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Article

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Latin American Journal of Central Banking (LAJCB)

Provided in Cooperation with:

Center for Latin American Monetary Studies, Mexico City

Suggested Citation: Romero, José Vicente; Naranjo-Saldrriaga, Sara (2024) : Weather shocks and inflation expectations in semi-structural models, Latin American Journal of Central Banking (LAJCB), ISSN 2666-1438, Elsevier, Amsterdam, Vol. 5, Iss. 2, pp. 1-23, <https://doi.org/10.1016/j.latcb.2023.100112>

This Version is available at:

<https://hdl.handle.net/10419/336399>

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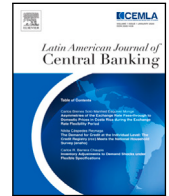
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Weather shocks and inflation expectations in semi-structural models[☆]

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ARTICLE INFO

JEL classification:

D84
E31
E52
Q54

Keywords:

Inflation
Inflation expectations
Inflation expectations anchoring
Weather shocks

ABSTRACT

Colombia is particularly affected by the El Niño Southern Oscillation (ENSO) weather fluctuations. In this context, this study explores how adverse weather events linked to ENSO affect inflation expectations in Colombia and how to incorporate these second-round effects into a small open economy New Keynesian model. Using BVARx models, we find evidence that inflation expectations – obtained from surveys and break-even inflation measures – are influenced by weather-related supply shocks. Building on this stylized fact, we modify one of the core forecasting models of the Banco de la República to incorporate the mechanisms through which weather-related shocks could affect marginal costs and inflation expectations. We conclude that ENSO shocks play a significant role in influencing both inflation and the dynamics of inflation expectations, a fact that should be considered by policymakers.

1. Introduction

Inflation expectations and the central bank's ability to anchor them to the inflation target play a central role in monetary policy (Łyziak and Paloviita, 2017). Furthermore, the central bank's ability to affect inflation expectations is a direct measure of central bank credibility and has a central role in price and wage formation (Bernanke, 2007; Belke et al., 2018). Nonetheless, extreme supply-related shocks that increase inflation could make this task harder. These weather-related shocks can have a wider impact on price setting, beyond its direct effect on food prices and the cost of utilities. In addition, the El Niño Southern Oscillation (ENSO) fluctuations can also affect the inflation expectations that are anchored to the inflation target if the shocks are significantly pronounced and persistent.

Although there are many studies that have tackled the assessment of anchoring the inflation expectations, the impact of weather shocks on inflation expectations has not been studied in Colombia. This study provides the first approach to analyze how weather shocks, particularly those related with the ENSO fluctuations, can affect inflation expectations and how to incorporate this fact into a small open economy New Keynesian model.

[☆] We would like to thank Hernando Vargas, Luis Fernando Melo and Jair Ojeda and participants at Banco de la República Research Seminar, 25th Central Bank Macroeconomic Modeling Workshop, 2023 CEBRA Annual Meeting, and 2023 Latin American Journal of Central Banking Conference, and the anonymous referees for their helpful comments. We also want to thank Professor Emanuele Campiglio and the Graduate Institute Geneva (BCC Program) for its support and guidance to this project.

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<https://doi.org/10.1016/j.latchb.2023.100112>

Received 5 July 2023; Received in revised form 5 September 2023; Accepted 20 September 2023

Available online 13 October 2023

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In this context, this study involves three different areas of research. The first area covers the empirical literature regarding the inflation expectations that are anchored to the inflation target. In this literature, the anchoring of inflation expectations has been tested by assessing the persistence of headline inflation (Davis et al., 2013), estimating the pass-through of either inflation or short-term inflation expectations to long-term inflation expectations (Gefang et al., 2012; Strohsal et al., 2016; Łyziak and Paloviita, 2017), measuring the variability and dispersion of inflation expectations (Bems et al., 2018), evaluating the deviations of long-term inflation expectations from the inflation target (Demertzis et al., 2008, 2010), and calculating the implicit inflation anchor (Demertzis et al., 2008; Mehrotra and Yetman, 2018). We contribute to this literature by showing that adverse weather may have statistically significant effects on inflation expectations and may affect the inflation expectations that are anchored to the inflation target.

The second area corresponds to the studies that have tackled the question of how weather shocks affect inflation in Colombia. Among the most relevant studies in this area, Abril-Salcedo et al. (2016) find that a strong El Niño shock has an important effect on the food inflation growth from six to nine months after the shock. In addition, they find evidence of a non-linear relationship between food inflation and ENSO shocks. Other important studies that have argued the significance between weather shocks and food inflation in Colombia include Caicedo (2007), Cano (2014) and Melo et al. (2017). In this area, we contribute by introducing simple mechanisms that allow for a better understanding of how inflation is affected directly and by second-round effects arising from adverse weather shocks.

The third area of focus involves small open economy New-Keynesian models, commonly known as semi-structural models. These models are frequently employed in central bank policy-making and forecasting exercises (Central-Banking, 2020). While not entirely micro-founded, these models offer several advantages. One of their primary strengths is the ability to balance theoretical rigor with empirical relevance, providing a good fit to economic data (Bańkowski, 2023). Additionally, these models are highly adaptable and can be easily modified to incorporate new features or address specific issues. Despite their flexibility and utility, a significant limitation of semi-structural models is that they are not fully micro-founded.

The origins of these models can be traced back to the Quarterly Projection Model (QPM), employed by various central banks for their forecasting and policy analysis tasks. The QPM is grounded in the principles of New-Keynesian open economy models and includes equations for output (the IS curve), inflation (the Phillips curve), the short-term interest rate (a policy reaction function), and the exchange rate (based on the uncovered interest rate parity condition). Extensive literature exists on the use and implementation of these models in several emerging market economies; for example, see Berg et al. (2006), Benes et al. (2017), and Gonzalez et al. (2020) among others. Some of these models have also incorporated simple adjustments to the food inflation Phillips curves to account for factors such as rainfall (Berg et al., 2006; Uribe et al., 2002; Benes et al., 2017). In this context, our work contributes to the existing literature by providing a theoretical framework that evaluates the extent to which central banks should react to such shocks to anchor inflation expectations.

The paper is structured as follows. Section 2 provides an overview of the relevance of weather shocks and ENSO in Colombia. In Section 3, we outline key observations related to inflation expectations and ENSO in the Colombian context. Section 4 employs BVARx models to establish that inflation expectations are indeed sensitive to weather shocks, controlling for other variables. Section 5 modifies a small open economy New Keynesian model to incorporate weather shocks and a central bank credibility mechanism. We use the 4GM model proposed by Gonzalez et al. (2020) as it aligns closely with Colombian data. Section 6 discusses the model dynamics and provides a historical decomposition of data during the severe 2015–2016 El Niño episode. Finally, Section 7 offers concluding remarks and suggests avenues for future research on the impact of weather shocks on inflation and inflation expectations.

2. The significance of weather shocks related to the ENSO in Colombia

The ENSO is a recurring climate pattern involving changes in the temperature of waters in the central and eastern tropical Pacific Ocean. The oscillations in the warming and cooling pattern directly affect the rainfall distribution in the tropics and can have a strong influence on weather. In fact, the ENSO is the Earth's strongest source of year-to-year climate variability (Santoso et al., 2017). This natural weather fluctuation oscillates between extreme events named El Niño and La Niña (Abril-Salcedo et al., 2016). The ENSO occurs in a quasi-oscillatory manner with an average period of approximately 4 years, owing to the tropical Pacific climate system's particularity. That is, the climatological elements of the tropical Pacific lead to the accumulation and lag times for their interaction that can take approximately 2 years for an El Niño to develop, peak, and decay, followed by a La Niña, and so forth in a quasi-cyclical fashion (Santoso et al., 2017).

Regarding its measurement, the estimates of ENSO fluctuations rely on the Oceanic Niño Index (ONI), which is calculated by the National Oceanic and Atmospheric Administration of the US (NOAA). The ONI tracks the running three-month average of sea surface temperatures in the east-central tropical Pacific between 120°–170° W, near the International Dateline, and assesses whether these temperatures are warmer or cooler than average (Lindsey, 2009). In addition to the ONI, there are measures based on observed sea level pressure, such as the Southern Oscillation Index (SOI), as well as multivariate measures that summarize several variables, such as the Multivariate ENSO Index Version 2 (MEI.v2). For this study, we use the ONI as our primary measure of ENSO fluctuations and employ the Multivariate ENSO Index for robustness checks.

