon region (Brazil, Colombia and Peru) were particularly affected, due to persistent drought from 2014 (Erfanian *et al.*, 2017). The 2015–2016 Amazon drought was associated with increased wildfires and crop damage that led to a decline in hydropower generation in Brazil and Colombia. Colombia's total damage from these wildfires has been estimated at $170 million (Jiménez-Muñoz *et al.*, 2016). In addition, marine heat waves associated with the development of *El Niño* events caused significant bleaching on coral reefs in Costa Rica and Peru, altering patterns of fishing (Chaston Radway *et al.*, 2016, Pécastaing & Salavarriga, 2022) and the migration of demersal species, particularly in Peru (Bacheler *et al.*, 2019). The average fishing deficit during a strong *El Niño* event was estimated to be approximately 480 000 tonnes by Bertrand *et al.* (2020). In Peru for example, the total volume of fisheries landings fell by 56% and 45%, respectively after the extreme *El Niño* events in 1982–1983 and 1997–1998 (Pécastaing & Salavarriga, 2022) making necessary the development of Marine Protected Areas (MPAs).

In contrast, the 2015–2016 *El Niño* caused extreme precipitation in other Latin America regions. Severe floods and rainfall events were observed in Southern Brazil and the Atlantic coast of Costa Rica. For instance, abundant rainfall over Southern Brazil and most of the La Plata basin caused extensive flooding and overflowing of the main rivers in Southern Brazil. Total damage has been estimated at $60-200 million.

Similarly, the 2015-2016 *El Niño* caused an increase in tropical storms in the North-Eastern Pacific, with, in some cases, adverse climatic consequences spreading to Central America countries. On October 20, 2015, Hurricane Patricia (a class five hurricane in terms of strength based on the Saffir–Simpson scale) was the strongest hurricane in the North-Eastern Pacific basin and one of the most intense to strike Mexico. Total damage associated with Hurricane Patricia have been estimated at $940 million. The agricultural sector and transportation infrastructure incurred most of these costs, which is in line with Dunstan *et al.* (2018), Poulain & Wabbes (2018) and Sainsbury *et al.* (2018), showing that tropical storms caused significant negative effects on fish stocks, fishing fleets, fishery yields, and aquaculture facilities.

3.1.2. La Niña-related natural disasters

Until recently, *La Niña* was less studied and not as well understood as *El Niño* (Ordinella, 2002). It is now well established that years of severe *La Niña* events are mainly associated with unusually cold weather, flooding, and tropical cyclones. *La Niña* events generally have less adverse economic consequences than *El Niño* events. However, in some countries, *La Niña* CP exposure results in more significant average annual economic losses than exposure to *El Niño* events (Aon Benfield's report, 2016). This can be explained by an increase in the frequency of costly landfalling and tropical cyclone events in the Atlantic Ocean basin. For instance, the strong *La Niña* event in 2010 was associated with Hurricane Karl (a class three hurricane), which impacted 114 municipalities in the state of Veracruz in Mexico with strong winds and heavy rainfall. Total damage has been estimated at $3.9 billion. Costa Rica and Panama were similarly affected by Hurricane Tomas and Tropical Storm Nicole, which caused severe damage to electrical and transportation infrastructures, housing, and agriculture. Moreover, heavy rainfall led to severe flooding and landslides in Southern Mexico and Southern Brazil. In the eastern parts of Southern Brazil, floods and mudslides killed 256 people and destroyed 25,000 homes. Total damage has been estimated at $14.2 billion. Similarly, in the central region of Colombia, flash floods and landslides inundated 250,000 homes and a large part of Colombia's agricultural area, with the estimated damage amounting to $300 million.

In contrast, severe *La Niña* events in Chile and Peru caused droughts during the winter from April to September, which adversely affected agriculture and the cattle and timber industries, as well as the energy and industrial sectors. These periods of droughts were also associated with cold spells, causing damage to agriculture and cattle farming.

3.1.3. ENSO-related natural disasters

On the basis of the two previous sub-sections, we can summarize the effects of ENSO events on the Latin American economies as follows.

- ENSO events are complex and are a function of their magnitude, frequency and nature (EP versus CP for example). The effects of the *El Niño* and *La Niña* phenomena on the Latin American economies present in our sample are thus very heterogeneous, depending on the geographical area and local weather conditions.

- In general, *El Niño* events tend to have greater negative consequences compared to *La Niña* events. This suggests a potential asymmetry regarding the effects of *El Niño* and *La Niña* events on the economies of Latin American countries and therefore on their degree of exposure to sovereign risk.

3.2. Sovereign bonds data

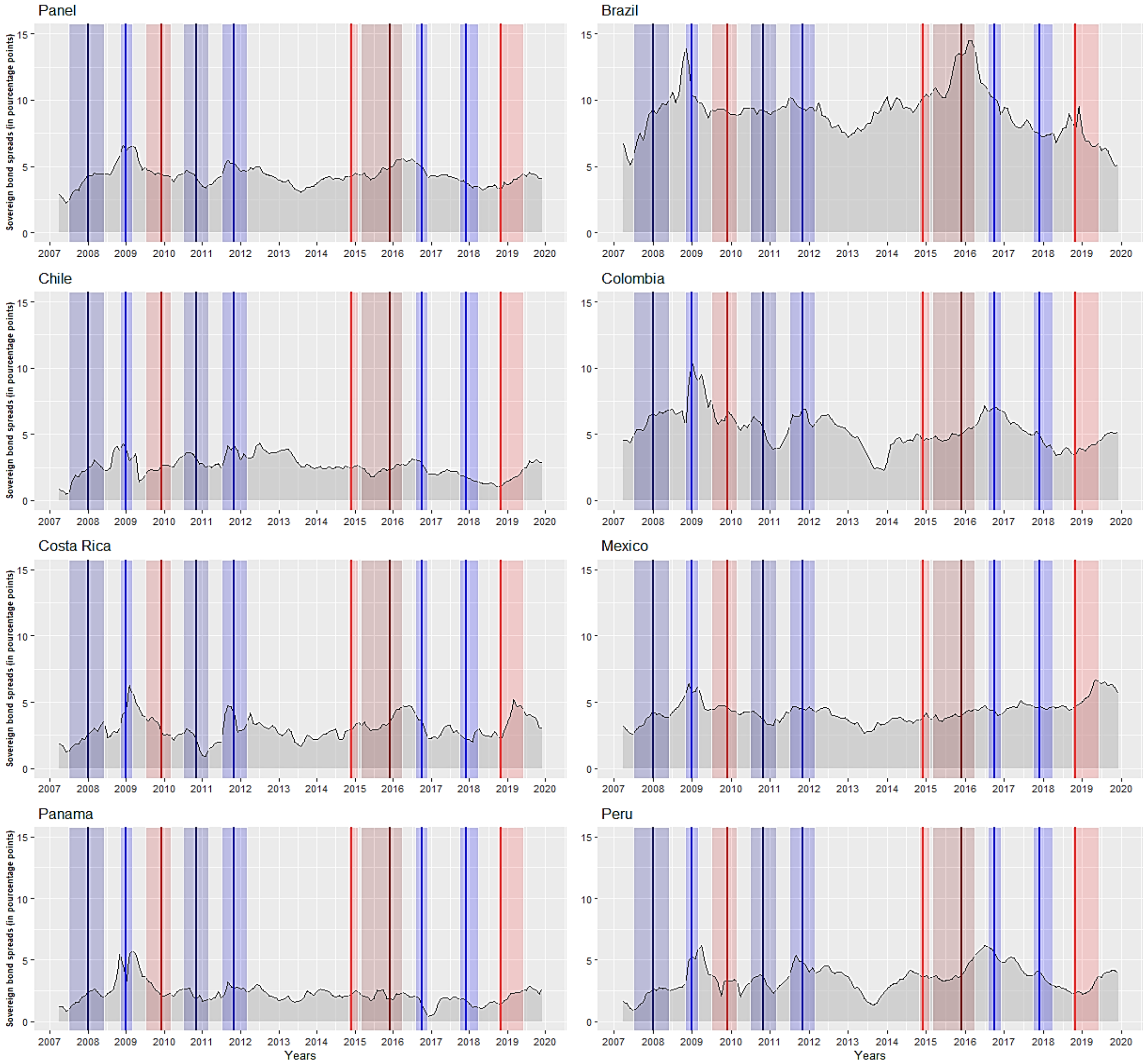
To proxy sovereign risk, we follow the literature (Martinez *et al.*, 2013; Cevik & Jalles 2020, 2022; Klusak *et al.*, 2021) and use as a baseline dependent variable the monthly spread between the ten-year yield on sovereign bonds from each of the seven Latin America countries in our sample and the ten-year US Treasury yield. Data comes from the Bloomberg database. We use sovereign spreads as baseline to proxy sovereign risk, since these enable us to control for global monetary and financial conditions that may influence the financing cost of Latin American countries in the international financial markets. Compared to sovereign bonds with shorter or longer maturity, ten-year spreads data has also the advantage of being more widely available, enabling us to keep our sample with a sufficient time-depth to estimate the dynamic impact of ENSO events on sovereign risk at monthly frequency.[8]

Figure 3 reports the dynamics of the sovereign bond spreads for each of the seven countries in our sample (*Brazil, Chile, Columbia, Costa Rica, Mexico, Panama and Peru*), its average for the whole panel (Panel) as well as ENSO events (with red bars for *El Niño* events and blue bars for *La Niña* ones). From Figure 3, it is apparent that:

- *El Niño* events are associated with an increase in sovereign spreads, as in the year 2015 during one recent strong *El Niño* event.
- In contrast, *La Niña* events tend to be associated with a decrease in sovereign spreads, except for the 2007-2009 period. This particular period corresponds to the subprime crisis, characterized by high financial volatility and risk aversion and also to the conjunction of two *La Niña* events.
- Finally, it seems that there is an asymmetry between *El Niño* and *La Niña* events and their associated effects on the sovereign spreads. This asymmetric finding is consistent with the literature, which emphasizes that *El Niño* events are linked to more significant climatic and economic impacts than *La Niña* events. Consequently, it is of interest to go further than descriptive statistics and to econometrically investigate these stylized facts.

[8] In section VI, for the purpose of robustness checks, we consider the monthly ten-year sovereign bond yield for each of the seven Latin America countries in our sample as an alternative dependent variable.

Figure 3. Dynamics of ten-year sovereign bonds spreads versus ENSO events



Note: the black lines denote the monthly average of sovereign bonds spreads. Vertical colored bars represent ENSO events and their intensity. The panel series is computed as the average of the sovereign bond spreads for the seven countries in our sample. The vertical scale has been standardized (values between 0 and 15).

3.3. Control variables

Many macroeconomic and financial factors may influence sovereign spreads. Therefore, in order to assess the dynamic impact of ENSO events on sovereign risk, while controlling for an omitted variable bias that could affect our results, we account for several potential macroeconomic and financial determinants of sovereign spreads. In line with the literature on the determinants of sovereign risk (e.g., Grandes, 2007; Hilscher & Nosbusch, 2010; Martinez *et al.*, 2013), the following variables are considered: real GDP (in logarithmic form), real GDP growth, inflation, general government debt/GDP, primary fiscal balance/GDP, foreign debt/GDP, and growth of terms of trade, current account balance/GDP, and exchange rate. Data come from Macrobond (Latin Macro Watch), IMF (Sovereign Investors), Bank of International Settlement and World Bank databases. All variables are taken at a quarterly frequency not monthly, for reasons of data availability, except for the exchange rate.

In addition, we use the monthly average of the S&P 500 Volatility Index (VIX) to account for the global financial risk exposure of the countries in our sample, especially the impact of global financial volatility on the dynamics of Latin American sovereign spreads. Pan & Singleton (2008) and Hilscher & Nosbusch (2010) find that the VIX index has a strong positive correlation with sovereign risk in emerging countries. Rey (2015) shows that VIX co-moves with the global financial cycle and international capital flows, on which Latin America countries are highly dependent. Thus, a worsening in global financial conditions (an increasing VIX) can lead to a fall in capital flows toward Latin America, which can lead to lower economic growth and a downturn in other macroeconomic determinants of sovereign risk (Wang and Yao, 2014). Note finally that we also use a dummy variable equal to 1 from April 2007 to December 2009 and 0 otherwise to consider the potential effect of the subprime crisis (see 6.3.2).[9]

IV. Econometric methodology

4.1. Local Projections

Local Projections (LP) *à la* Jorda (2005) is an econometric methodology especially well-suited to estimate the dynamic impact of ENSO events (shocks) on sovereign bond spreads of Latin American countries in our sample. Compared with traditional *Vector AutoRegressive* (VAR) models, LP is a flexible semi-parametric approach to estimate dynamic effects, imposing less restrictions to compute the associated *Impulse Response Functions* (IRF). Moreover, LP estimates are robust to model misspecification and is not subject to the "*curse of dimensionality*" problem typically associated with VAR models. This enables us to include a larger range of control variables in our econometric model in order to better isolate the impact

[9] In Appendix 3, see Table A3.1 for more details on the source and definition of each of these control variables and Tables A3.2-A3.3 for their descriptive statistics.

of ENSO events on sovereign bonds spreads. In addition, LP can be easily estimated through traditional linear regression models.