Although the impact of these fluctuations are heterogeneous in different areas of the world, in Colombia, the El Niño phase of the ENSO cycle is associated with a decrease in rainfall and droughts in majority of the country, while the La Niña phase is

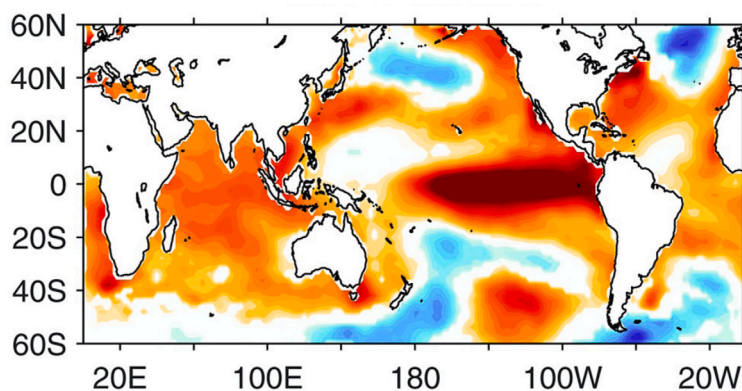


Fig. 1. Sea Surface Temperature (SST) anomalies at the mature phase of the 2014–2016 El Niño event.
Source: (NOAA, 2016)

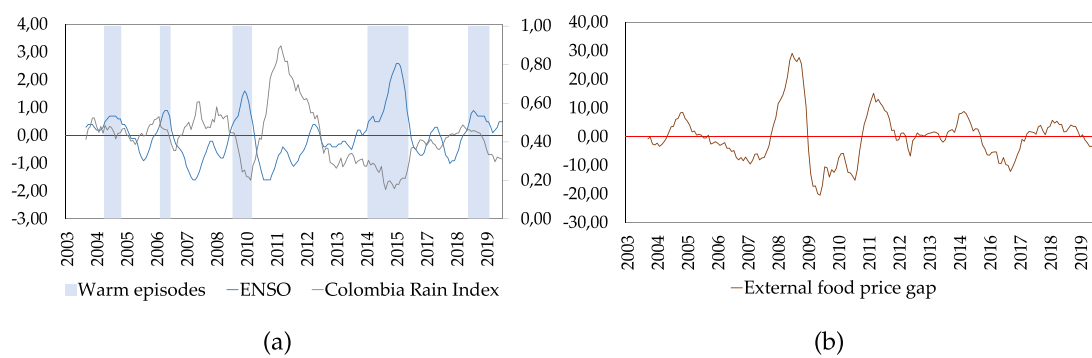


Fig. 2. The ENSO Fluctuations, Colombian rain index, and external food prices: possible channels.

Notes: The Colombia rain index is constructed as the 12-month moving average of precipitations and it is normalized with the mean = 0 and the standard deviation = 1 and is displayed in the right-hand axis (RHA). The external food price gap is constructed as the cyclical component of the World Bank's nominal international food price index.

Source: NOAA, Banco de la República, World Bank and authors' calculations.

characterized by higher-than-average rain precipitations. Among the most intense occurrences of the El Niño, the 2015–2016 episode was particularly strong (NOAA, 2016) and had a severe effect on Colombia (Fig. 1).³

There are two primary channels through which the ENSO cycles can affect inflation in Colombia. The first channel is directly related to changes in local weather conditions, notably rain precipitation. As evidenced in Fig. 2 (left-hand side), there exists a strong negative correlation between ENSO fluctuations and rain precipitation in Colombia. Extreme warm episodes, such as El Niño, are associated with lower rainfalls, which in turn directly affect the production of locally sourced perishable food items and hydroelectric generation.⁴

This reduction in rainfall leads to a spike in the prices of perishable food items, a phenomenon that has been well-documented (Caicedo, 2007; Cano, 2014; Abril-Salcedo et al., 2016; Melo et al., 2017; Abril-Salcedo et al., 2020). Lower precipitation also affects hydroelectric generation, forcing a switch to more expensive electricity sources and thereby affecting the overall inflation rate through an increase in utility prices.

The second channel through which ENSO influences inflation is via its impact on international commodity prices, as shown in Fig. 2 (right-hand side). Studies have found that ENSO has significant effects on global commodity prices (Brunner, 2002; Cashin et al., 2017). In light of these observations, our empirical approach incorporates international food prices into the model, as discussed in Section 4.

³ The 2015–2016 event was a very strong El Niño event. It developed rapidly and had spectacular climatic impacts worldwide. It also followed the recent research which found that the frequency of extreme El Niño will likely double in the 21st century, if greenhouse gas emissions continue unabatedly (Santoso et al., 2017). Other strong El Niño events include the 1982/83 and 1997/98 episodes.

⁴ Around 68% of Colombia's electric energy generation is hydroelectric, making the country highly vulnerable to drought conditions (Planas-Martí and Cárdenas, 2019).

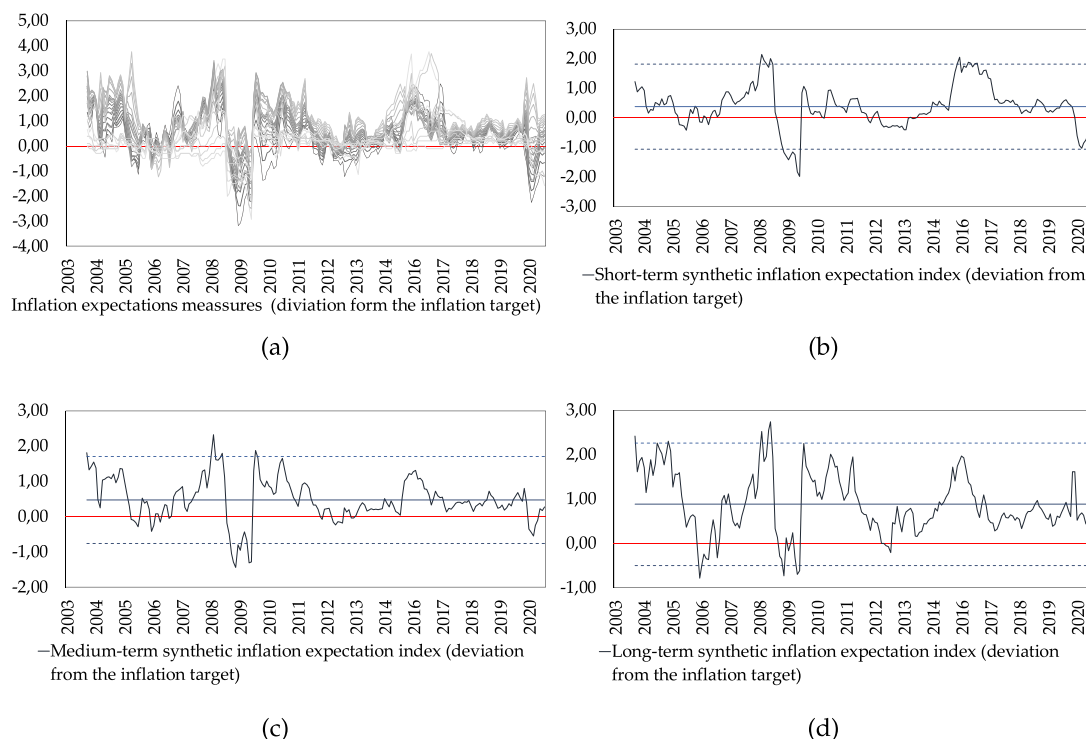


Fig. 3. The inflation expectations dynamics in Colombia.

Notes: The dotted blue lines represent 2-standard deviation intervals around the mean of the inflation expectations indicator. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Source: FocusEconomics, Banco de la República, and authors' calculations.

3. Inflation expectations in Colombia and some stylized facts

3.1. Inflation expectations data in Colombia

The majority of the literature regarding inflation expectations in Colombia analyses short-term measures (usually one or two years ahead). Contrarily, this study also analyzes the behavior of medium- and long-term inflation expectations from three sources.⁵ First, we use the inflation expectations from FocusEconomics.⁶ The advantages of this survey are the stability of its respondents (mainly local and international financial institutions), its monthly periodicity, and the availability of medium-term expectations. In this survey, inflation expectations from one up to five years are available since the early 2000s, allowing us to capture the reduction of inflation and various inflation-shocks episodes in Colombia. Second, we use Banco de la República's monthly survey by economic and financial analysts. This source is a widely used reference for the inflation expectations in Colombia. Finally, we examine the inflation expectations obtained from local government bonds, namely Break-even inflation (BEI), Forward Break-even inflation (FBEI) expectations, and BEI measures that control for inflation risk and liquidity premium (E-BEI).⁷ These measures are published periodically in several reports by Banco de la República.

Although we study the impact of weather shocks on each of the individual inflation expectations series, we also construct synthetic measures for short-, medium-, and long-term inflation expectations.⁸ These indicators were computed using the first principal component of the deviations in the inflation expectations measures to the inflation target for each term.⁹ The evolution

⁵ See Appendix A.1 for a summary of the available inflation expectations indicators in Colombia.

⁶ FocusEconomics provides economic analysis and forecasts. The inflation expectations obtained from this source corresponds to the median response of several local and international analysts surveyed in its monthly report.

⁷ BEI inflation expectations are computed as the difference between the yields of fixed-rate and inflation-indexed government bonds. FBEI inflation expectations are computed using the term structure of BEI expectations. E-BEI are inflation expectations measures extracted from the BEI indicators, excluding the inflation risk and liquidity premium that is included in bonds' market yields.

⁸ For the synthetic indicators, short-term inflation expectations include one and two years ahead measures, medium-term inflation expectations that collect three-, four-, and five-year expectations, while long-term inflation expectations comprise all the expectation measures that are higher than five years ahead.

⁹ See Appendix A.2 for the estimation details of the synthetic indicators.

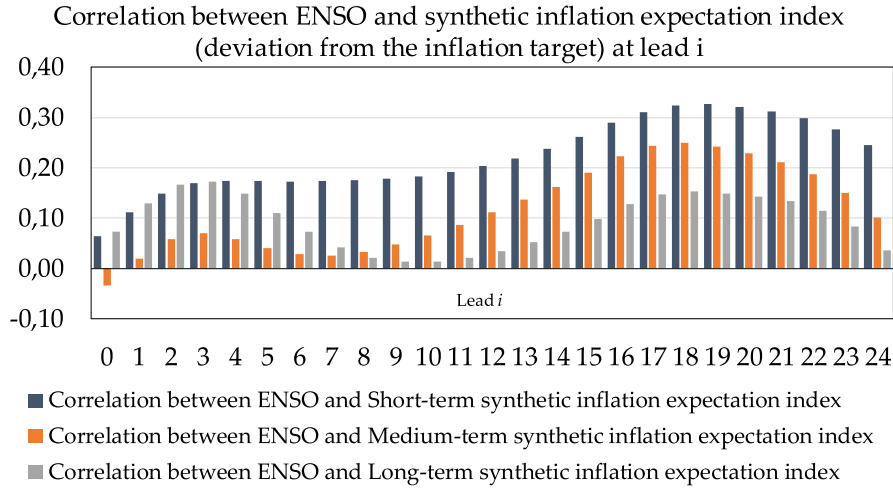


Fig. 4. The ENSO index and inflation expectations cross-correlations.
Source: Authors' calculations.

of the inflation expectations as deviations from the official inflation target,¹⁰ along with the synthetic measure for each term, are shown in Fig. 3.