Since ENSO events are difficult to predict, they can be viewed as exogenous shocks resulting from a random trial, or at least a quasi-random trial, thus limiting endogeneity concerns when estimating their impact on sovereign spreads. Indeed, although ENSO cycles are quasi-periodic events (with a duration ranging from two to seven years) that can be modeled through sophisticated climatic and/or physical models, it is a weak assumption to considerer the occurrence of ENSO events such as *El Niño* and *La Niña* ones (either weak, moderate or strong) as not predictable. In other words, the average oscillation in ENSO is predictable, whereas its associated peaks (*El Niño*) and troughs (*La Niña*) are not.[10]

4.2. Panel and time-series frameworks

Based on an LP econometric setup, we first assess the average dynamic impact of ENSO events on the sovereign bond spreads of the seven countries in our sample by computing IRFs. Starting with panel data estimates enable us to have a first overview of the relationship between ENSO events and sovereign risk in Latin America countries, while controlling for time-invariant unobserved heterogeneity at the country level (e.g. long-term institutional or cultural country characteristics that may be correlated with sovereign risk) using country fixed-effects.[11] This way, we can compute the expectation of the average response of sovereign bond spreads following an ENSO event (either *El Niño* or *La Niña*), while accounting for the counterfactual dynamics of sovereign spreads in periods without ENSO events. In this panel setting, the following two equations are estimated:

$$\Delta s_{i,t+h} = \theta_1 \Delta s_{i,t-1} + \theta_2 \Delta s_{i,t-2} + \beta_1 ENSOevent_{t-1} + \alpha_i + \varepsilon_{i,t+h} \qquad (1)$$

$$\Delta s_{i,t+h} = \theta_1 \Delta s_{i,t-1} + \theta_2 \Delta s_{i,t-2} + \beta_1 ENSOevent_{t-1} + vX_{i,t} + \alpha_i + \varepsilon_{i,t+h} \qquad (1')$$

where $\Delta s_{i,t+h} = \left[\frac{s_{i,t+h} - s_{i,t-1}}{s_{i,t-1}}\right].100$ represents the cumulative change in percentage points for country *i* between month *t-1* and month *t+h* in sovereign bonds spreads to an ENSO event in *t-1*, scaled by sovereign bonds spreads in *t-1*. We consider the time-horizon $h \in [0, 15]$ as a tradeoff between the ability to assess the short- to medium-term effect of ENSO events on

[10] For a review about ENSO oscillation complexity and a presentation of a conceptual view of ENSO dynamics, see Timmermann *et al.* (2018). For popular conceptual models aiming at describing the *El Niño* oscillations, see Jin (1997) and Roberts *et al.* (2016).
[11] While Nickell's bias is inherent to dynamic panel estimates including country fixed-effects, our extended time dimension maintains such a bias in a very low range of $O(1/T)$.

sovereign spreads and the significant loss of degree of freedom associated with the increase in the considered time-horizon that could adversely affect the precision of our estimates. This assumption seems to be in phase with the recent empirical literature about sovereign spreads (Gilchrist *et al.*, 2022).

ENSOevent is a dummy variable accounting for either *El Niño* or *La Niña* shocks. In line with section III, to assess the effect on sovereign spreads of significant ENSO events, our baseline estimates focus on strong *El Niño* or *La Niña* shocks. Thus, the dummy variable takes 1 when a strong event occurs at a given month regarding the ONI and 0 otherwise (see Figure 2). In that way, our LP framework is not so far from panel events methodologies (Freyaldenhoven *et al.*, 2019, 2021) consisting in estimates of the impact of exposure to some quasi-experimental events (such as exposure to a policy reform).

In addition, since the average oscillation in ENSO is predictable, this information is already included in sovereign spreads through investors' anticipations. However, peaks (*El Niño*) and troughs (*La Niña*) are difficult to forecast, thus representing relevant quasi-random shocks that may influence sovereign spreads. This is why, the coding of *El Niño* or *La Niña* shocks only account for the month associated with the peak (*El Niño*) or through (*La Niña*) value of ONI during a given ENSO event. As a result, the *ENSOevent* dummy for *El Niño* shocks equals 1 in month *t* if ONI is at its peak value for a given strong *El Niño* event, and equals 0 otherwise; leading to the identification of one strong *El Niño* shock over the studied period in December 2015 (see Appendix 1). Similarly, the *ENSOevent* dummy for *La Niña* shocks equals 1 in month *t* if ONI is at its trough value for a given strong *La Niña* event, and equals 0 otherwise; leading to the identification of two strong *La Niña* shocks over the studied period in January 2008 and November 2010 (see Appendix 1). Moreover, to account for potential lagged effects from these *El Niño* and *La Niña* shocks on sovereign spreads, through theirs adverse economic and financial consequences (see section II), we consider the one-month lag of these ENSO event dummies. Finally, to avoid collinearity issues, we sequentially account for these two *El Niño* and *La Niña* shocks dummies in our econometric model.

Given the strong persistence in sovereign spreads overtime, we account for their past short-term dynamics using the first two-month lags change in sovereign spreads with the $\Delta s_{i,t-1}$ and $\Delta s_{i,t-2}$ variables.[12] In equation (1'), $X_{i,t}$ further account for the contemporaneous effect on Latin

[12] This strong persistence of sovereign spreads is illustrated in Appendix 4 showing the graphs of the autocorrelation and partial autocorrelation functions of the sovereign spreads for each country in our sample. The choice of the first two-month lags of the change in sovereign spreads is based on traditional AIC and BIC information criteria.

American sovereign spreads of a selection of baseline key macroeconomic variables, namely, inflation, the growth of current account balance/GDP and the growth of terms of trade.[13] α_i are country fixed-effects that allow controlling for time-invariant unobserved heterogeneity at the country level, whereas $\varepsilon_{i,t+h}$ is an *i.i.d.* error term with zero mean and constant variance. Coefficients associated with equations (1) and (1') are estimated using the *Ordinary Least Squares* (OLS) estimator for each time-horizon $h \in [0, 15]$. Given the strong persistence of sovereign spreads overtime and their potential strong correlations between countries due to contagion effects, we use the Driscoll-Kraay's (1998) heteroskedasticity-robust standard errors adjusting for temporal and spatial dependence.

The cumulative Impulse Response Functions (IRFs) associated with *El Niño* and *La Niña* shocks on sovereign spreads are then computed using their estimated coefficients at each time-horizon $h \in [0, 15]$. Confidence bands are set to 90% and are computed based on the standard errors associated with these estimated coefficients. Following Jorda (2005), based on equation (1') including baseline macroeconomic controls, the average response of sovereign bonds spreads at month $t+h$ following an ENSO event at month *t-1* (either a *El Niño* or a *La Niña* shock) can be estimated as:

$$\tau(h) = E\left(s_{i,t+h} - s_{i,t-1} \middle| ENSOevent_{t-1} = 1; \Delta s_{i,t-1},\ \Delta s_{i,t-2}, X_{i,t}\right) - E\left(s_{i,t+h} - s_{i,t-1} \middle| ENSOevent_{t-1} = 0; \Delta s_{i,t-1},\ \Delta s_{i,t-2}, X_{i,t}\right) \quad (2)$$

Then, to get complementary insights about the impact of *El Niño* and *La Niña* shocks on the dynamics of sovereign spreads in each of the seven Latin American countries included in our sample, equation (1) and (1') and associated IRFs are estimated separately for each of these countries. Thus, the following two equations are estimated:

$$\Delta s_{t+h} = \theta_1 \Delta s_{t-1} + \theta_2 \Delta s_{t-2} + \beta_1 ENSOevent_{t-1} + \varepsilon_{t+h} \quad (3)$$

$$\Delta s_{t+h} = \theta_1 \Delta s_{t-1} + \theta_2 \Delta s_{t-2} + \beta_1 ENSOevent_{t-1} + vX_t + \varepsilon_{t+h} \quad (3')$$

Based on equation (3') including baseline macroeconomic controls, the response of a country sovereign bonds spreads at month $t+h$ following an ENSO event at month *t-1* (either a *El Niño* or a *La Niña* shock) can be estimated as:

[13] The other macroeconomic and financial control variables mentioned in section III are accounted for in robustness checks (see section VI).

$$\tau(h) = E(s_{t+h} - s_{t-1}|ENSOevent_{t-1} = 1; \Delta s_{t-1},\ \Delta s_{t-2}, X_t) - E(s_{t+h} - s_{t-1}|ENSOevent_{t-1} = 0; \Delta s_{t-1},\ \Delta s_{t-2}, X_t) \quad (4)$$

This complementary time-series setup allows to investigate the potential heterogeneous effects of ENSO events on the sovereign risk exposure of the seven Latin American countries included in our sample.

V. Main results

First, as baseline estimates, we use panel data on the seven Latin American countries included in our sample to assess the average impact of strong *El Niño* and *La Niña* shocks on sovereign spreads. Then, based on time-series data, we carry-out complementary estimates aiming at assessing the response of sovereign spreads to these ENSO events for each of these seven countries.

5.1. Baseline panel data estimates

Based on equation (1) and (1'), Figure 3 displays the average response of sovereign spreads to both strong *El Niño* and *La Niña* shocks for the seven countries in our sample.

Three main results are derived from Figure 3 in line with the previous theoretical analysis.

1. We note the high volatility of sovereign spreads as a response to strong *El Niño* and *La Niña* shocks. In line with the arguments presented in section II, this high volatility could reflect the uncertainty for investors regarding the financial and economic consequences induced by ENSO events and thus the difficulty of correctly anticipating the degree of exposure to risks of the Latin American countries subject to strong climatic disorder.
2. The effects of *El Niño* and *La Niña* shocks on sovereign spreads are not symmetric, as a result of heterogeneous economics and financial consequences generated by these two events.
3. The impact of ENSO events on sovereign spreads is not transitory but persistent.

Figure 3a focuses on the *El Niño* shocks. Again, three main conclusions may be drawn.

1. There is a large and significant increase in the spreads – around 15% – during the first 6 months after a strong *El Niño* shock. This increase is then abruptly corrected

downwards between the 6th and 10th month before slowly converging towards its pre-shock level. This result remains true whatever the specification considered (with or without macroeconomic controls).

2. The high volatility of sovereign spreads due to an *El Nino* shock may reflect an overreaction by investors facing a high degree of uncertainty resulting from the economic and financial consequences generated by climatic disorders.
3. Sovereign spreads tend to appreciate significantly in the short term in response to a strong *El Niño* shock. This could hamper the ability of countries to raise sufficient funds on the international financial markets to deal with the immediate economic and financial consequences of this shock.

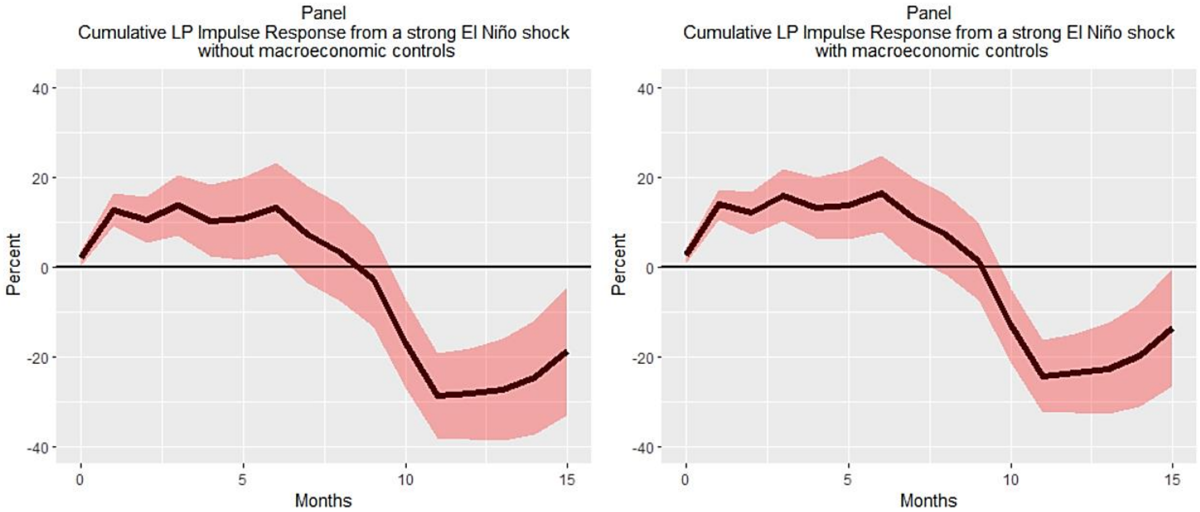
Figure 3b focuses on the *La Niña* shocks. Here again, three main conclusions can be derived.

1. A *La Niña* shock leads to a short-term reduction of around 10% in spreads during the five months following the initial shock, but the significance of this effect is quite weak, especially in the specification with no macro controls. However, this initial reduction is followed by a sharp upward correction in sovereign spreads over the following five months, before converging towards its level preceding the shock. This result is robust to the different specifications considered.
2. We also observe an overreaction phenomenon with a surge in the sovereign spreads after a strong *La Niña* shock. However, in contrast to *El Niño* events, the increase in spreads following a strong *La Niña* shock is delayed. This delay in integrating into sovereign spreads the consequences associated with a strong *La Niña* shock testifies to a certain asymmetry from the standpoint of the consequences of *El Niño* and *La Niña* shocks on sovereign risk. This asymmetry can be explained by the greater uncertainty about the economic and financial consequences of strong *La Niña* shocks.
3. It is crucial to note that unlike *El Niño* events, *La Niña* shocks are likely to have positive climatic consequences. Therefore, it is only once the *La Niña* event is already well under way and its climatic consequences are noticeable, that investors revise their risk expectations upwards. This leads to a delayed upward effect of strong *La Niña* shocks on the sovereign risk of the countries in our sample.

Overall, our results tend to demonstrate the existence of a positive and significant impact of ENSO events on sovereign risk exposure for the panel of seven Latin American countries studied in this paper. However, the effects of *El Niño* and *La Niña* are not symmetric. Since they can have heterogeneous impacts on sovereign risk depending on the different geographical areas in which the ENSO shocks occur and even heterogeneous effects inside the teleconnected countries[14], it is necessary to supplement our previous panel analysis with a country-by-country time series investigation.

Figure 3. Response of sovereign spreads to ENSO shocks: panel data estimates

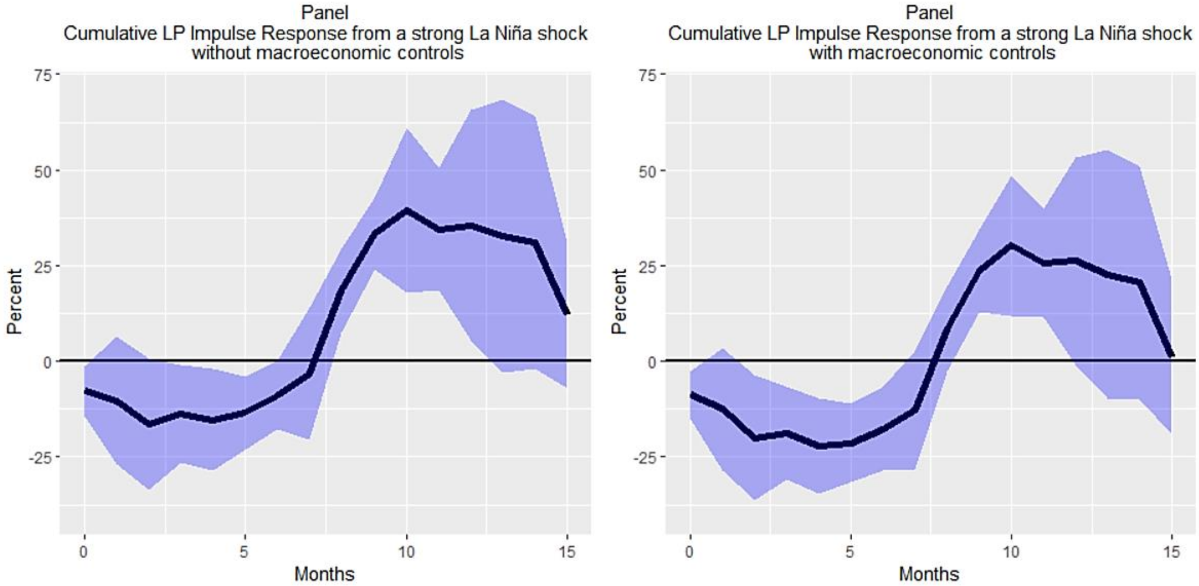
(a) Response of sovereign spreads to a strong El Niño shock (without and with macroeconomic controls)



Note: Impulse Response Functions (IRFs) are calculated using equations (1) and (1') respectively. Shaded areas represent the 90% confidence bands around estimated responses.

[14] For example, Pécastaing & Chávez (2020) show in Peru that rural communities that depend on dry forests are 5% less likely to be poor than those not located in dry forest areas.

(b) Response of sovereign spreads to a strong La Niña shock (without and with macroeconomic controls)



Note: Impulse Response Functions (IRFs) are calculated using equations (1) and (1') respectively. Shaded areas represent the 90% confidence bands around estimated responses.

5.2. Additional time-series estimates

To complement the previous panel data estimates, in this section, based on a time-series country-by-country computation of the IRFs, we investigate the potential heterogeneous effect on sovereign spreads associated with strong *El Niño* and *La Niña* shocks for each of the seven countries in our sample.

As shown in Appendix 5 (Figures A5.1 and A5.2), the IRFs are fairly similar to the previous panel estimates. Strong *El Niños* are associated with a short-term phase of rising spreads followed by a downward correction phase. The duration and magnitude of the upward and then downward phases varies from country to country in terms of duration and magnitude. Strong *La Niñas* are associated with a short-term downward phase in spreads followed by an upward correction phase. Again, the duration and magnitude of the downward and then upward phases varies from country to country in terms of duration and magnitude.

Two groups of countries stand out quite clearly from these time series estimates. First, Costa Rica and Peru, for which the results are relatively similar to those obtained on panel data. Second, Colombia, Mexico, Brazil, Chile and Panama, for which the estimates obtained are much less robust in terms of sign and significance. This difference between these two groups of countries can be explained by the fact that Costa Rica and Peru are the countries in our sample most exposed to *El Niño* and *La Niña* shocks. Conversely, Colombia, Mexico, Brazil, Chile and Panama are historically less exposed to *El Niño* and *La Niña* shocks. In addition, because these countries are larger in area and have a more diversified productive structure, together with better macroeconomic fundamentals, they have a greater capacity of resilience in response to the negative consequences of a strong *El Niño* or *La Niña* shock. Consequently, we focus our analysis on the results associated with Costa Rica and Peru. Although less robust than those obtained in panel, these results provide us with a first indicative view of the dynamics of sovereign risk within two countries highly exposed to *El Niño* and *La Niña* shocks.

From the IRFs associated with Costa Rican and Peruvian sovereign spreads in response to a strong *El Niño* (Figure 4a) and a strong *La Niña* (Figure 4b) certain conclusions may be drawn.

- Regarding Figure 4a, in line with the results obtained on panel data, we see a short-term increase in the sovereign spreads of these two countries following a strong *El Niño,* followed by a downward correction phase and then a return to their initial levels. We note in the case of Peru that the short-term increase is more severe and more persistent, while the subsequent downward correction is weaker (although estimated with much less precision). This may reflect the fact that for Peru, investors anticipate more marked and more lasting economic and financial consequences from a strong *El Niño* shock.

- Regarding Figure 4b, we also see a pattern of results similar to that observed on panel data, although less robust due to a loss of precision in our estimates. Thus, in these two countries there is a short-term decline in sovereign spreads, followed by an upward correction phase and then a return to their initial levels. The IRF is, however, mostly non-significant, with the exception of the upward phase of Peru for the specification with control variables.

- Overall, our results conform to the panel results, although the number of observations is significantly reduced in a time series context and is not uniform among countries. Despite being less robust, these results seem to be consistent with the three salient facts associated with our panel data results, namely: (i) high volatility in sovereign spreads in response to a strong *El Niño* or *La Niña* shock; (ii) asymmetry of the respective effects of these shocks, reflecting the heterogeneity of their climatic, economic and financial consequences; (iii) the persistence of the impact of these shocks on the dynamics of sovereign spreads in the countries studied.

To illustrate the strong exposure of Costa Rica and Peru to ENSO-related natural disasters and their heterogeneity, Appendix 6 presents a detailed analysis of the relationship between ENSO events, local climatic conditions and natural disasters in these two countries. In brief, the related damage associated with ENSO events in Costa Rica and Peru has been estimated at hundreds of millions of dollars in recent years. Using long-run historical data, Caramanica *et al.* (2020) show that the cost of reconstruction following ENSO events rises with each event. Poor and vulnerable people, especially in the agricultural and informal sectors, are particularly impacted by these events despite heterogeneity, resulting in strong adverse macroeconomic consequences that entail higher public and reconstruction expenditure, as well as negative productivity shocks. Our results suggest that these adverse macroeconomic consequences are likely to translate into higher sovereign risk for these countries.

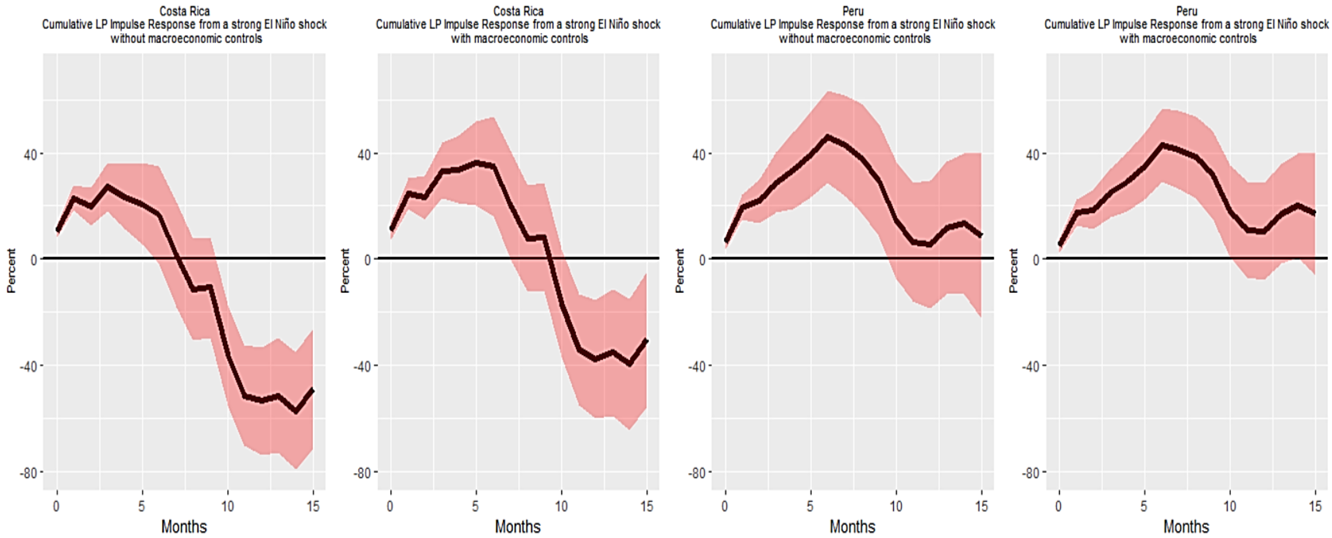
Regarding Costa Rica, on the Pacific coast, *El Niño* is associated with severe droughts and high temperatures. On the Atlantic side, *El Niño* brings above-average rainfall leading to dramatic floods and landslides. In contrast, *La Niña* is associated with an increased frequency of tropical storm events on the Atlantic coast. For example, the Hurricane Tomas and the Tropical Storm Nicole caused severe damages to electrical and road infrastructures, as well as to housing and agricultural production.

In the case of Peru, extreme weather events associated with *La Niña* translate into heavy rains that cause serious flooding and destructive landslides in Amazonia. In contrast, droughts and cold waves during winter periods (April to September) adversely impact agriculture and cattle farming, as well as the energy and industrial sectors. More broadly, as stressed by Pécastaing & Salavarriga (2022), Peru has one of the highest exposure to increasing SST and sea levels induced by *El Niño* events leading to an alteration on marine ecosystems and fishing sectors.

Finally, although these time series estimates enable us to illustrate the heterogeneity of the response of the sovereign spreads of the countries in our sample to ENSO shocks, the constraints in terms of data availability associated with each country mean that panel data estimates seem more relevant to us to capture a more representative and precise overall average dynamic of the sovereign spreads of Latin American countries in response to these shocks. For this reason, Section VI focuses on evaluating the robustness of the results obtained on panel data.

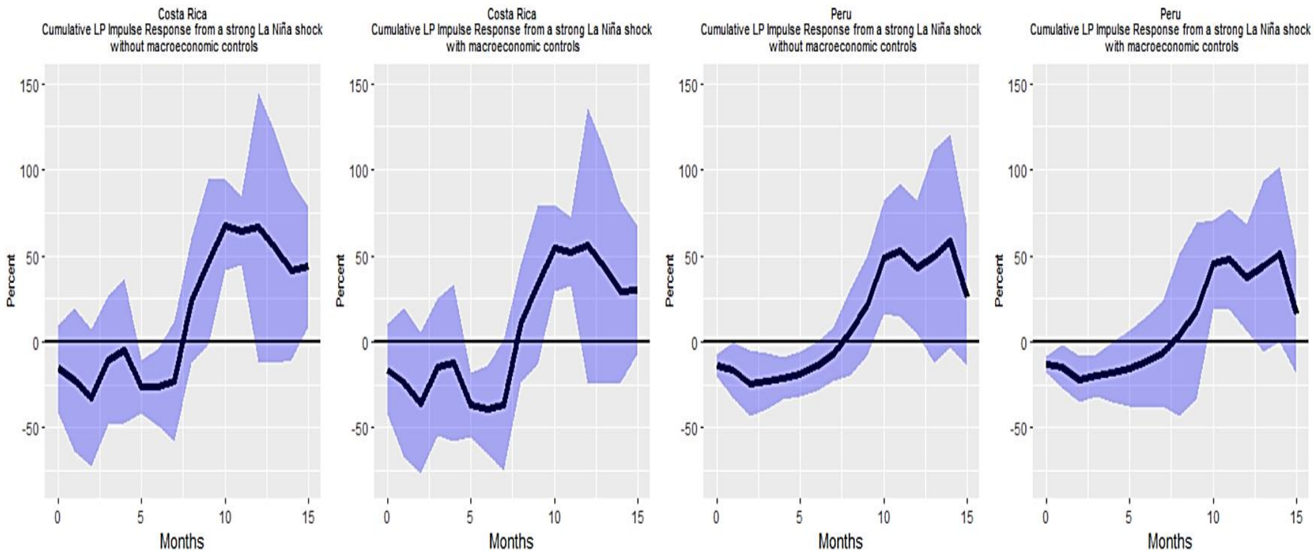
Figure 4. Response of sovereign spreads to ENSO shocks: time-series estimates for Costa Rica and Peru

(a) Response of sovereign spreads to a strong El Niño shock (without and with macroeconomic control variables)



Note: Impulse Response Functions (IRFs) are calculated using equation (3) without macroeconomic control variable (on the left for each country) and equation (3') with macroeconomic control variables (on the right for each country). Shaded areas represent the 90% confidence bands around estimated responses.

(b) Response of sovereign spreads to a strong La Niña shock (without and with macroeconomic control variables)



Note: Impulse Response Functions (IRFs) are calculated using equation (3) without macroeconomic control variable (on the left for each country) and equation (3') with macroeconomic control variables (on the right for each country). Shaded areas represent the 90% confidence bands around estimated responses.

VI. Robustness

In this section, we check the robustness of the previous baseline panel data estimates by taking into account an alternative dependent variable to proxy sovereign risk, an alternative classification of ENSO events, and the inclusion of additional control variables.

6.1. Alternative dependent variable: sovereign bond yield

As an alternative dependent variable, based on the Bloomberg database, we follow e.g. Cevik & Jalles (2020), and use the monthly ten-year sovereign bond yields to proxy sovereign risk for each of the seven Latin American countries in our sample.

Figure 5 shows that the average response to *El Niño* shocks remains qualitatively the same compared to estimates based on sovereign bond spreads, with a significant short-term increase in sovereign bond yields followed by a significant downward correction. Nonetheless, the shape of the response is associated with a more clear-cut short-term increase in sovereign yields following an *El Niño* shock, although lower in terms of magnitude. More importantly, the response of sovereign bond yields to a *La Niña* shock is now positive and significant in the immediate subsequent months. Thus, compared to the sovereign spreads estimates, there is almost no delay in the response of sovereign yields to a *La Niña* shock. Sovereign bond yields significantly increase from the second to the tenth month following a *La Niña* shock, and then, undergo a downward correction similar to the one observed for sovereign spreads. As a result, these estimates suggest that *La Niña* shocks also lead to an almost immediate and persistent surge in sovereign risk, probably because these ENSO events give rise to a huge amount of damage from hurricanes and floods that may have adverse economic consequences, such as productivity losses and reconstruction expenditure that will push up sovereign bond yields.