3.2. Some stylized facts regarding the ENSO fluctuations and inflation expectations in Colombia

This section investigates whether the ENSO fluctuations are correlated with inflation expectations. If the ENSO fluctuations only affect short run inflation and if inflation expectations are fully anchored, it would be reasonable to expect a non-significant correlation between them.

Fig. 4 shows the correlation between the ENSO fluctuations and our synthetic measures of inflation expectations at different leads, providing evidence for a co-movement between these series. To further assess the impact of these shocks on inflation expectations, we use an approach that allows us to control for other supply shocks and fundamentals that could affect the inflation expectations.

4. Assessing the impact of weather shocks on inflation expectations: a BVARx approach

This section proposes an empirical approach to assess the impact of ENSO shocks on inflation expectations. Particularly, our BVARx model takes the following form:

$$y_t = Ay_{t-1} + Bx_t + \mu_t \quad (1)$$

The residuals are distributed according to:

$$\mu_t \sim \mathcal{N}(0, \Sigma) \quad (2)$$

In our empirical model, we assume that inflation expectations deviations from the inflation target are affected by external variables, internal supply shocks, short-term inflation surprises, and demand shocks. Additionally, we incorporate weather fluctuations as an exogenous driver that affects the anchoring of inflation expectations to the target. These variables are intended to capture the channels that have been described in Section 2 and to control for several fundamentals that may have an impact on the inflation expectations. Thus, in our specification the vector y_t is given by:

$$y_t = \begin{pmatrix} pf_t^* \\ RER_t \\ \pi_t^s \\ RP_t \\ IP_t \\ \pi_{t,t^c} - \bar{\pi}_t \end{pmatrix} \quad (3)$$

where pf_t^* , RER_t , RP_t , and IP_t , denote the log-deviations of the World Bank's international food price index, the real exchange rate, the relative price of local food prices, and industrial production from the HP filter trend, respectively.¹¹

¹⁰ In 2009, the inflation target was increased from 4% to 5%. In 2010 the inflation target was set to its long-term goal of 3%.

¹¹ Similar qualitative results are obtained using alternative trend measures.

π_t^s represents the short-term monthly inflation surprises that are obtained from Banco de la República's monthly survey,¹² and $\pi_{i,t} - \bar{\pi}_i$ refers to each of the inflation measures that we use in this study as a deviation from the inflation target. In x_t , we include the ENSO index.

In this setting, the external food price gap is included to control external cost-push shocks that could translate into higher inflation expectations. Furthermore, the real exchange rate gap is included to capture the pressures arising from increased foreign exchange pressures. The monthly inflation surprises capture the forecast errors in the monthly inflation that is printed by analyst which can lead to revisions in inflation expectations. The relative food price gap is considered to be the cyclical component of the relative price between the food price index and CPI excluding the food index. It is intended to capture supply shocks. This variable allows us to capture the impact of supply shocks on inflation expectations and also how these shocks are reversed (i.e. after a strong increase in supply-side-related shocks, food prices increase but they also tend to revert rapidly). The industrial production gap is included to account for any remaining business cycle effect that could affect the deviations of expectations from the inflation target. Importantly, this specification implies that inflation expectations are partially anchored, and that a set of known macroeconomic and weather variables can explain deviations of inflation expectations from their target.

The main advantage of using a BVARx model is that we can assume ENSO fluctuations are completely exogenous. For identifying shocks in the remaining variables within the model, we employ a Cholesky decomposition, designating deviations in inflation expectations from the target as the most contemporaneously endogenous variable.¹³ This specification acknowledges that ENSO fluctuations may impact the external food price gap, while external food prices themselves are not influenced by other variables in the system. Given that our primary focus is on ENSO-related shocks, the BVARx approach serves as a suitable strategy for assessing these exogenous fluctuations. Nonetheless, alternative identification methods, such as sign restrictions or proxy-SVAR, could be employed in future research to further distinguish between weather-related and other cost-push shocks.

The models are estimated using monthly data from October 2003 to December 2020 for the individual expectations series, except for the E-BEI and synthetic indicators of BVARx models that are estimated from June 2004 to December 2020. Reducing the sample to exclude the COVID-19 period does not seem to alter the impulse response results. To select the lag structure, we use standard information criteria, which in most cases stood at four lags. To estimate the BVARx models we use the independent normal-Wishart prior which assumes that Σ is unknown.¹⁴

Fig. 5 displays the impact of a one-degree Celsius change in the ENSO index on our synthetic inflation expectations indicators, measured as deviations from the inflation target. The weather shock, commonly linked with droughts in Colombia, increases these deviations. For the short-term measure, the effect dissipates within about six months. In contrast, the impact on medium- and long-term measures seems to fade within approximately four months. Notably, for these latter indicators, minor corrections – likely due to the reversal of the supply shock – appear between the 5th and 12th months post-shock.

Table 1 summarizes the responses of various inflation expectations as deviations from the inflation target to a one degree Celsius ENSO shock. The impact of the shock varies from 4 basis points (b.p) to 13 b.p during the initial period. The most affected measures are those from the Central Bank survey and the FocusEconomics surveys for the end of the current year. In contrast, FocusEconomics expectations for 3, 4, and 5 years appear to be largely unaffected by these shocks. Moreover, in most instances, the effect seems to dissipate after 6 months. It is important to note that there have been episodes where ENSO shocks displayed extreme readings, such as the 2015–2016 episode in which it reached 2.6 degree Celsius anomalies in sea surface temperatures in the Pacific Ocean. To more comprehensively assess the accumulated impact on inflation expectation measures, the subsequent section presents the historical decomposition of the BVARx model for the three synthetic indicators.¹⁵

5. A semi-structural new keynesian model incorporating the ENSO weather shocks

The previous section showed that inflation expectations are affected by weather-related shocks in Colombia, even after controlling for other supply-related shocks and fundamentals. This implies that there can be a second round of effects on inflation arising from weather shocks that should be considered by the monetary authority. In this context, disentangling this particular shock, and assessing its magnitude and persistence from other cost-push shocks is important to evaluate the policy response.

This section integrates these considerations into a small, open-economy New Keynesian model, recognizing that weather shocks have a direct impact on both inflation and inflation expectations. We adapt one of Banco de la República's core forecasting models (Gonzalez et al., 2020), where inflation is broken down into several components: goods, services, regulated items, and food. According to this classification, weather shocks directly affect regulated items (which include electricity prices) and the food basket (comprising perishable food products). Additionally, we introduce a mechanism by which inflation expectations are influenced by these shocks, contingent upon the central bank's level of credibility.

¹² As a robustness check, we also construct a surprise measure using Bloomberg's monthly survey. This survey includes a similar set of analysts but has a longer response period.

¹³ Descriptions of the series, unit root tests, and impulse responses for the variables used in the BVARx models can be found in Appendices A.1, A.3, and A.5.

¹⁴ A brief description of the estimation procedure is shown in Appendix A.5.

¹⁵ As a robustness check, we present in Appendix A.6 the impulse responses of inflation expectations to an alternative measure of ENSO fluctuations — namely, the Multivariate ENSO Index. We obtain similar results using this alternative measure.

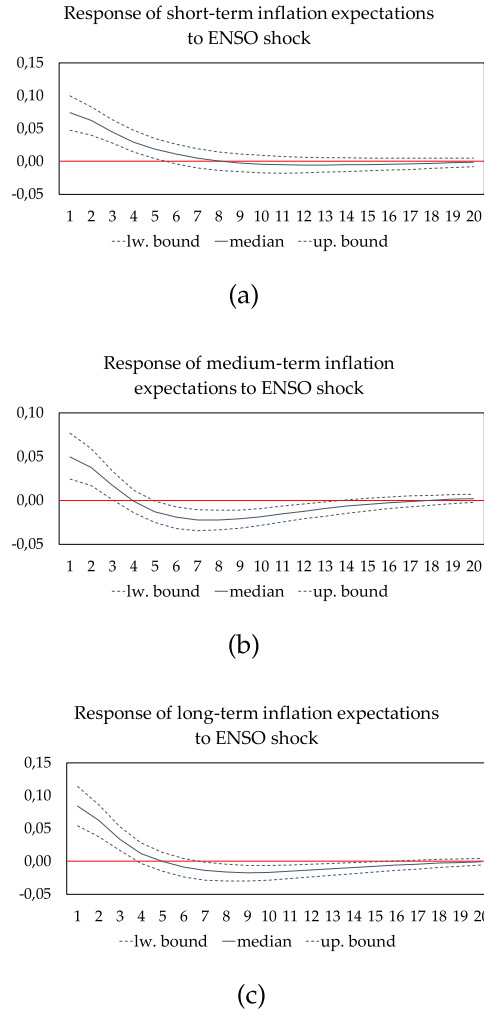


Fig. 5. Response of the inflation expectations (deviations from the inflation target) to a one-degree Celsius ENSO shock (68% confidence interval) in the BVARx model.

Source: Authors' calculations.