Unlike spreads, yields are absolute and not relative measures of sovereign risk. Yields therefore tend to more quickly reflect the information associated with the negative domestic economic and financial consequences of a climate shock on sovereign risk. Conversely, being a relative measure of sovereign risk, spreads also reflect the state of financial conditions in international financial markets. This may limit the speed of reaction of sovereign spreads to localized climatic shocks associated with consequences relatively difficult to predict, which is the case for *La Niña* shocks.

Figure 5. Response of sovereign bond yields to strong *El Niño* and *La Niña* shocks (without and with macroeconomic control)

Note: Impulse Response Functions (IRFs) are calculated using equation (1) without macroeconomic control variable (on the left for both *El Niño* and *La Niña* shocks) and equation (1') with macroeconomic control variables (on the right for both *El Niño* and *La Niña* shocks). Shaded areas represent the 90% confidence bands around estimated responses.

6.2. Alternative classification of ENSO events: weak El Niño and La Niña shocks

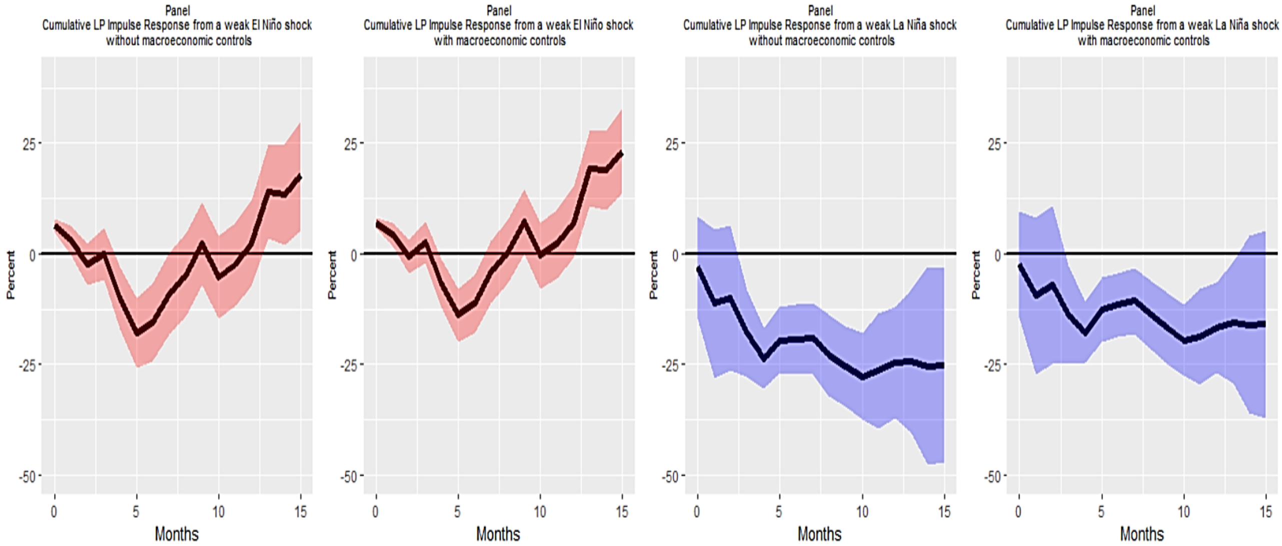
In section IV associated with our baseline estimates, we focused on strong *El Niño* and *La Niña* shocks to assess the effect of significant ENSO events on sovereign spreads. We found that a strong *El Niño* shock leads to a short-term increase in sovereign spreads, while a strong *La Niña* shock is associated with a delayed increase in sovereign spreads, suggesting that strong ENSO events may entail a higher sovereign risk for Latin American countries exposed to these climatic anomalies. For robustness, we assess the response of sovereign spread to weak *El Niño* and *La Niña* shocks.

In line with section III, these weak ENSO events are potentially associated with beneficial climatic consequences. As a result, we would expect these weak *El Niño* and *La Niña* events to reduce sovereign risk or, at least, not to significantly influence it. To test this hypothesis, based on the econometric methodology presented in section III, we estimate equation (1) and (1') for weak *El Niño* and *La Niña* shocks. Thus, the *ENSO event* dummy for *El Niño* shocks equals 1 in month *t* if ONI is at its peak value for a given weak *El Niño* event, and equals 0 otherwise, leading to the identification of two weak *El Niño* shocks over the period studied: December 2014 and November 2018 (see Appendix 1). Similarly, the *ENSOevent* dummy for *La Niña* shocks equals 1 in month *t* if ONI is at its trough value for a given weak La Niña event, and equals 0 otherwise, leading to the identification of three *La Niña* shocks over the period studied: January 2009, October 2016 and December 2017 (see Appendix 1).

Results displayed in Figure 6 are consistent with our expectations since both weak *El Niño* and *La Niña* shocks are associated with a significant decrease in sovereign spreads, with a greater and more persistent effect for weak *La Niña* shocks. Regarding weak *El Niño* shocks, we see a short-term negative response until the fifth month, followed by an upward correction. As for *La Niña* shocks, we see a significant and persistent decrease in sovereign spreads, although less precisely estimated when accounting for macroeconomic control variables. This can be explained by the potential beneficial effects associated with *La Niña* shocks of low magnitude. For instance, weak *La Niña* usually enhances rainfall and then increases crop development in some areas associated with drier-than-normal weather. Bertrand *et al.* (2020) also find that marine landings from the coastal Pacific increase during weak *La Niña* events, which could generate positive gains in the fishing industry. Caramanica *et al.* (2020) suggest that *El Niño* events can replenish groundwater and boost agricultural production in certain arid regions, such as the northern coast of Peru while Vining *et al.* (2022) show that South American vegetation in arid lands (for example in hyperarid coastal desert of Peru) profoundly changes under *El Niño* conditions with enhanced green growth and seedbank development.[15]

[15] In Appendix 7, Table A7.1 show that similar results are obtained when considering moderate *El Nino* and *La Nina* events only, with an even more clear-cut significant downward effect of these ENSO events on sovereign spreads. This confirms that only strong *El Nino* and *La Nina* events are associated with a significant increase in sovereign risk.

Figure 6. Response of sovereign bond spreads to weak *El Niño* and *La Niña* shocks (without and with macroeconomic control)



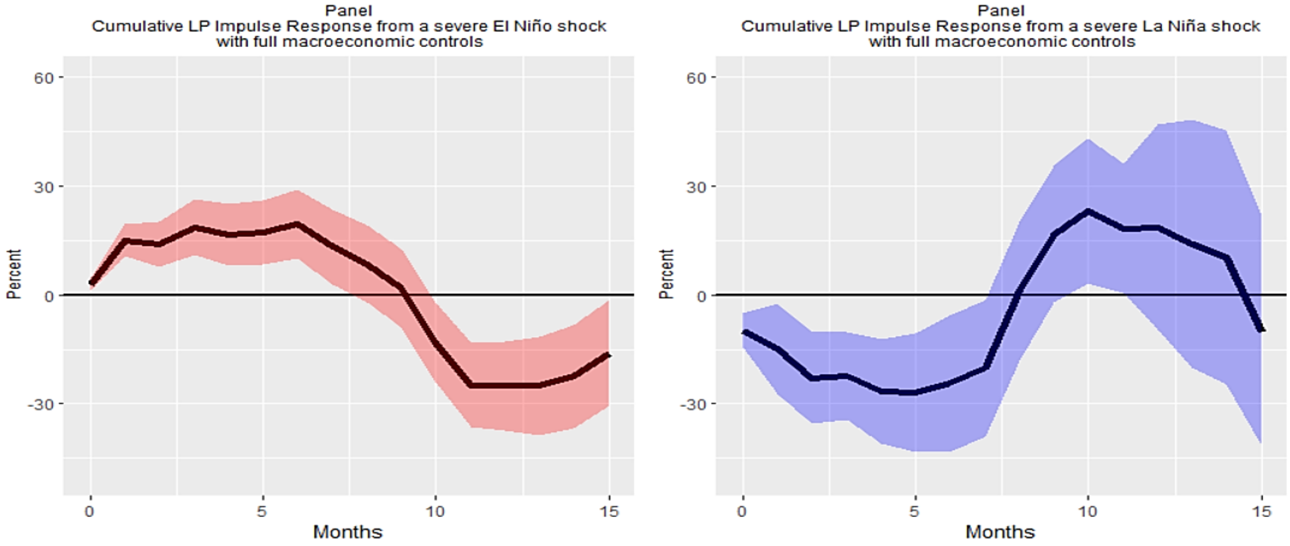
Note: Impulse Response Functions (IRFs) are calculated using equation (1) without macroeconomic control variable (on the left for both *El Niño* and *La Niña* shocks) and equation (1') with macroeconomic control variables (on the right for both *El Niño* and *La Niña* shocks). Shaded areas represent the 90% confidence bands around estimated responses.

6.3. Accounting for additional control variables

6.3.1. Macroeconomic controls

We check the robustness of our baseline panel estimates by accounting in equation (1') for the contemporaneous effect of additional macroeconomic control variables that are considered to be key determinants of sovereign risk in the existing literature (see previously), namely, real GDP, GDP growth, general government debt/GDP, primary fiscal balance/GDP, foreign debt/GDP, and exchange rate growth. Figure 7 shows that when all macroeconomic controls are included in our econometric model, the response of sovereign spreads to both strong *El Niño* and *La Niña* shocks is qualitatively similar to our baseline results.

Figure 7. Response of sovereign bond spreads to strong *El Niño* and *La Niña* shocks: full set of macroeconomic control variables



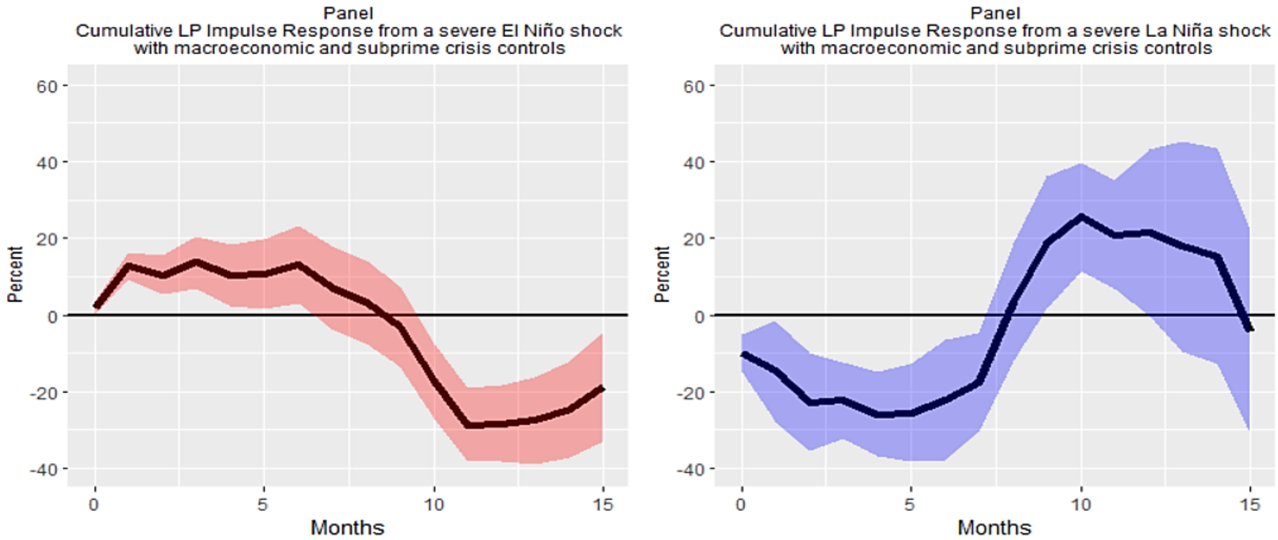
Note: Impulse Response Functions (IRFs) are calculated using equation (1') with the full set of macroeconomic control variables for both strong *El Niño* (left) and *La Niña* (right) shocks. Shaded areas represent the 90% confidence bands around estimated responses.

6.3.2. Financial controls

We further check the robustness of our baseline panel estimates by taking into account two additional important financial control variables.

First, the 2007-2009 *subprime* crisis had a large adverse impact on international financial markets, leading to a significant surge in sovereign bond spreads, especially in developing countries such as those in Latin America (see Figure 3), due to flight to quality from investors who became significantly more risk averse. We can see that during this period of high financial instability, three ENSO events occurred: a strong *La Niña* from July 2007 to June 2008, a weak *La Niña* from November 2008 to March 2009, and a moderate *El Niño* from July 2009 to March 2010 (see Appendix 1). In this case, our assessment of the response of sovereign spreads to ENSO events, at least for the strong 2007-2008 *La Niña* associated with our baseline estimates, may be potentially influenced by the increase in financial instability caused by the 2007-2009 *subprime* crisis. More generally, sovereign bond spreads are wider when uncertainty or risk aversion is higher (Gilchrist *et al.*, 2022). To account for this potential omitted variable bias, we include in equation (1') a dummy variable that is equal to 1 from April 2007 (the starting month of our sample) to December 2009 and 0 otherwise. Figure 8 displays the IRFs associated with equation (1') when accounting for the contemporaneous effect of the *subprime* dummy variable and shows that the average response of sovereign spreads of the seven countries in our sample to both strong *El Niño* and *La Niña* shocks is very similar to our baseline results. This suggests that our estimates are not driven by the influence of the 2007-2009 *subprime* crisis on sovereign spreads.

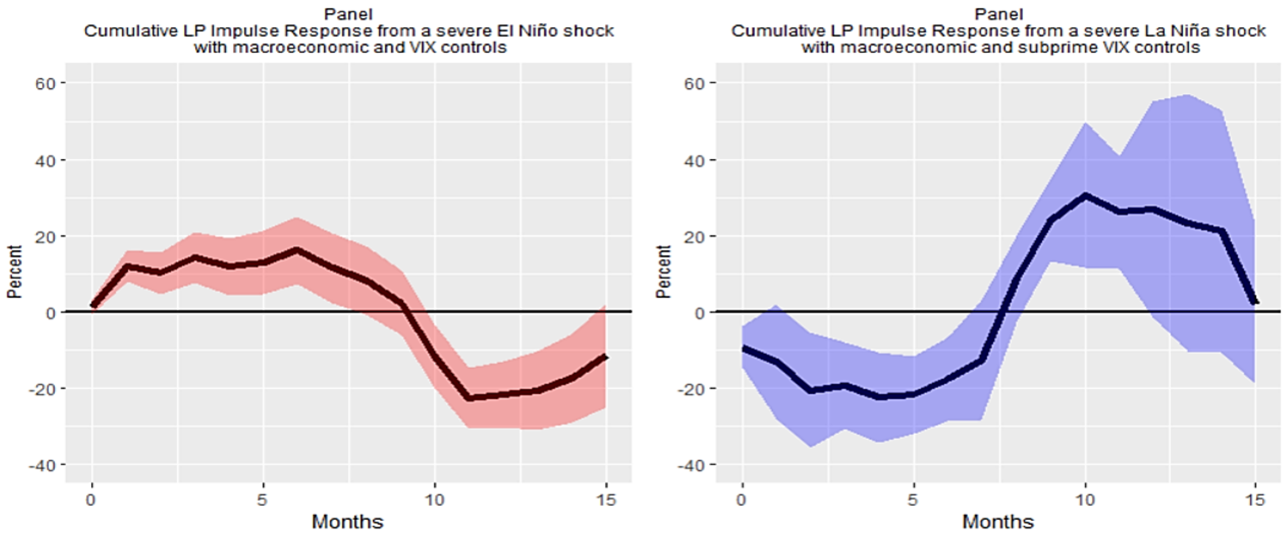
Figure 8. Response of sovereign bond spreads to strong *El Niño* and *La Niña* shocks: accounting for the 2007-2009 *subprime* crisis



Note: Impulse Response Functions (IRFs) for both strong *El Niño* (left) and *La Niña* (right) shocks are calculated using equation (1') including a dummy variable for the 2007-2009 *subprime* crisis (from April 2007 to December 2009). Shaded areas represent the 90% confidence bands around estimated responses.

In addition to the *subprime* crisis, in order to account more broadly for the contemporaneous impact of global financial volatility on the dynamics of the Latin America sovereign spreads, we include in equation (1') the monthly average of the S&P 500 Volatility Index (VIX). Figure 9 displays the IRFs associated with equation (1') when taking into account the VIX and shows that the average response of sovereign spreads to both strong *El Niño* and *La Niña* shocks are again very similar to our baseline results; which indicates that our main results are not driven by the influence of global financial instability on sovereign spreads.

Figure 9. Response of sovereign bond spreads to strong *El Niño* and *La Niña* shocks: accounting for global financial volatility using VIX

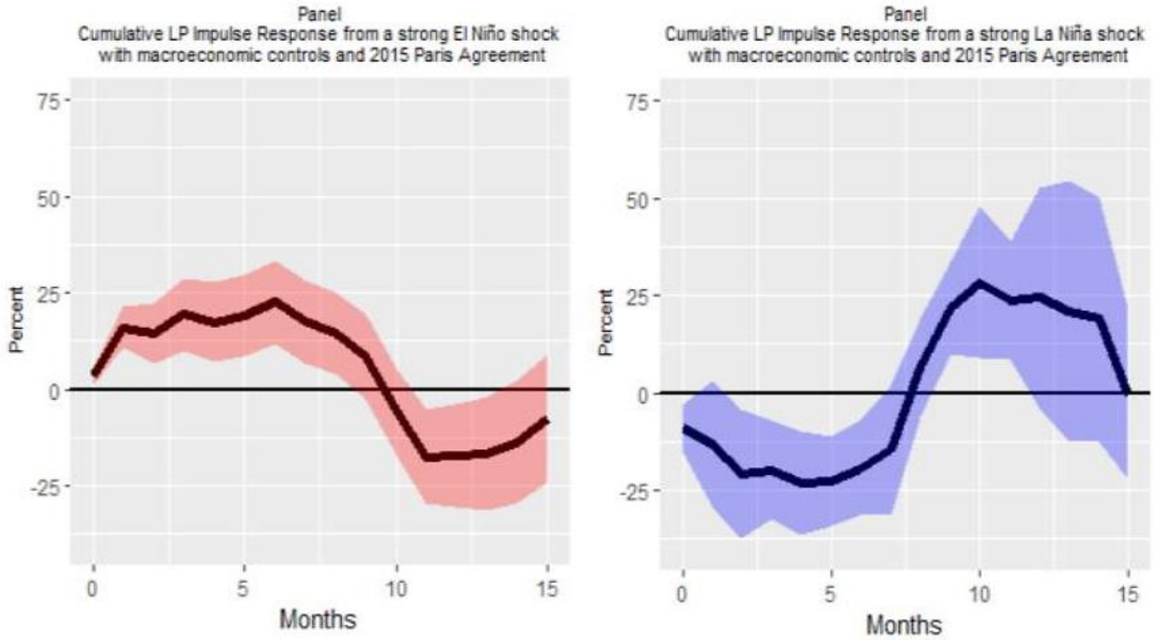


Note: Impulse Response Functions (IRFs) for both strong *El Niño* (left) and *La Niña* (right) shocks are calculated using equation (1') including VIX to proxy for global financial instability. Shaded areas represent the 90% confidence bands around estimated responses.

6.3.3. International institutional change: accounting for the 2015 Paris Agreement

We consider the potential influence that COP21 and the associated Paris Agreement of December 2015 may have on investors' behaviors as this international institutional change induced an increased awareness in the financial community about the financial risks associated with climate change. In this case, there may be increased risk aversion from investors toward countries exposed to strong ENSO events, such as, the seven in our sample, leading to higher sovereign spreads that are not related to strong *El Niño* or *La Niña* shocks *per se*. This, in turn, may lead to incorrect estimates of the impact of these strong ENSO events on the sovereign spreads of the countries in our sample. To control for this potential effect on sovereign spreads of the Paris Agreement, we estimate equation (1') by adding a dummy variable equal to 1 from January 2016 to December 2019 (the ending month of our sample), and 0 otherwise. Figure 10 displays the IRFs associated with equation (1') when accounting for the contemporaneous effect of the Paris Agreement dummy variable and shows that the average response of sovereign spreads to both strong *El Niño* and *La Niña* shocks are very similar to our baseline results. This suggests that our estimates are not driven by the potential influence of the 2015 Paris Agreement on sovereign spreads.

Figure 10. Response of sovereign bond spreads to strong *El Niño* and *La Niña* shocks: accounting for the 2015 Paris Agreement



Note: Impulse Response Functions (IRFs) for both strong *El Nino* (left) and *La Nina* (right) shocks are calculated using equation (1)' including a dummy variable for the 2015 Paris Agreement (from January 2016 to December 2019). Shaded areas represent the 90% confidence bands around estimated responses.

VII. Conclusion

In this paper, using monthly panel data over the period 2007-2019 for seven Latin American countries, we assess, for the first time, the dynamic impact of climate oscillations, proxied through ENSO events, on sovereign risk. In this way, our paper complements the very recent literature on climate finance and more especially on sovereign risk. Local Projections estimates show that climate anomalies associated with strong *El Niño* and *La Niña* shocks lead to a significant increase in sovereign spreads, but with different timing depending on the type of shock considered.

Main results. Our results suggest that strong *El Niño* events are associated with a significant short-term increase in sovereign spreads (up to six months on average), while strong *La Niña* events are associated with a delayed but significant increase in sovereign spreads from the sixth to the tenth month following this climate shock. Thus, these results suggest a potential asymmetry in the effect of these ENSO events on sovereign risk along the lines of the previous literature on the relationship between ENSO and GDP growth. Considering that *La Niña* leads generally to less detrimental effects than *El Niño* and could even have positive effects on agricultural sector, the related *La Niña* shocks and their associated financial consequences are more difficult to anticipate for investors and they need time to become aware of the shock and revise their risk expectations upwards. This could explain why sovereign spreads increase in response to *La Niña* shocks with a delay. Complementary time-series estimates suggest that, among the seven countries in our sample, Costa Rica and Peru are especially subject to the impact of these strong *El Niño* and *La Niña* shocks on sovereign risk. These results are in line with the climate literature showing that these countries are among the most 'teleconnected' and vulnerable to ENSO events. In sum, our results suggest that, in the case of Latin American countries, that are vulnerable both financially and in terms of climate, weather shocks associated with strong ENSO events may have adverse macroeconomic and financial consequences that in turn can lead to an increase in sovereign risk. This could induce vicious circles and limit these countries' ability to combat climate change in the long-run.

Robustness. We show that this positive and significant effect of strong *El Niño* and *La Niña* shocks on sovereign spreads is robust when controlling for a large set of macroeconomic and financial control variables, as well as for the international institutional change in terms of climate change policy following the 2015 Paris Agreement. In addition, estimates using sovereign bond yields as an alternative dependent variable confirm the adverse effect of strong *El Niño* and *La Niña* shocks on sovereign risk, with even more clear-cut and persistent effect for strong *La Niña* shocks compared with baseline estimates. Finally, considering weak *El Niño* and *La Niña* shocks as an alternative coding for ENSO events, we show that only strong *El Niño* and *La Niña* events are associated with a significant increase in sovereign risk. This confirms certain results from the climatology literature about the potentially beneficial effects of weak ENSO events, especially *La Niña* ones, on the macroeconomy.

Limitations. Our paper obviously has certain limitations that are directly related to its value added: by focusing on seven Latin American countries using higher frequency data than the previous literature, we are able to better investigate the dynamics of the effects of climate shocks on sovereign risk for vulnerable countries. However, it is difficult to generalize our results for all types of countries, especially less vulnerable ones (in terms of climate and finance). In addition, time series estimations have been computed on a smaller sample than panel estimates. Although we collected fine country-by-country data, its availability is not homogeneous and the number of missing observations is not uniform. This could have an influence on the message we derived from time series estimates. Another limitation is related to the assumption about ENSO randomness; indeed, ENSO is only quasi-random and it could be objected that *La Niña* events frequently occur after a period of *El Niño* shocks. However, our results are unlikely to be significantly modified, and at worst the positive effects of *El Niño* on sovereign spreads should be less pronounced that those derived here.

Policy implications. Since climate change is likely to affect the most vulnerable countries more strongly, these countries could be trapped in a vicious circle: from climate vulnerability to financial vulnerability and to thus further climate vulnerability. Indeed, the financial fragility induced by the climatic shocks associated with ENSO events would limit the capacity of these countries to use countercyclical policies in the short-run to mitigate the macroeconomic effects of extreme climatic events as well as their ability to adapt in the long run by implementing new investments (buildings, infrastructure, etc.) in response to climate change. Our results thus have important policy implications for Latin American countries and more generally vulnerable countries given the expected increase in the magnitude and frequency of climatic shocks in the future and the observed upward trend in ENSO events and the frequency of extreme events (Cai et al., 2021). In the absence of effective economic policies aimed at increasing the resilience of these countries to climate shocks, the economic and financial consequences induced by ENSO events could lead to an increase in sovereign risk which in turn, through a contagion effect, could spread internationally and lead to a significant increase in financial instability at a broader geographical level. Our results also highlight the importance of better predicting the ENSO oscillations in order to minimize its adverse economic and financial effects.

Future research. Future research should go further in investigating the economic and financial transmission channels likely to explain the impact of strong *El Niño* and *La Niña* events on sovereign risk. For Latin American countries, it would be interesting to study the impact of ENSO on other categories of economic actors, in particular the banking sector, in order to assess the impact of these climatic shocks on both individual and systemic risks encountered by Latin American banks. Finally, it would be of great interest to extend the coverage of our sample by integrating countries from other regions that are also highly ‘teleconnected’, particularly in Southeast Asia and Sub-Saharan Africa.

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Appendix for Climate and sovereign risk: the Latin American experience with ENSO events

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Appendix 1. Classification of ENSO events

Table A1. Classification of ENSO events

Enso	Types	Intensity	Start date	End date	Peak date
La Niña	CP	Strong	07/2007	06/2008	01/2008
La Niña	CP	Weak	11/2008	03/2009	01/2009
El Niño	CP	Moderate	07/2009	03/2010	12/2009
La Niña	CP	Strong	07/2010	03/2011	11/2010
La Niña	CP	Moderate	07/2011	03/2012	11/2011
El Niño	Mix	Weak	11/2014	02/2015	12/2014
El Niño	Mix	Strong	03/2015	04/2016	12/2015
La Niña	CP	Weak	08/2016	12/2016	10/2016
La Niña	EP	Weak	10/2017	04/2018	12/2017
El Niño	CP	Weak	10/2018	06/2019	11/2018

Note: This table presents the different types of *El Niño* and *La Niña* events over the studied period according to their intensity (weak, moderate or strong) and according to whether the maximum warming in the tropical Pacific SST is located in the Eastern Pacific (EP) or the Central Pacific (CP). This classification is consistent with the ENSO literature (Agus Santoso *et al.*, 2017; Cai *et al.*, 2020; Timmermann *et al.*, 2018).