5.1. Model structure

To incorporate the effect of weather shocks on a small open economy New-Keynesian model we modify the 4GM model proposed by [Gonzalez et al. \(2020\)](#). This model is a modification of the IMF's quarterly projection model that incorporates several features of the Colombian economy. The advantage of this model is that it has a good empirical fit and allows to better disentangle the sources of inflation pressures, as it decomposes inflation in several baskets. The structure of the model consists of the following blocks (i) IS curve and potential output, (ii) Phillips curve and inflation expectations, (iii) monetary policy credibility process, (iv) Taylor rule and interest rates, and (v) determination of the exchange rate. The complete set of equations for the model is given in [Appendix A.7](#).

IS curve and potential output

Following [Gonzalez et al. \(2020\)](#), the output level in logarithmic terms y_t is defined in terms of a cyclical component $\hat{y}_t$ (output gap), and a trend $\bar{y}_t$ (potential output):

$$y_t = \bar{y}_t + \hat{y}_t \quad (4)$$

The output gap is modeled using a modified IS curve in the following way:

$$\hat{y}_t = \beta_1 \hat{y}_{t-1} + \beta_2 E_t \hat{y}_{t+1} - \beta_\phi \phi_t + \beta_{\hat{y}^*} \hat{y}_t^* + \beta_{\hat{r}_{oil}} \hat{r}_{oil} + \eta_t^{\hat{y}_t} \quad (5)$$

where $\hat{y}_{t-1}$ captures the persistence of the economic cycle, and $E_t \hat{y}_{t+1}$ is the forward-looking component. In this specification, the output gap $\hat{y}_t$ depends on a real monetary condition index that is defined as $\phi_t = \beta_{\hat{r}_t} \hat{r}_t + (1 - \beta_{\hat{r}_t}) \hat{z}_t$. This real monetary condition index

Table 1
Inflation expectations response to the ENSO shocks.

Inflation expectation measure (deviation from the inflation target)	Classification	Sample average (Deviation from the inflation target)	ENSO Shocks (1 degree Celsius)					
			Contemporaneous effect			At t = 6		
			lw. bound	median	up. bound	lw. bound	median	up. bound
Synthetic inflation expectation index								
Short-term inflation expectations		0.27	0.05	0.07	0.10	0.00	0.01	0.03
Medium-term inflation expectations		0.40	0.02	0.05	0.08	−0.03	−0.02	−0.01
Long-term inflation expectations		0.84	0.05	0.08	0.11	−0.02	−0.01	0.00
Central Bank Survey								
1-year ahead	short-term	0.51	0.04	0.06	0.08	0.00	0.01	0.03
End of the current year	short-term	0.33	0.09	0.13	0.17	0.01	0.04	0.06
FocusEconomics Survey								
End current year	short-term	0.51	0.09	0.12	0.16	0.01	0.03	0.05
End second year	short-term	0.21	0.03	0.05	0.07	−0.01	0.00	0.01
End third year	medium-term	0.11	−0.02	0.01	0.05	−0.04	0.00	0.04
End fourth year	medium-term	(0.02)	−0.03	0.01	0.04	−0.05	−0.01	0.03
End fifth year	medium-term	(0.09)	0.02	0.04	0.06	−0.01	0.00	0.01
Break-even Inflation								
1Y - BEI	short-term	0.21	0.03	0.07	0.11	0.00	0.02	0.04
2Y - BEI	short-term	0.30	0.03	0.06	0.10	−0.02	0.00	0.02
3Y - BEI	medium-term	0.39	−0.04	0.02	0.07	0.00	0.17	0.33
4Y - BEI	medium-term	0.48	0.03	0.06	0.09	−0.03	−0.02	0.00
5Y - BEI	medium-term	0.56	0.03	0.06	0.09	−0.03	−0.02	−0.01
6Y - BEI	long-term	0.63	0.03	0.06	0.10	−0.03	−0.02	−0.01
7Y - BEI	long-term	0.69	0.04	0.07	0.10	−0.03	−0.02	−0.01
8Y - BEI	long-term	0.73	0.05	0.07	0.10	−0.03	−0.02	0.00
9Y - BEI	long-term	0.77	0.05	0.08	0.11	−0.03	−0.01	0.00
10Y - BEI	long-term	0.81	0.05	0.08	0.11	−0.02	−0.01	0.00
E-BEI (correcting for liquidity)								
1Y - EBEI	short-term	0.01	0.03	0.07	0.10	−0.01	0.00	0.02
2Y - EBEI	short-term	0.02	0.03	0.05	0.08	−0.01	0.00	0.02
3Y - EBEI	medium-term	0.08	0.02	0.05	0.07	−0.01	0.00	0.02
5Y - EBEI	medium-term	0.20	0.02	0.04	0.06	−0.01	0.01	0.02
8Y - EBEI	long-term	0.33	0.02	0.04	0.06	0.00	0.01	0.02
Forward Break-even Inflation								
FBEI_1_1	short-term	0.39	0.02	0.05	0.09	−0.03	−0.02	0.00
FBEI_2_1	medium-term	0.58	0.01	0.05	0.08	−0.05	−0.03	−0.02
FBEI_3_1	medium-term	0.75	0.02	0.06	0.09	−0.05	−0.03	−0.02
FBEI_4_1	medium-term	0.88	0.03	0.07	0.10	−0.04	−0.03	−0.01
FBEI_5_1	long-term	0.97	0.05	0.08	0.12	−0.03	−0.02	0.00
FBEI_6_1	long-term	1.03	0.06	0.10	0.13	−0.02	−0.01	0.01
FBEI_7_1	long-term	1.07	0.07	0.11	0.15	−0.01	0.00	0.02
FBEI_8_1	long-term	1.09	−0.03	0.01	0.05	−0.06	−0.02	0.03
FBEI_9_1	long-term	1.10	0.09	0.13	0.17	−0.01	0.01	0.03

Source: Authors' calculations.

captures the effect of the real interest rate gap $\hat{r}_t$ and the real exchange rate gap $\hat{z}_t$. The IS curve also depends on the foreign output gap $\hat{y}_t^*$ and the real oil price gap $\hat{r}^{oil}_t$ which reflect the effects of these variables on domestic demand. The IS equation includes a demand shock $\epsilon_t^{\hat{y}}$ that follows an AR(1) process given by $\eta_t^{\hat{y}} = \beta_{\eta^{\hat{y}}} \eta_{t-1}^{\hat{y}} + \epsilon_t^{\hat{y}}$.

The annualized potential output growth and the quarterly output level can be expressed as:

$$\Delta \bar{y}_t = \rho_{\Delta \bar{y}} \Delta \bar{y}_{t-1} + (1 - \rho_{\Delta \bar{y}})(\Delta \bar{y}_{ss} + \kappa_{\Delta \bar{y}}(\Delta \bar{r}^{oil}_t - \Delta \bar{r}^{oil}_s)) + \epsilon_t^{\Delta \bar{y}} \quad (6)$$

This equation describes the law of motion of potential growth. It depends on its lagged value $\Delta \bar{y}_{t-1}$, the long-term growth rate (steady state) $\Delta \bar{y}_{ss}$, deviations of the trend growth of the real oil price from its steady-state rate $(\Delta \bar{r}^{oil}_t - \Delta \bar{r}^{oil}_s)$ and shocks to potential growth $\epsilon_t^{\Delta \bar{y}}$.

The output gap reflects the dynamic of the aggregate demand and it is an indicator of the business cycle. Thus, a negative gap indicates economic slack, while a positive one signals an overheating economy. It is worth noting that together, Eqs. (4) and (5), imply that the output gap summarizes the net balance between supply and demand shocks.

Phillips Curve and inflation expectations including ENSO

In this model specification the inflation rates of the food and regulated, goods, and services are modeled as a hybrid form of the Phillips curves:

$$\pi_t^j = \alpha_{\pi^j} \pi_{t-1}^j - (1 - \alpha_{\pi^j}) \pi_t^{e,j} + \alpha_{rmc^j}^{\pi^j} rmc_t^j + \epsilon_t^{\pi^j} \quad (7)$$

For $j = \text{Goods (g), Services (s), Regulated (r), and Food (f)}$.

where π_t^j is the annualized quarterly inflation, and depends on its inertia π_{t-1}^j , expected value π_{t+1}^j , the real marginal cost rmc_t^j , and a basket-specific cost push shock $\epsilon_t^{\pi^j}$. In this setting the real marginal cost is given by:

$$rmc_t^j = \begin{cases} \alpha_{\hat{y}}^{rmc^j} \hat{y} + (1 - \alpha_{\hat{y}}^{rmc^j})(\hat{z}_t - \hat{r}p_t^j) & \text{for } j = g, s \\ \alpha_{\hat{y}}^{rmc^j} \hat{y} + (1 - \alpha_{\hat{y}}^{rmc^j})(-\hat{r}p_t^{F*} + \hat{z}_t + \lambda^f ENSO_t - \hat{r}p_t^j) & \text{for } j = f \\ \alpha_{\hat{y}}^{rmc^j} \hat{y} + (1 - \alpha_{\hat{y}}^{rmc^j})(-\hat{r}p_t^{oil} + \hat{z}_t + \lambda^f ENSO_t - \hat{r}p_t^j) & \text{for } j = r \end{cases} \quad (8)$$

In Eq. (8) the real marginal cost rmc_t^j depends positively on the output gap $\hat{y}$ and the real exchange rate gap $\hat{z}_t$. For all baskets, and following Gonzalez et al. (2020), the rmc_t^j includes the basket relative price $\hat{r}p_t^j$ gap. Furthermore, the rmc_t^j for food and regulated items include the real relative price gaps of world food prices $\hat{r}p_t^{F*}$ and oil $\hat{r}p_t^{oil}$, respectively. Furthermore, we include weather-related shocks $\lambda^f ENSO_t$ as a variable that affects marginal costs for food and regulated prices. The rationale for including this variable is straight forward. Food prices include perishable food products that are highly sensitive to adverse weather while regulated items includes electric energy, which is mostly based on hydro-electric generation and is affected by rainfall. Finally, $\pi_t^{e,j}$ stands for inflation expectations for the basket j , following these processes:

$$\pi_t^{e,j} = c_t \pi_{t+1}^j + (1 - c_t)(\pi_{t-1}^j + \psi ENSO_t) + \epsilon_t^{\pi^{e,j}} \text{ for } j = f, r \quad (9)$$

$$\pi_t^{e,j} = c_t \pi_{t+1}^j + (1 - c_t)(\pi_{t-1}^j) + \epsilon_t^{\pi^{e,j}} \text{ for } j = g, s \quad (10)$$

In Eqs. (9) and (10) π_{t-1}^j correspond to a backward-looking (inertial) component while π_{t+1}^j represents the forward-looking rational expectations. Accordingly, and based with the empirical evidence shown in the previous section, we allow the inflation expectations to be affected by weather-related shocks. Specifically, we include $ENSO_t$ in the formation of inflation expectations for food and regulated items. The process c_t represents the stock of credibility of the monetary authority which we discuss in the next block of the model. For the food and regulated inflation prints if the credibility stock c_t is lower than one, the inflation expectations for these baskets are going to be affected by both the backward-looking component π_{t-1}^j and by $ENSO_t$. For the case of goods and services inflation, a credibility stock lower than one implies that expectations have an inertial component. If credibility is perfect ($c_t = 1$), the inflation expectations in all four baskets are completely forward-looking.

Credibility of the monetary authority:

An additional feature that we include in our model is a process for the stock of credibility of the monetary authority as presented by Benes et al. (2017). Credibility is constructed as a stock (c_t) measured between 0 and 1 that affects the way inflation expectations are formed in Eq. (5). The inflation expectations are more backward-looking with lower credibility. If the monetary authority is fully credible the inflation expectations are fully forward-looking. Furthermore, the specification of the process by which credibility changes is non-linear. This implies that at a lower level of credibility, monetary policy needs to be sufficiently aggressive to achieve disinflation. However, as credibility stock increases, the policy reactions need not do much to achieve the same quantum of disinflation (Benes et al., 2017).

Credibility can only improve gradually over time, thus, it has a large AR coefficient (0.95). Credibility responds to a signal (ξ_t) that is good if inflation has been converging to the target (π^{good}), and is bad if rising toward a high-inflation state (π^{bad}).

$$c_t = \rho^c c_{t-1} + (1 - \rho^c) \xi_t \quad (11)$$

The credibility signal weighs the relative likelihood of the inflation converging to the target versus it being unanchored. It is higher if the current realized inflation is closer to the target. The forecasting error under the bad (good) regime is defined as the difference between the realized inflation and the expected inflation under the bad (good) regime.

$$\xi_t = \frac{(\epsilon_t^{bad})^2}{(\epsilon_t^{bad})^2 + (\epsilon_t^{good})^2} \quad (12)$$

$$\epsilon_t^{bad} = \pi_t - [\rho^e \pi_{t-1} + (1 - \rho^e) \pi_t^{bad}] \quad (13)$$

$$\epsilon_t^{good} = \pi_t - [\rho^e \pi_{t-1} + (1 - \rho^e) \pi_t^{good}] \quad (14)$$

To control for boundary conditions, we set $\xi_t = 0$ if $\epsilon_t^{bad} > 0$ and $\xi_t = 0$ if $\epsilon_t^{good} < 0$.

Monetary Policy Rule and Interest Rates

The monetary policy rate i_t follows an inflation-forecast-based reaction function. The equation is as follows:

$$i_t = \rho_i i_{t-1} + (1 - \rho_i) \left[\bar{i}_t + \psi_\pi (E_t \pi_{t+3}^A - E \pi_{t+3}^A) + \psi_{\hat{y}} \hat{y}_t \right] + \epsilon_t^i. \quad (15)$$

Where i_{t-1} refers to an interest rate smoothing term, $\bar{i}_t$ is the neutral nominal interest rate and ϵ_t^i are monetary policy shocks. The reaction function also depends on the output gap $\hat{y}$ and the deviation of annual inflation expectations from the three periods ahead

Table 2
Calibrated parameters values and description.

Parameter	Value	Description
Steady State		
$\Delta \bar{y}$	3.3%	Long run Potential Output Growth
$\bar{\pi}$	3%	Long run inflation
$\bar{r}$	2%	Long run neutral real interest rate
$\bar{\pi}^*$	2%	Long run US inflation
$\bar{r}^*$	0.5%	Long run US neutral real interest rate
$\Delta \bar{z}$	0%	Long run depreciation
$\bar{\omega}$	1.5%	Long run risk premium
δp_t^{oil}	0%	Trend growth, of real oil prices
δp_t^{F*}	0%	Trend growth, of real foreign food prices
Credibility		
$\bar{c}$	1	Long run credibility
ρ^c	0.8	Backward component
π^{bad}	4	Bad inflation regime
π^{good}	3	Good inflation regime
ENSO		
λ^f	1.7	Sensibility of food inflation to ENSO shocks
λ^r	3.7	Sensibility of regulated inflation to ENSO shocks
ψ	0.5	Effect of ENSO into inflation expectations
ρ_{Enso}	0.78	ENSO Backward component
σ_{Enso}	0.8	Standard Deviation of ENSO fluctuations

Source: Authors' compilation.

target $E_t \pi_{t+3}^A - E_t \pi_{t+3}^A$. The three-quarter-ahead inflation-forecast-based reaction function ensures more robustness as policy is reacting to a mix of current data, near-term forecast, and model-based projection in the initial periods (see Benes et al. (2017)).

The neutral nominal interest rate is defined by the Fisher equation $\bar{i}_t = \bar{r} + \pi_{t+1}$, where $\bar{r}$ is the neutral real interest rate and π_{t+1} represents inflation expectations. Therefore, the long depreciation will be constant and given by:

$$\Delta \bar{z} = \bar{r} - \bar{r}^* + \overline{prem}$$

Where $\bar{r}^*$ and $\Delta \bar{z}_t$ are the US neutral real interest rate, and the depreciation of the real exchange rate trend, respectively.

Modified Risk-Adjusted Uncovered Interest Parity (UIP)

The risk adjusted Uncovered Interest Parity (UIP) condition is given by:

$$\Delta s_{t+1} = i_t^* - i_t + prem + \epsilon_t^{Is} \quad (16)$$

Where Δs_t is the nominal depreciation, i_t^* is the FED funds rate, i_t is the monetary policy interest rate, $prem$ is a constant risk premium, and ϵ_t^{Is} is an idiosyncratic shock to the UIP condition.

Regarding the real exchange rate, z_t is where one can identify a trend $\bar{z}_t$ and a cyclical component $\hat{z}_t$ which follows: $z_t = s_t + \pi_t^* - \pi_t$

$$z_t = \bar{z}_t + \hat{z}_t \quad (17)$$

$$\Delta \bar{z}_t = \rho_{\Delta z} \Delta \bar{z}_{t-1} + (1 - \rho_{\Delta z})(\Delta \bar{z}_{ss} - \epsilon_{\Delta \bar{z}}(\Delta \bar{r}_t^{oil} - \Delta \bar{r}_{ss}^{oil})) + \epsilon_t^{\Delta \bar{z}} \quad (18)$$

Lastly, the nominal and real depreciation are related through $\Delta z_t = \Delta s_t + \pi_t^* - \pi_t$.

5.2. Calibration and estimation

The parameters of the model are divided into two groups: calibrated and estimated parameters. Among the first group, there are parameters related to the steady state, the credibility block and the ENSO shock. The calibrated parameters for the steady state of the model include the long-run GDP growth rate, the inflation target and the convergence of each basket to its long-term value, where the persistence of some of the exogenous processes were taken from Gonzalez et al. (2020). The parameters regarding the credibility process were taken from Benes et al. (2017) and the inflation regimes correspond to the tolerance band around the long-term inflation target.

The parameters related to the ENSO shock were calibrated to match the impulse responses showed in Section 4 and time series estimations to capture the persistence and variance of the ENSO series. The values for these parameters are presented in Table 2.

The second group of parameters were estimated using a Bayesian technique, following the model specification proposed in Gonzalez et al. (2020). For the estimation we use quarterly data containing 19 domestic variables and 9 foreign variables from 2003Q1 to 2019Q4. The first set of variables includes the real GDP y_t , in millions of Colombian Pesos, monetary policy rate i_t ,

Table 3
Estimated parameters description.

Parameter	Value	Description
Phillips Curve (Food)		
α_{π^F}	0.3062	Backward component weight
$\alpha_{\pi^A}^{rmc}$	0.1212	Real marginal cost weight
$\alpha_{\pi^A}^{rmc^A}$	0.6424	Output gap weight
Phillips Curve (Regulated)		
α_{π^R}	0.271	Backward component weight
$\alpha_{\pi^R}^{rmc}$	0.0209	Real marginal cost weight
$\alpha_{\pi^R}^{rmc^R}$	0.8523	Output gap weight
Phillips Curve (Goods)		
α_{π^G}	0.3061	Backward component weight
$\alpha_{\pi^G}^{rmc}$	0.1432	Real marginal cost weight
$\alpha_{\pi^G}^{rmc^G}$	0.2598	Output gap weight
Phillips Curve (Services)		
α_{π^S}	0.3462	Backward component weight
$\alpha_{\pi^S}^{rmc}$	0.0783	Real marginal cost weight
$\alpha_{\pi^S}^{rmc^S}$	0.6397	Output gap weight
IS Curve		
β_1	0.5773	Backward component weight
β_2	0.0505	Forward component weight
β_{phi}	0.1400	MCI weight
β_{y^*}	0.0956	Foreign output gap weight
$\beta_{p^{oil}}$	0.0157	Oil gap weight
β_r	0.7500	Real interest rate gap weight
Taylor rule		
ρ_i	0.7	Backward component weight
ψ_π	1.5	MCI weight
$\psi_{\hat{y}}$	0.375	Foreign output gap weight

Source: Authors' calculations.

annual inflation target $\bar{\pi}_t$, nominal exchange rate s_t , CPI p_t , core CPI p_t^c , and the price index for the baskets of goods p_t^b , services p_t^s , food p_t^f , and regulated items p_t^r .