Appendix 2. Latin American disasters associated with strong ENSO events over the period 2007-2019

Table A2.1. Latin American disasters associated with the strong *El Niño* event from 2015-2016

Location	Disaster type	Date	Notable event	Estimated Damage	Additional information
North of America					
Mexico					
Central region	Climatological	Summer of 2015	Drought		The reduced summer rainfall in Mexico's central highlands, attributed to El Niño, resulted in decreased crop yields.
Pacific coast	Meteorological	Oct. 2015	Hurricane Patricia	940	Hurricane Patricia holds the distinction of being the most powerful hurricane ever recorded in the eastern North Pacific basin. It formed on October 20th and rapidly intensified to a Category 5 hurricane on the Saffir-Simpson scale. The estimated number of individuals affected by Hurricane Patricia is approximately 15 000.
Central America					
Pacific Slope of Central America	Hydrological	Oct. 2015	Extreme below average rains	NA	Affected countries: Azuero Peninsula, Panama; Guanacaste, Costa Rica; Pacific slopes of Nicaragua, El Salvador, Honduras, and Guatemala. Approximately 3.5 million individuals impacted, with over 2 million requiring assistance in food, medical, and sanitation.
Panama					
The Pacific slope	Climatological	Sep. 2015	Drought	Millions	The drought associated with El Niño has resulted in crop damage and the loss of 2500 cattle.
The Atlantic slope	Meteorological	2015	Extreme temperature	NA	NA
Costa Rica:					
The Atlantic slope	Hydrological	Oct.-Nov. 2015	Floods	173	The Central Valley, Sarapiqui, and Turrialba cantons, as well as the province of Limon, have experienced floods and landslides triggered by heavy rainfall. These events have resulted in five fatalities and economic losses amounting to USD 173 million.
The Pacific slope	Climatological	2015	Drought	NA	Dry and low-level moisture conditions made worse by El Niño has led to drought.
South of America					
Brazil					
Northeast	Climatological	2015	Drought and heat wave	2	The drought, exacerbated by El Niño, resulted in heightened wildfire activity, crop damage, and a scarcity of potable water resources.
Southeastern and West central	Meteorological	Oct. 2015	Heat wave	NA	A deviation of approximately 4°C–5°C from the normal temperatures has been observed.
Southern	Hydrological	2015	Floods and riverine floods	200	Significant floods were caused by the overflow of the main rivers due to abundant rainfall over Southern Brazil and most of the La Plata basin.
Chile:					
Central region	Meteorological	June-Aug. 2015	Extreme temperature	NA	In Chile, positive anomalies ranging from +1°C to +1.5°C were recorded for maximum temperatures.
	Climatological	June 2015	Drought	NA	Santiago, the capital of Chile, experienced its most arid conditions.
Colombia:					
Country (Global)	Climatological	2015	Drought and Wildfire	608	The estimated total government expenditure amounts to USD 608 million.
Caribbean coast (Cesar)	Meteorological	Sep.-Dec. 2015	Extreme temperature	NA	On the Caribbean coast, maximum temperatures registered positive anomalies of +5°C.
Central and Northern regions	Climatological	Sep. 2015	Drought and Wildfire	170	The severe drought, attributed to El Niño, has resulted in water supply restrictions for consumption, agriculture, and hydro-power generation. The El Niño phenomenon has also contributed to widespread forest fires, which have ravaged approximately 68,000 hectares of forest and impacted 12 out of the country's 32 provinces.
Peru:					
Pacific Coast	Meteorological	Jul.-Nov. 2015	Extreme temperature	NA	El Niño-related elevated temperatures (ranging from +1°C to +4°C) have been systematically observed in the coastal zone, surpassing, in certain cases, the record-high temperatures recorded in 1998. The intensified El Niño event resulted in reduced productivity of coastal ecosystems, impacting fisheries and marine aquaculture. Notable changes were observed in the migration patterns of demersal species (Bacheler et al., 2019) and fishing practices (Radway, Manley, and Mangubhai, 2016).

Note: compiled by authors with data from IMF's "State of the climate" reports from 2007 to 2019, OECD and the World Bank reports, Aon Benfield's "Annual Global Climate and Catastrophe" reports from 2010 to 2017, EM-DAT database and national government reports. Natural Disasters classification follows the EM-DATA guidelines. The EM-DAT was created by the Center for Research on the Epidemiology of Disasters (CRED). Total affected corresponds to the sum of injured, affected and homeless.

Table A2.2. Latin American disasters associated with the strong *La Niña* events from 2007-2008 and 2010-2011

Location	Disaster type	Date	Notable event	Estimated Damage	Additional information
North of America					
Mexico					
Southern	Hydrological	2010	Flood and landslide	250	The intensified rainfall due to La Niña resulted in numerous floods and landslides across multiple states in Mexico. For instance, significant damage occurred, with at least 150,000 homes being destroyed or damaged in the states of Tabasco, Veracruz, Chiapas, and Oaxaca, resulting in over 600,000 people being displaced from their homes.
	Meteorological	Aug.-Sep. 2007	Hurricane Karl, Dean and Henriette	3 900	The impact of Hurricane Karl (Category 3) was observed in 114 cities in the state of Veracruz, with strong winds and heavy rainfall. Similar events include Hurricanes Dean (13–23 August 2007) and Lorenzo (25–28 September 2007), which formed in the Atlantic Ocean, and Hurricane Henriette (30 August–6 September 2007), which formed in the Pacific Ocean.
Central America:					
Costa Rica					
The Atlantic slope	Meteorological	Sep. 2010	Tropical Storm Nicole	13	Tropical Storm Nicole has resulted in significant damage to electric and transportation infrastructures, housing, and agriculture.
The Atlantic slope	Meteorological	Nov. 2010	Hurricane Tomas	330	Hurricane Tomas impacted Costa Rica, bringing about strong winds and heavy rainfall, which led to numerous landslides, power outages, road closures, and unfortunately resulted in 28 fatalities.
South of America					
Brazil					
Northeast	Hydrological	June 2010	Flood and mudslides	860	The heavy rains, intensified by the influence of La Niña, have led to widespread flooding and mudslides. These events have resulted in the destruction and damage of at least 115,000 homes and a loss of 72 lives.
Amazon	Climatological	2010	Drought	NA	The onset of the drought occurred during the El Niño event in 2009 and subsequently intensified during La Niña. In the Amazon region, these prolonged dry spells have had adverse effects on water availability, transportation infrastructure, and fishing activities, primarily caused by exceptionally low river levels.
Southeastern and West central	Hydrological	Apr. 2010	Flood and mudslides	14 200	A total of 25 000 local homes have been destroyed, and 256 people have been killed or injured as a result of floods and mudslides associated with La Niña.
Southern	Meteorological	Apr.-Sep. 2010	Cold wave and drought	NA	The combination of reduced precipitation and lower temperatures, exacerbated by the presence of La Niña, has resulted in drought conditions and significant damage to agricultural and livestock sectors. These circumstances have further aggravated water scarcity issues for summer crops such as soybean, maize, and rice, as well as pastureland.
Chile:					
Andes	Meteorological	July and Aug. 2010	Cold wave	NA	The severe drought associated with La Niña has resulted in the death of thousands of livestock. The Chilean government has declared an agricultural emergency in response.
	Climatological	Second half of 2010	Drought	NA	The sectors most affected include agriculture, livestock, timber industries, energy, and industrial sectors.
Southern region	Meteorological	July 2010	White earthquake	NA	On July 10th, an unprecedented drop in temperatures and a significant white earthquake prompted the Chilean government to declare an agricultural emergency. The accumulation of over one meter of snow resulted in severe damage to crops and livestock. This weather event, known as a "white earthquake," had not been witnessed since 1995 prior to 2010.
Colombia:					
Country (Global)	Hydrological	2010/2011	Floods and landslides	6300	The floods triggered by the La Niña event of 2010/2011 resulted in an approximate cumulative damage cost of USD 6.3 billion. The total government expenditure, encompassing both immediate response and recovery efforts, was estimated at USD 1.5 billion.
Central region	Hydrological	Nov.-Dec. 2010	Flood	+ 300	The flash floods and landslides associated with La Niña have submerged 250,000 homes and a significant portion of Columbia's agricultural regions. The event resulted in a minimum of 176 fatalities and left 225 individuals injured.
Northwest	Hydrological	Sep. 2010	Floods and landslides	+ 400	The landslides and floods, exacerbated by La Niña, have resulted in extensive damage. According to government authorities, over 552 municipalities in 28 out of the country's 32 departments have been affected, and more than 201 700 homes have been destroyed.
Peru:					
Country (Global)	Climatological	July-Sep. 2010	Drought	NA	Precipitation levels experienced a notable decline, with observed deficits reaching up to 100%.
Low-lying Amazon rainforest	Hydrological	Nov. 2010	Flood	230	The torrential rains associated with La Niña resulted in substantial landslides, resulting in the loss of life of a minimum of two individuals and causing injuries to 100 others.
Peruvian Altiplano	Meteorological	July 2010	Cold wave	NA	The Peruvian Altiplano, densely populated by impoverished farmers, experienced record-low temperatures of -20 degrees. Government reports indicate that at least 409 individuals lost their lives as a result of hypothermia, pneumonia, and carbon monoxide poisoning.

Note: compiled by authors with data from IMF's "State of the climate" reports from 2007 to 2019, OECD and the World Bank reports, Aon Benfield's "Annual Global Climate and Catastrophe" reports from 2010 to 2017, EM-DAT database and national government reports. Natural Disasters classification follows the EM-DATA guidelines. The EM-DAT was created by the Center for Research on the Epidemiology of Disasters (CRED). Total affected corresponds to the sum of injured, affected and homeless.

Appendix 3. Data description, sources and descriptive statistics

Table A3.1. Data description and sources

Variable	Description	Sources
Sovereign risks:		
Ten-year sovereign bond spreads	Monthly spread between the ten-year yield sovereign bond and 10-year US Treasury yield (Nominal, local currency)	Bloomberg database
Ten-year sovereign bond yields	Monthly ten-year sovereign bond yields (Nominal, local currency)	Bloomberg database
Climate indices:		
ONI	Monthly Oceanic Niño Index (ONI)	National Oceanic and Atmospheric Administration (NOAA) Database
Post Paris	Dummy that is 1 after Paris Agreement (December 2015)	By authors
Macroeconomic controls:		
Log.Real GDP	Quarterly natural logarithm of GDP in constant 2010-local-currency prices	Latin Macro Watch Database
Growth Real GDP	Quarterly natural logarithm change of GDP in constant 2010-local-currency prices	Latin Macro Watch Database
Inflation	Quarterly first difference in natural logarithm of consumer price index	World Bank Database
General government debt (% GDP)	Quarterly general government (GG) debt (% of gross domestic product)	Latin Macro Watch via Macrobond and IMF Debt Investor Database
Foreign general government debt (% GDP)	Quarterly foreign general government (GG) debt (% of gross domestic product)	Latin Macro Watch Database and IMF Debt Investor Database
Primary fiscal balance (% GDP)	Quarterly Primary Fiscal Balance (PFB) (% of gross domestic product)	Latin Macro Watch Database
Δ Current account Balance (% GDP)	Quarterly first difference of Current Account Balance (% of gross domestic product)	Latin Macro Watch Database
Growth Terms of Trade	Quarterly first difference in natural logarithm of Terms of Trade	Latin Macro Watch Database
Δ Exchange rate	Monthly first difference of Nominal exchange rate, Local Currency per USD, Monthly Average	Latin Macro Watch Database
Financial controls:		
VIX	Monthly $S\&P$ 500 Volatility Index (VIX), Monthly Average	Chicago Board Options Exchange (CBOE)
Crisis	Dummy that is 1 during Subprime crisis (between April 2007 and December 2009)	By authors

Table A3.2. Descriptive statistics: sovereign bond spreads and yields

Panel A: Ten-year sovereign bond spreads (in percent)

	Brazil	Chile	Colombia	Costa Rica	Mexico	Panama	Peru	Panel
N	153	153	153	153	153	153	153	1071
Mean	9.08	2.57	5.37	3.00	4.30	2.21	3.49	4.29
Median	9.20	2.53	5.26	2.86	4.29	2.10	3.50	3.68
Std. dev.	1.81	0.80	1.37	0.94	0.82	0.84	1.13	2.48
Skewness	0.56	-0.06	0.65	0.62	0.70	1.71	0.17	1.32
Kurtosis	4.10	2.83	4.47	3.49	3.86	8.43	2.83	4.54
Min	5.03	0.49	2.28	0.90	2.59	0.40	0.90	0.40
Max	14.50	4.32	10.47	6.26	6.67	5.70	6.17	14.50

Panel B: Ten-year sovereign bond yields (in percent)

	Brazil	Chile	Colombia	Costa Rica	Mexico	Panama	Peru	Panel
N	153	153	153	153	153	153	153	1071
Mean	11.79	5.27	8.07	5.70	7.00	4.92	6.19	6.99
Median	11.95	5.29	7.55	5.46	6.98	4.60	6.13	6.32
Std. dev.	1.85	0.83	1.59	0.92	0.96	1.13	0.86	2.51
Skewness	0.13	0.45	0.76	0.92	0.09	1.15	0.25	1.29
Kurtosis	3.76	2.40	3.12	3.72	2.08	4.71	3.85	4.29
Min	6.84	4.16	5.07	4.31	4.94	2.89	4.13	2.89
Max	17.53	7.92	12.99	9.13	9.12	9.14	9.10	17.53

Table A3.3. Descriptive statistics: macroeconomic and financial controls

Variables	Panel A: Full sample							
	N	Mean	Median	Std. dev.	Skewness	Kurtosis	Min	Max
Log.Real GDP	1071	24.78	24.82	1.46	0.04	1.83	22.35	27.08
Growth Real GDP	1071	0.85	0.87	1.40	0.001	6.91	-5.24	7.59
Inflation	1071	0.32	0.27	0.28	0.69	6.23	-0.71	1.59
Δ Current account balance (% GDP)	1071	-0.046	0.054	0.86	0.83	13.94	-4.87	5.99
Growth Terms of Trade (% GDP)	1071	0.04	-0.08	2.48	-0.81	22.51	-16.94	16.59
General government debt (% GDP)	1071	37.31	35.99	16.73	0.75	3.64	7.13	87.60
Foreign general government debt (% GDP)	1071	15.01	11.15	8.73	1.16	3.39	3.82	43.41
Primary fiscal balance (% GDP)	1071	0.44	0.04	2.41	0.65	3.60	-6.86	8.88
Δ Exchange rate	1071	1.38	0	31.10	2.74	33.62	-212.24	291.39
VIX	1071	19.38	16.86	8.79	2.41	10.33	10.13	62.25
	Panel B: by country (only means are reported)							
	Brazil	Chile	Colombia	Costa Rica	Mexico	Panama	Peru	
Log.Real GDP	26.99	24.78	25.09	23.02	26.37	22.78	24.44	
Growth Real GDP	0.42	0.65	0.87	0.88	0.44	1.62	1.07	
Inflation	0.46	0.28	0.33	0.35	0.35	0.22	0.22	
Δ Current account balance (% GDP)	-.072	-0.19	-0.037	0.05	0.01	0.01	0.01	
Growth Terms of Trade	0.04	0.24	0.23	0.10	-0.10	-0.16	-0.16	
General government debt (% GDP)	68.08	16.58	38.75	37.10	37.18	40.14	23.31	
Foreign general government debt (% GDP)	8.35	20.76	12.36	7.88	11.79	32.09	11.81	
Primary fiscal balance (% GDP)	0.76	0.44	1.36	-1.59	0.14	0.63	1.32	
Δ Exchange rate	0.01	1.15	8.08	0.32	0.05	0	0.01	

Appendix 4. ACF and PACF analysis

We analyse the dynamics and persistence of sovereign bond spreads using the autocorrelation and partial autocorrelation functions graphs (ACF and PACF, respectively). Figures A4.1 and A4.2 present the ACF and PACF from lag 0 to 24 for sovereign bond spreads in both level and difference. The red dotted lines represent the two standard error bounds computed as ±1.96/ T.