This data set also includes the trend components of relative prices of the goods basket $\bar{p}_t^b$, food basket $\bar{p}_t^f$, and regulated goods basket $\bar{p}_t^r$. The set of foreign variables consists of the US CPI p_t , the US monetary policy rate i_t^* , proxied by the 1-Year US FED rate, the Colombian risk premium $prem_t$ measured through the 5-year CDS spread on sovereign Colombian bonds, and the real oil price pr_t^{Oil} in US dollars. We also include estimates of the US neutral real interest rate r_t^* , gaps for the foreign output y_t^* , relative price of world food p_t^{F*} , trend components of the risk premium $\bar{prem}$, and real oil price $\bar{p}_t^{oil}$. Trends and gaps of external variables correspond to off-model estimates that combine satellite models and judgments as proposed by [Gonzalez et al. \(2020\)](#). [Table 3](#) summarizes the estimation results.

6. Results

6.1. Impulse responses of the model to an ENSO shock

This section analyzes the model's dynamics in response to a transitory ENSO shock of 100 basis points (b.p.), equivalent to a one-degree Celsius change in the historical ENSO series. [Fig. 6](#) illustrates that this ENSO shock leads to a rise in both food and regulated inflation. The increase in these specific categories is twofold: first, the adverse weather conditions directly elevate marginal costs for these goods; second, inflation expectations also climb as a consequence of the shock. Specifically, food inflation experiences an initial jump of nearly 30 b.p., while regulated inflation sees an increase of about 7 b.p.

As a result of the increase in food and regulated inflation, along with their corresponding expectations, both headline inflation and total inflation expectations also rise. In the specific parametrization we propose, headline inflation and total inflation expectations each initially rise by approximately 5 basis points (b.p.) due to the shock. In response to these developments, the monetary policy authority is compelled to raise interest rates by 4 to 6 b.p. to anchor inflation expectations. The central bank's reaction to weather shocks in our model is influenced by the existing stock of credibility, an essential mechanism in our proposed framework. To illustrate how this credibility mechanism operates within the model, [Appendix A.8](#) presents the impulse responses conditional upon various levels of credibility. It is noteworthy that our model does not account for other potential channels through which weather-related shocks might impact the economy, such as contagion effects from food and regulated prices to core prices; these considerations may form part of future research agendas.

In this model, ENSO shocks have no direct impact on economic activity; therefore, any decrease in the output gap results from a tightening of monetary policy. However, this impact is moderate in the current parametrization.

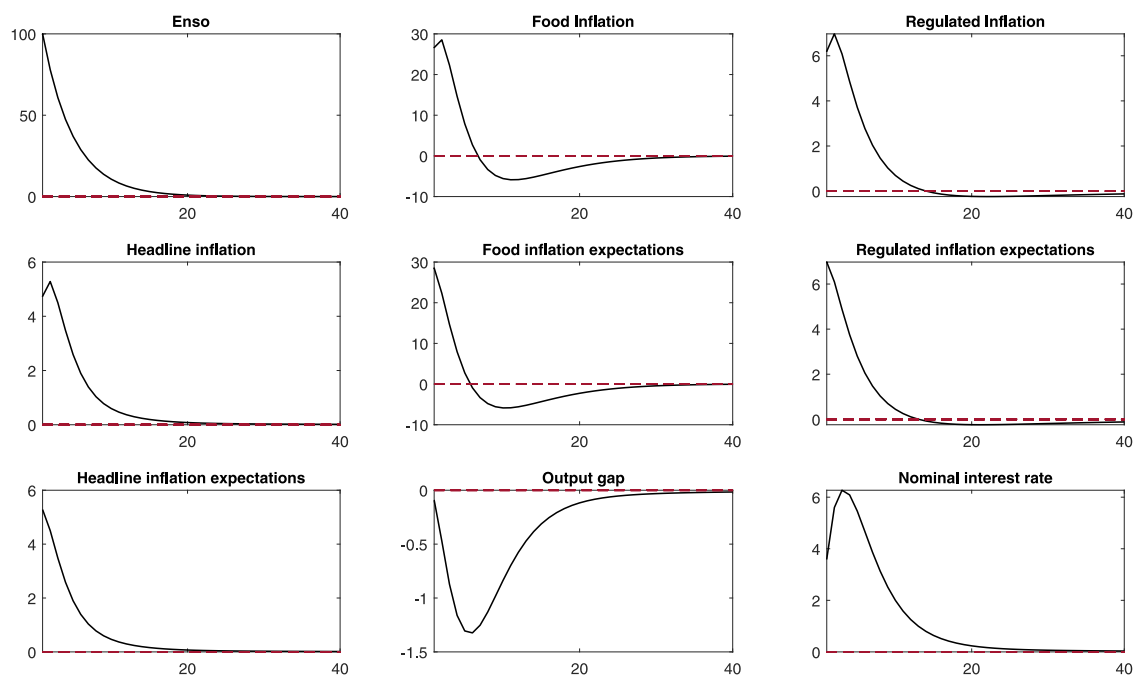


Fig. 6. Response of selected variables (deviation from the steady state) to an ENSO shock. The responses of the endogenous variables are in basis points (b.p). Source: Authors' calculations.

It is important to highlight that these quantitative results correspond to a transitory, one-degree Celsius change shock in the ENSO series. As we have seen, extreme weather events could be higher and more persistent as the episode in 2014–2016. Thus, in the next sub-section we study this episode using the model's historical shock decomposition. This approach gives a better assessment of how persistent shocks affect inflation, inflation expectations and monetary policy.

6.2. Disentangling the underlying shocks during an adverse weather event

This section discusses the contribution of the ENSO shocks during the most intense El Niño phase in recent history: the 2015–2016 event. As discussed by [Abril-Salcedo et al. \(2016, 2020\)](#) El Niño in 2015–2016 was particularly strong and had a significant effect on inflation in Colombia. To understand this event, and how the ENSO affected inflation and inflation expectations, we use our proposed model to disentangle the underlying shocks during this period. To do this we use the historical shock decomposition.¹⁶

[Fig. 7](#) illustrates, for the period 2015–2019, the historical shock decomposition of five macroeconomic variables: food inflation, regulated inflation, headline inflation, inflation expectations, and the monetary policy rate.

Disentangling the different shocks that affected the Colombian economy during 2015–2016 is not an easy task. During this time, the economy experienced several strong and persistent shocks. Among these, the Colombian economy was affected by a severe fall in its terms of trade, strong exchange rate depreciation (as a result of a dramatic drop in oil prices), local supply disruptions in transportation, and adverse weather related to the El Niño phenomenon.

As shown in [Fig. 7](#), food and regulated inflation prints are mostly affected by different kinds of cost push shocks. Nonetheless, the inclusion of ENSO fluctuations in the model helps to further assess their drivers. Particularly, it is clear that the ENSO affected these baskets in 2015 and early 2016. Regarding headline inflation, the shock decomposition shows the relevance of cost-push shocks arising from food inflation. This food cost push shock was particularly relevant from the second quarter of 2015 to the first quarter of 2016. Furthermore, using our proposed model, we can distinguish the specific contribution that the ENSO fluctuations had during this episode. This result is in line with anecdotal evidence and the published Inflation Reports produced by Banco de la República during this time. We can also quantitatively distinguish how the ENSO shocks affected inflation expectations during this period, which relates to the BVARx evidence shown in [Section 4](#). Furthermore, our decomposition allows for a better assessment of the multiple shocks that affected inflation and inflation expectations. Finally, the model suggest that the impact of weather shocks should have been considered earlier in the monetary response to the inflationary pressures arising in 2015 and 2016.

¹⁶ The historical shock decomposition represents the estimated latent variables in terms of contributions of the estimated structural shocks of the model and is estimated using a Kalman smoother.