ACF graphs show a slow decline, whereas the PACF shows one, two, or, at maximum, three significant picks for Colombia, Costa Rica, Mexico, Panama, and Peru. Thus, a second-order autoregressive model seems appropriate to modelize the dynamics of the spreads. Indeed, the correlogram of sovereign bond spreads (in difference) shows that both ACF and PACF are equal to zero after two lags.

Figure A4.1. Correlogram of the sovereign bond spreads

(a) ACF **(b) PACF**

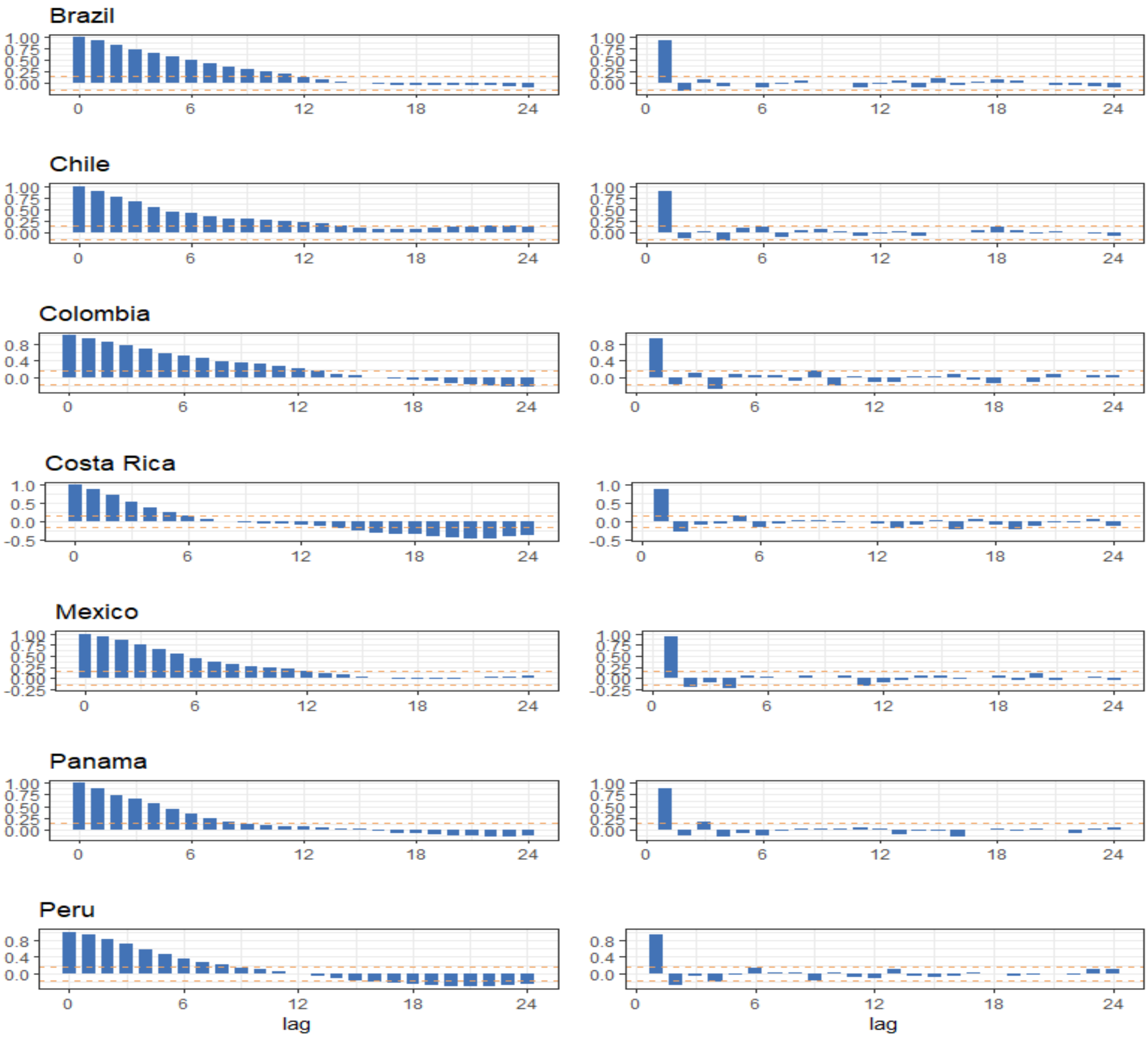
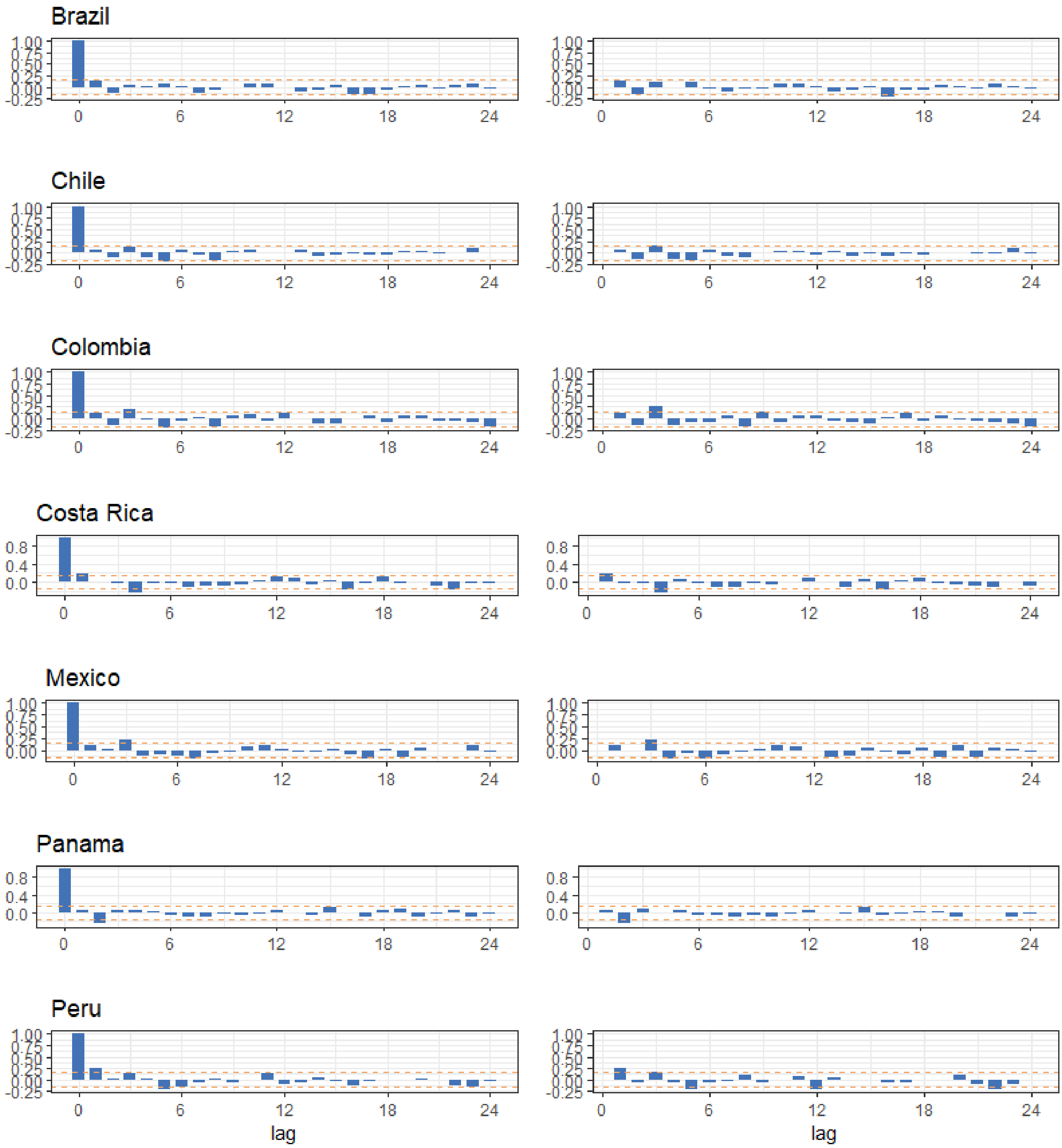


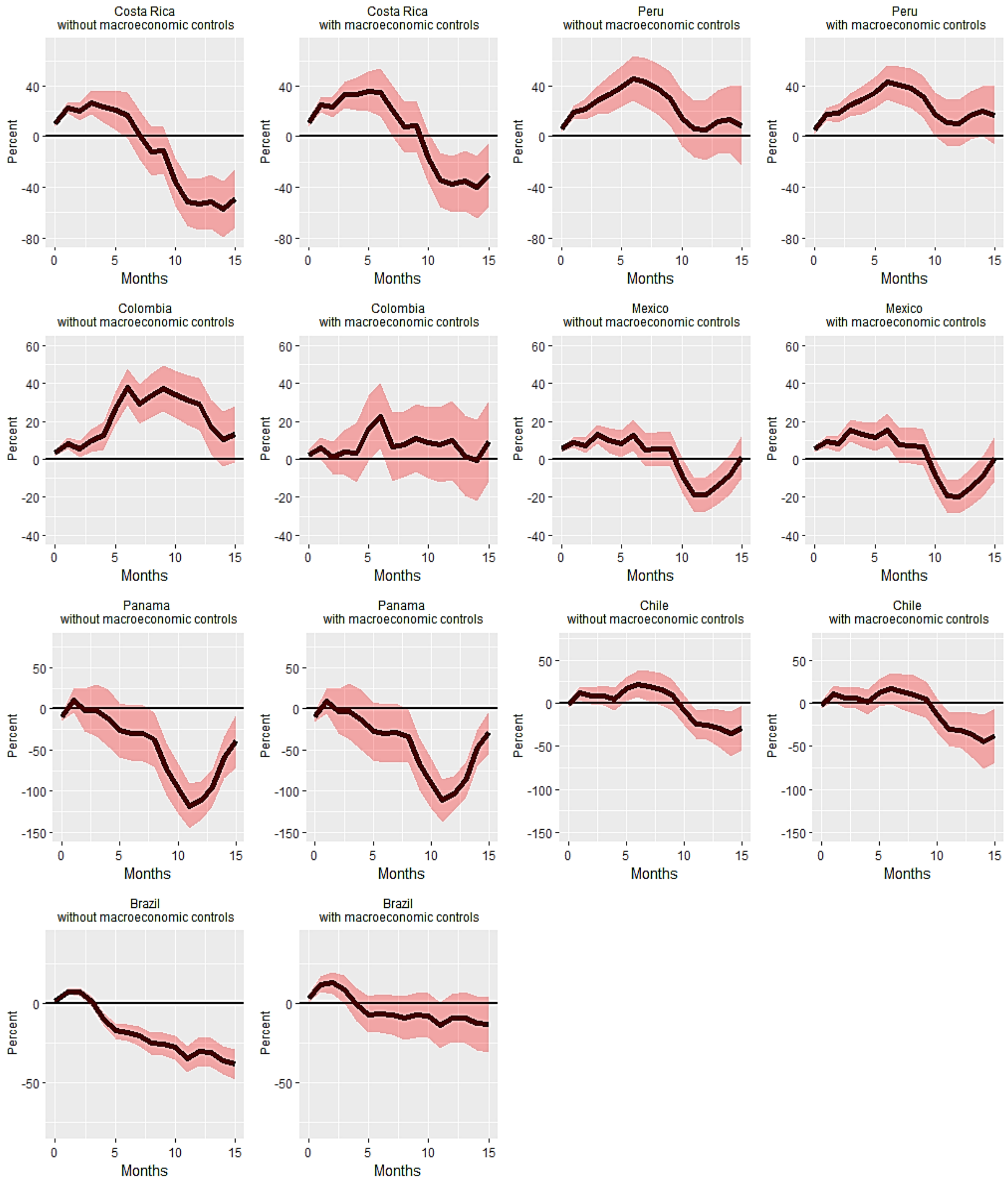
Figure A4.2. Correlogram of the sovereign bond spreads (in difference)