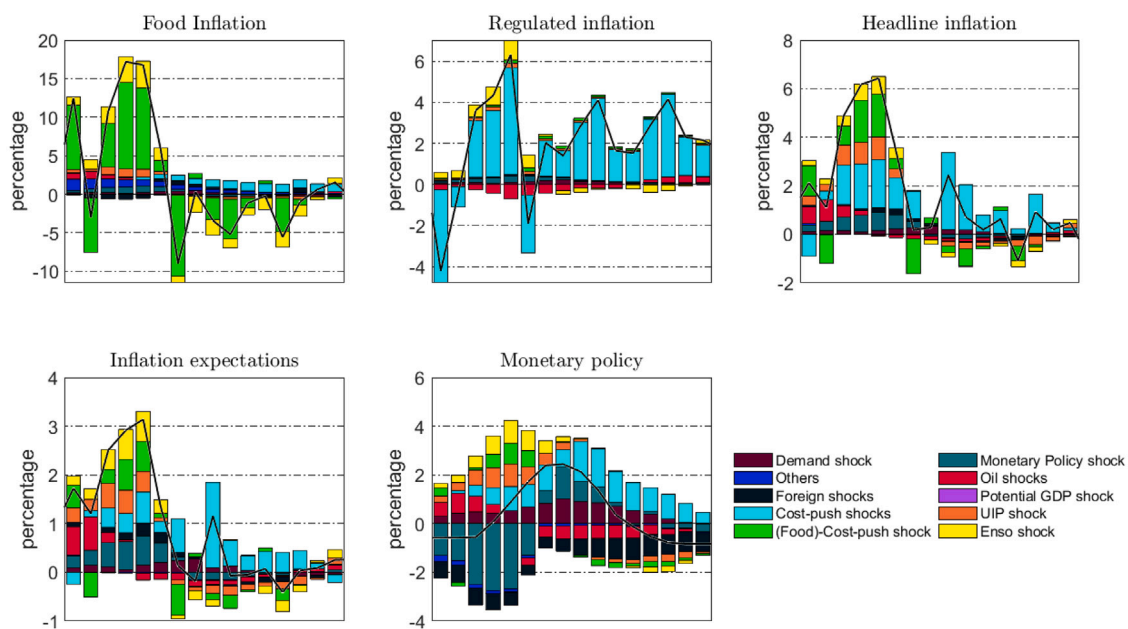


Fig. 7. 2014–2019 Historical Decomposition as the deviation from the steady state. Note: Inflation series correspond to quarterly annualized changes. Source: Authors' calculations.

7. Concluding remarks

In this study we find evidence of second-round effects of weather-related cost-push shocks on inflation. The mechanism appears to be related to the fact that inflation expectations are partially anchored to the inflation target and can be affected by the ENSO fluctuations. Using BVARx models, we provide evidence for this fact using a broad set of Colombian inflation expectations. We incorporate this finding in a semi-structural model that captures different sources of inflationary pressures and the dynamics of different CPI baskets. In our model, we allow the ENSO shocks to affect the marginal costs of regulated goods and food prices in the Phillips curves and inflation expectations. The results in terms of impulse-response function and historical shock decomposition illustrate the properties of the model, and allow us to better assess episodes of extreme weather shocks such as the strong El Niño event of 2015–2016.

Regarding policy implications, identifying the ENSO-shocks and incorporating them the specific models that are usually used for forecasting and policy analysis could be an important tool to construct scenarios of extreme weather fluctuations in countries that are affected by the ENSO fluctuations. Additionally, we find that these shocks had an important role in the dynamics of both inflation and inflation expectations, and that this fact should be considered by the central bank when assessing its monetary policy stance.

Nonetheless, this study is just an initial approximation on how to include weather shocks into such models and hence, further research is required on this issue. In particular, it is important to work incorporating the impact that weather shocks have on different sectors, how to disentangle weather shocks from other supply shocks using different identification approaches, evaluating alternative mitigation policies, and how to simulate scenarios. Finally, as shown in the literature, there could be non-linear features related to weather shocks that should be incorporated in the analysis and into models with economic content.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: JOSE VICENTE ROMERO reports administrative support and travel were provided by Graduate Institute (BCC PROGRAM).

Appendix

A.1. Inflation expectations availability in Colombia

Over the last two decades there has been an important increase in the availability and diversity of inflation expectations measures in Colombia. The oldest surveys on record were collected by private institutions (Consensus Economics and Focus Economics) with information that dates to the 1990s. Although these surveys mostly focused on one- or two-year ahead expectations, they also

Table 4
Inflation expectations measures and related inflation indicators in Colombia.

Inflation expectations	Available inflation expectations measures	Entity in charge of its release	Periodicity and availability	Included in this study
Monthly financial sector survey	Monthly inflation expectation; yearend, two-year ahead, 12-month and 24-month expectations. Core-inflation expectations.	Banco de la República	Monthly since 2003. Headline and core inflation expectation for the end of next year and 24-month expectations started to be collected in 2015.	Yes
Quarterly inflation survey	Four-quarter ahead inflation expectations. Eight-quarter ahead inflation expectations. Next year and two year ahead wage-inflation expectations.	Banco de la República.	Quarterly since 2000. Eight quarter ahead inflation expectations started to be collected in 2015.	No
BEI, Forward BEI and Expected BEI	These measures range from one to ten years ahead.	Banco de la República	Daily and monthly since 2003. FBFI is presented in the annex report of the CB's minutes.	Yes
Consensus Economics Survey	Yearend and next year inflation expectations. Long term inflation expectations.	Consensus Economics	Bi-monthly (alternate months) between March 1993 and April 2001 and monthly thereafter.	No
Focus Economics Survey	Yearend and next year inflation expectations. Yearend inflation expectations up to five years.	Focus Economics	Monthly since 1999.	Yes
Fedesarrollo-BVC survey	Inflation expectations balance. Yearend inflation expectations.	Fedesarrollo	Monthly since 2005. In 2014 Fedesarrollo started to ask for point forecasts.	No
Citibank survey	Monthly inflation expectation; yearend, two-year ahead, 12-month and 24-month expectations. Core-inflation expectations.	Citi Research	Monthly since 2003. Inflation expectation for the end of next year started to be collected in 2015.	No

Source: Authors' compilation.

Notes: Financial information providers such as Bloomberg and Reuters also have monthly and year end inflation forecasts from market analysts.

Table 5
Sources of variables in BVARX model.

Variable	Source	Notes
ENSO	NOAA	
Multivariate ENSO	NOAA	
Relative Price Gap	Authors' computation	Cyclical; HP/Hamilton filters
Monthly Inflation Surprises	Banco de la República	Obtained from the monthly financial sector survey
Intl. Food Price Gap	Authors' computation	HP/Hamilton filters using World Bank data
IP Gap	Authors	HP/Hamilton filters using DANE's data
Real Exchange Rate Gap	Authors' computation	Banco de la república data

Source: Authors' compilation.

included some sort of long-term inflation expectations. Citibank's survey focused on short-term inflation expectations (month-ahead and year-end) and gradually started to include two-year ahead inflation forecasts (see [Table 4](#)).

Fedesarrollo's survey began in 2005, but originally was focused on inflation perceptions, reporting the balance of survey respondents who thought that the inflation was going to increase/decrease. In 2014, Fedesarrollo started to ask for the expected point inflation forecast by the respondents. Since 2000, Banco de la República (Central Bank of Colombia — CB) has published a quarterly survey on a broad set of agents. Three years later, it started to publish a monthly survey of professional forecasters, and bond-derived break-even (BI) and forward break-even (FBFI) inflation rates. Most of the CB's surveys incorporate year-end and one-year ahead expectations, and it started to include two-year-ahead expectations in 2015. Market based expectations (BEI and FBFI) have information since 2003.

Break-even inflation measures are extracted from the prices of government bonds indexed to inflation (TES UVR) and fixed nominal rate bonds (TES fixed rate) at different terms (one to ten years). FBFI measures are constructed using the same market information than BEI expectations but considering its time structure. For simplicity, when we mention the FBFI at period n , we refer to the expected inflation one year after $n-1$ years that are extracted from the prices of fixed nominal rate bonds and bonds indexed to inflation. In synthesis, we selected these measures as they are available for a relatively long-time span, they are computed at different terms, and they are widely used by both analysts and policy makers. [Table 4](#) summarizes the main characteristics of inflation expectations series available for Colombia.

The sources for the remaining series used in the empirical exercise are in [Table 5](#).

Table 6
Inflation expectations principal component — short-term expectations.

Principal Components Analysis					
Sample (adjusted): 2004M06 2020M12					
Included observations: 207 after adjustments					
Balanced sample (listwise missing value deletion)					
Computed using: Ordinary correlations					
Eigenvalues: (Sum = 8, Average = 1)					
Number	Value	Difference	Proportion	Cumulative value	Cumulative proportion
1	7.09	6.17	0.79	7.09	0.79
2	0.92	0.52	0.10	8.01	0.89
3	0.40	0.04	0.04	8.41	0.93
4	0.35	0.21	0.04	8.76	0.97
5	0.15	0.08	0.02	8.91	0.99
6	0.07	0.05	0.01	8.98	1.00
7	0.01	0.00	0.00	8.99	1.00
8	0.01	0.01	0.00	9.00	1.00
9	0.00	–	0.00	9.00	1.00

Eigenvectors (loadings):

Variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9
BEI_1	0.33	–0.39	–0.33	0.05	0.49	–0.38	0.07	–0.04	0.48
BEI_2	0.35	–0.34	–0.14	0.30	0.09	–0.08	0.05	0.01	–0.80
EBEI1	0.34	–0.27	0.26	–0.41	0.07	0.24	–0.71	0.04	0.00
EBEI2	0.34	–0.16	0.43	–0.47	–0.08	0.05	0.67	0.04	0.00
FBEI_1_1	0.33	–0.23	0.14	0.60	–0.46	0.33	0.03	0.07	0.36
FOCUS_1	0.33	0.41	–0.40	–0.09	0.14	0.34	0.08	0.64	0.00
FOCUS_2	0.28	0.50	0.54	0.35	0.47	–0.08	–0.05	–0.14	0.00
BR_1	0.35	0.28	–0.02	–0.10	–0.51	–0.69	–0.17	0.12	0.00
BR_DIC1	0.35	0.28	–0.39	–0.15	–0.12	0.27	0.04	–0.74	0.00

Ordinary correlations:

	BEI_1	BEI_2	EBEI1	EBEI2	FBEI_1_1	FOCUS_1	FOCUS_2	BR_1	BR_DIC1
BEI_1	1.00								
BEI_2	0.96	1.00							
EBEI1	0.85	0.87	1.00						
EBEI2	0.78	0.81	0.97	1.00					
FBEI_1_1	0.81	0.93	0.79	0.76	1.00				
FOCUS_1	0.67	0.69	0.68	0.68	0.64	1.00			
FOCUS_2	0.45	0.56	0.57	0.64	0.63	0.76	1.00		
BR_1	0.69	0.75	0.77	0.81	0.75	0.89	0.78	1.00	
BR_DIC1	0.74	0.77	0.75	0.75	0.71	0.98	0.72	0.93	1.00

Source: Authors' calculations.