(a) ACF **(b) PACF**



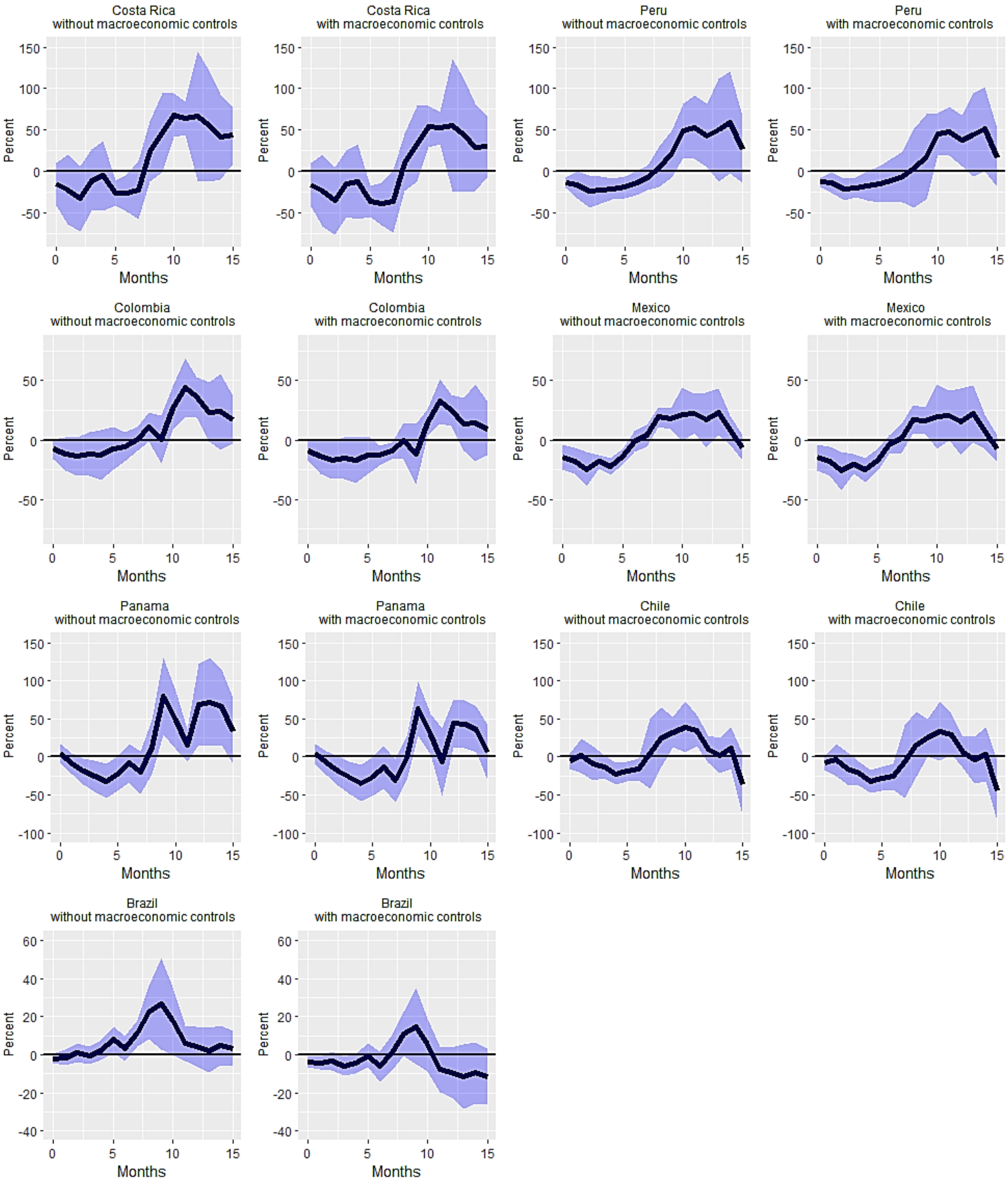
Appendix 5. Country-specific responses to ENSO shocks

Figure A5.1. Country-specific responses to *El Niño* shocks



Note: Impulse Response Functions (IRFs) are calculated using equation (3) without macroeconomic control variable (on the left for each country) and equation (3') with macroeconomic control variables (on the right for each country). Shaded areas represent the 90% confidence bands around estimated responses.

Figure A5.2. Country-specific responses to *La Niña* shocks



Note: Impulse Response Functions (IRFs) are calculated using equation (3) without macroeconomic control variable (on the left for each country) and equation (3') with macroeconomic control variables (on the right for each country). Shaded areas represent the 90% confidence bands around estimated responses.

Appendix 6. Relationships between ENSO, key natural hazards and local climatic conditions in Costa Rica and Peru

This section presents a summary of the interaction between the main extreme climate risks related to the phases of ENSO and the economic vulnerability of Costa Rica and Peru associated with the agricultural sector.

Figure A6.1. Temperature anomalies and droughts during ENSO phases for Costa Rica and Peru

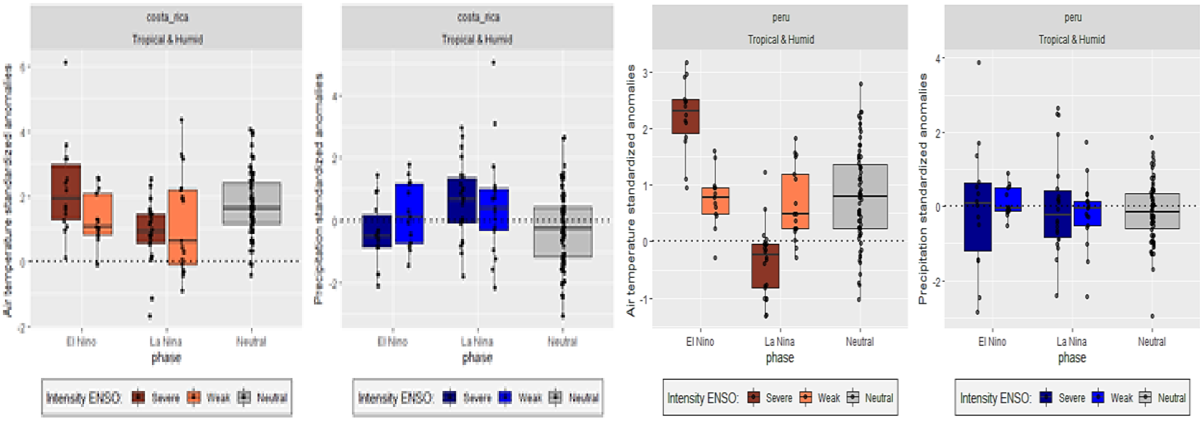
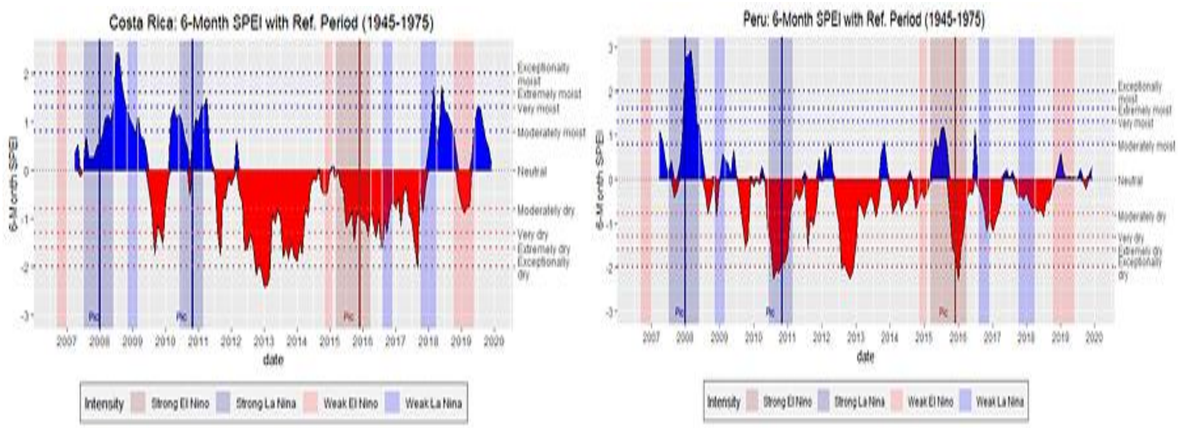


Figure A6.2. Temporal variability of the standardized precipitation evapotranspiration index (SPEI-6) for Costa Rica and Peru



Figures A6.1 and A6.2 present a brief summary of the local weather variability during severe, weak and neutral *El Niño* and *La Niña* events over the period 2007-2019. Figure A6.1 represents the distribution of monthly standardized temperature and precipitation anomalies. Figure A6.2 represents the SPEI-6 index. During an extreme *El Niño* event, Costa Rica and Peru are exposed to a period of extreme drought expressed by the SPEI-6 index (Figure A6.2). This drought is explained by a decrease in the frequency of precipitation anomalies and an increase in temperature anomalies (Figure A6.1). Conversely, an extreme *La Niña* event is characterized by periods of high humidity. In addition, we observe that low-intensity *El Niño* and *La Niña* events do not show strong significant variability on the local climatic conditions.

Figure A6.3. Key natural hazards for Costa Rica and Peru from Climate Change Knowledge Portal (World Bank)

(a) (b) (c) (d)

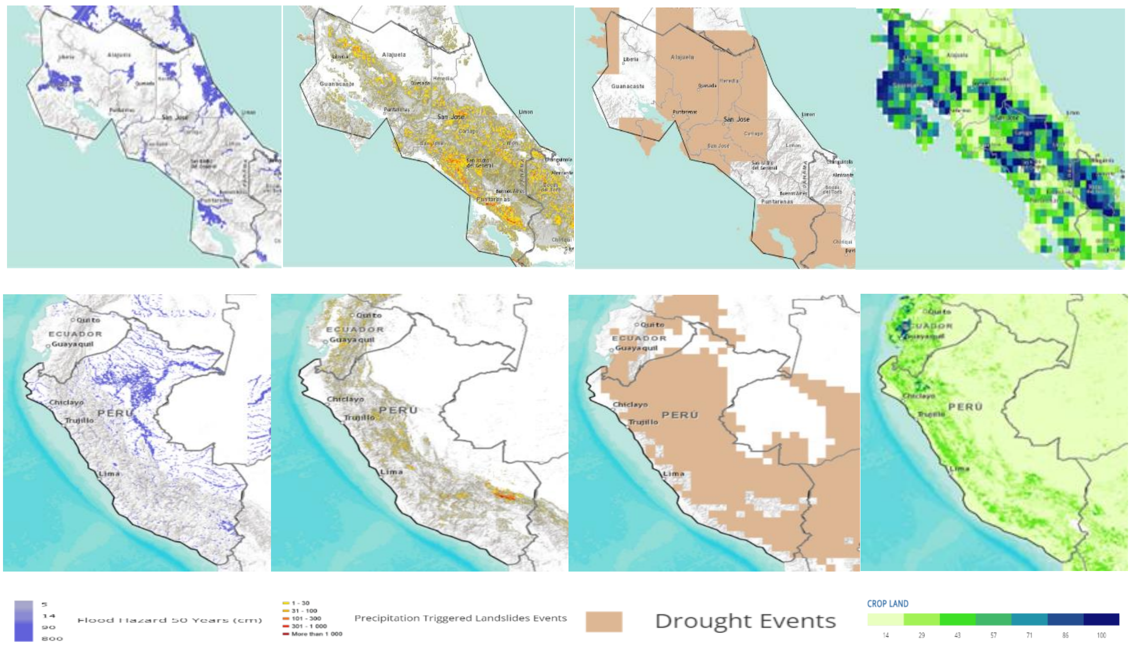
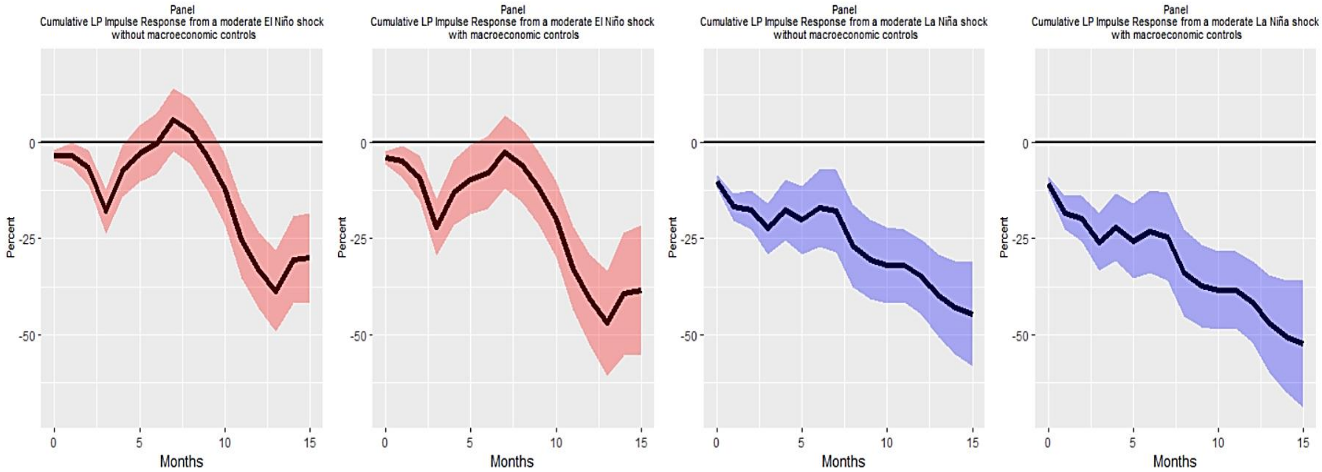


Figure A6.3 summarizes the geographical exposure of Costa Rica and Peru respectively to the main natural hazards over the past 50 years. Graph (a) shows the intensity (in centimeters) and the geographical location of the main floods. Graph (b) is the number of landslides triggered by heavy rainfall. Graph (c) corresponds to an annual estimate of the distribution of droughts. Graph (d) is an estimate of the actual cultivated area.

The interaction of this set of graphs clearly shows that the main cultivated areas are highly exposed to the effects of the opposing conditions of flooding (during *La Niña*) and drought (during *El Niño*), which directly affect crop yields, with indirect consequences on economic growth. As a result, the impact of *La Niña* and *El Niño* varies depending on the geographical location of the countries.

Appendix 7. Accounting for moderate *El Niño* and *La Niña* shocks

Figure A7. Response of sovereign bond spreads to moderate *El Niño* and *La Niña* shocks (with and without macroeconomic controls)



Note: Impulse Response Functions (IRFs) are calculed using equation (1) without macroeconomic control variable (on the left for both *El Niño* and *La Niña* shocks) and equation (1') with macroeconomic control variables (on the right for both *El Niño* and *La Niña* shocks). Shaded areas represent the 90% confidence bands around estimated responses.