A.2. Synthetic inflation expectations measures

See [Tables 6–8](#).

A.3. BVARx impulse response for the synthetic inflation expectations measures

See [Figs. 8–10](#) to see the main results of the synthetic inflation expectations at different tenures.

A.4. Unit root tests

See [Table 9](#).

Table 7
Inflation expectations principal component — medium-term expectations.

Principal Components Analysis					
Sample (adjusted): 2004M06 2020M12					
Included observations: 207 after adjustments					
Balanced sample (listwise missing value deletion)					
Computed using: Ordinary correlations					
Eigenvalues: (Sum = 8, Average = 1)					
Number	Value	Difference	Proportion	Cumulative Value	Cumulative Proportion
1	6.99	4.62	0.64	6.99	0.64
2	2.36	1.13	0.21	9.35	0.85
3	1.23	0.98	0.11	10.59	0.96
4	0.26	0.16	0.02	10.84	0.99
5	0.10	0.06	0.01	10.94	0.99
6	0.03	0.02	0.00	10.98	1.00
7	0.02	0.01	0.00	10.99	1.00
8	0.01	0.01	0.00	11.00	1.00
9	0.00	0.00	0.00	11.00	1.00
10	0.00	0.00	0.00	11.00	1.00
11	0.00	–	0.00	11.00	1.00

Eigenvectors (loadings):											
Variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10	PC 11
BEI_3	0.34	–0.15	–0.23	–0.53	0.13	0.11	0.01	0.13	–0.04	0.45	0.52
BEI_4	0.35	–0.19	–0.12	–0.33	0.09	0.03	0.01	0.09	0.14	0.12	–0.82
BEI_5	0.36	–0.21	–0.02	–0.18	0.07	0.16	0.01	0.07	0.04	–0.85	0.18
EBEI3	0.28	0.19	–0.53	0.24	0.03	0.17	0.09	–0.72	0.03	0.01	0.00
EBEI5	0.26	0.27	–0.49	0.43	–0.03	–0.10	–0.09	0.64	–0.02	–0.01	0.00
FBEI_2_1	0.35	–0.23	0.11	0.10	–0.02	–0.71	–0.07	–0.17	–0.52	0.01	0.01
FBEI_3_1	0.32	–0.26	0.27	0.32	–0.06	–0.21	0.00	–0.04	0.75	0.14	0.16
FBEI_4_1	0.30	–0.26	0.34	0.41	–0.02	0.61	0.01	0.06	–0.38	0.19	–0.03
FOCUS_3	0.28	0.39	0.19	–0.20	–0.77	0.01	0.33	0.02	–0.02	0.00	0.00
FOCUS_4	0.23	0.47	0.27	–0.12	0.08	0.07	–0.79	–0.10	0.03	0.00	0.00
FOCUS_5	0.20	0.48	0.32	0.01	0.61	–0.08	0.50	0.05	–0.01	0.00	0.00

Ordinary correlations:											
	BEI_3	BEI_4	BEI_5	EBEI3	EBEI5	FBEI_2_1	FBEI_3_1	FBEI_4_1	FOCUS_3	FOCUS_4	FOCUS_5
BEI_3	1.00										
BEI_4	0.98	1.00									
BEI_5	0.95	0.99	1.00								
EBEI3	0.72	0.67	0.61	1.00							
EBEI5	0.61	0.56	0.51	0.98	1.00						
FBEI_2_1	0.86	0.93	0.96	0.52	0.44	1.00					
FBEI_3_1	0.74	0.84	0.91	0.37	0.30	0.97	1.00				
FBEI_4_1	0.66	0.78	0.85	0.28	0.22	0.91	0.98	1.00			
FOCUS_3	0.47	0.49	0.49	0.58	0.61	0.48	0.43	0.40	1.00		
FOCUS_4	0.32	0.34	0.34	0.49	0.55	0.35	0.31	0.30	0.94	1.00	
FOCUS_5	0.22	0.24	0.26	0.41	0.48	0.28	0.27	0.26	0.86	0.96	1.00

Source: Authors' calculations.

A.5. BVAR estimation procedure

This section is based on [Dieppe et al. \(2016\)](#). In our estimation we use an independent normal-Wishart prior with unknown Σ and arbitrary ω_0 . We start by defining the likelihood of the data in the following form:

$$f(y | \beta, \Sigma) \propto |\Sigma|^{-\frac{T}{2}} \exp\left[-\frac{1}{2}(\beta - \hat{\beta})'(\Sigma \otimes (X'X)^{-1})^{-1}(\beta - \hat{\beta})\right] \times \exp\left[-\frac{1}{2}\text{tr}\left\{\sum_{t=1}^T (Y - X\hat{\beta})'(Y - X\hat{\beta})\right\}\right] \quad (19)$$

Table 8

Inflation expectations principal component — Long-term expectations.

Principal Components Analysis					
Sample (adjusted): 2004M06 2020M12					
Included observations: 207 after adjustments					
Balanced sample (listwise missing value deletion)					
Computed using: Ordinary correlations					
Eigenvalues: (Sum = 10, Average = 1)					
Number	Value	Difference	Proportion	Cumulative value	Cumulative proportion
1	8.81	7.55	0.80	8.81	0.80
2	1.26	0.43	0.11	10.06	0.91
3	0.83	0.72	0.08	10.89	0.99
4	0.11	0.11	0.01	11.00	1.00
5	0.00	0.00	0.00	11.00	1.00
6	0.00	0.00	0.00	11.00	1.00
7	0.00	0.00	0.00	11.00	1.00
8	0.00	0.00	0.00	11.00	1.00
9	0.00	0.00	0.00	11.00	1.00
10	0.00	0.00	0.00	11.00	1.00
11	0.00	–	0.00	11.00	1.00

Eigenvectors (loadings):

Variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10	PC 11
BEI_6	0.30	0.34	–0.21	–0.27	0.07	0.32	0.24	0.27	0.49	0.44	0.08
BEI_7	0.32	0.27	–0.19	–0.17	0.01	0.24	–0.10	0.43	–0.44	–0.54	0.15
BEI_8	0.32	0.20	–0.16	–0.13	–0.07	0.29	–0.01	–0.80	–0.05	–0.14	–0.23
BEI_9	0.33	0.14	–0.10	–0.13	–0.08	–0.68	0.47	–0.07	–0.34	0.18	0.08
BEI_10	0.34	0.07	–0.04	–0.17	0.00	–0.45	–0.74	0.05	0.26	0.03	–0.15
EBEI8	0.09	0.60	0.75	0.26	–0.02	0.00	0.00	0.00	0.00	0.00	0.00
FBEI_5_1	0.32	–0.05	–0.20	0.64	0.60	–0.08	0.10	–0.03	0.19	–0.17	0.06
FBEI_6_1	0.33	–0.18	–0.05	0.43	–0.31	0.26	–0.24	0.08	–0.41	0.53	0.02
FBEI_7_1	0.32	–0.28	0.12	0.15	–0.50	–0.01	0.29	0.21	0.32	–0.32	–0.45
FBEI_8_1	0.30	–0.35	0.28	–0.13	–0.14	0.04	–0.02	–0.18	0.20	–0.13	0.76
FBEI_9_1	0.27	–0.39	0.42	–0.37	0.51	0.14	0.06	0.08	–0.22	0.13	–0.32

Ordinary correlations:

	BEI_6	BEI_7	BEI_8	BEI_9	BEI_10	EBEI8	FBEI_5_1	FBEI_6_1	FBEI_7_1	FBEI_8_1	FBEI_9_1
BEI_6	1.00										
BEI_7	1.00	1.00									
BEI_8	0.98	1.00	1.00								
BEI_9	0.97	0.98	1.00	1.00							
BEI_10	0.94	0.97	0.98	1.00	1.00						
EBEI8	0.36	0.33	0.31	0.30	0.29	1.00					
FBEI_5_1	0.86	0.90	0.93	0.94	0.94	0.11	1.00				
FBEI_6_1	0.80	0.85	0.89	0.92	0.94	0.11	0.98	1.00			
FBEI_7_1	0.71	0.77	0.82	0.86	0.90	0.12	0.91	0.98	1.00		
FBEI_8_1	0.60	0.66	0.72	0.78	0.83	0.15	0.81	0.91	0.98	1.00	
FBEI_9_1	0.49	0.56	0.62	0.69	0.75	0.17	0.70	0.83	0.93	0.98	1.00

Source: Authors' calculations.

Concerning the prior for β , we assume that it follows a multivariate normal distribution with mean β_0 ($aq \times 1$ vector) and a covariance matrix ω_0 which is an arbitrary $q \times q$ matrix. Hence:

$$\beta \sim \mathcal{N}(\beta_0, \Omega_0) \quad (20)$$

In typical applications, Ω_0 will take the form of the Minnesota covariance matrix but any choice is possible. Similarly, β_0 will typically be defined as the Minnesota β_0 vector but any structure could be adopted. Given β_0 and Ω_0 , the prior density for β is given by:

$$\pi(\beta) \propto \exp\left[-\frac{1}{2}(\beta - \beta_0)' \Omega_0^{-1}(\beta - \beta_0)\right] \quad (21)$$

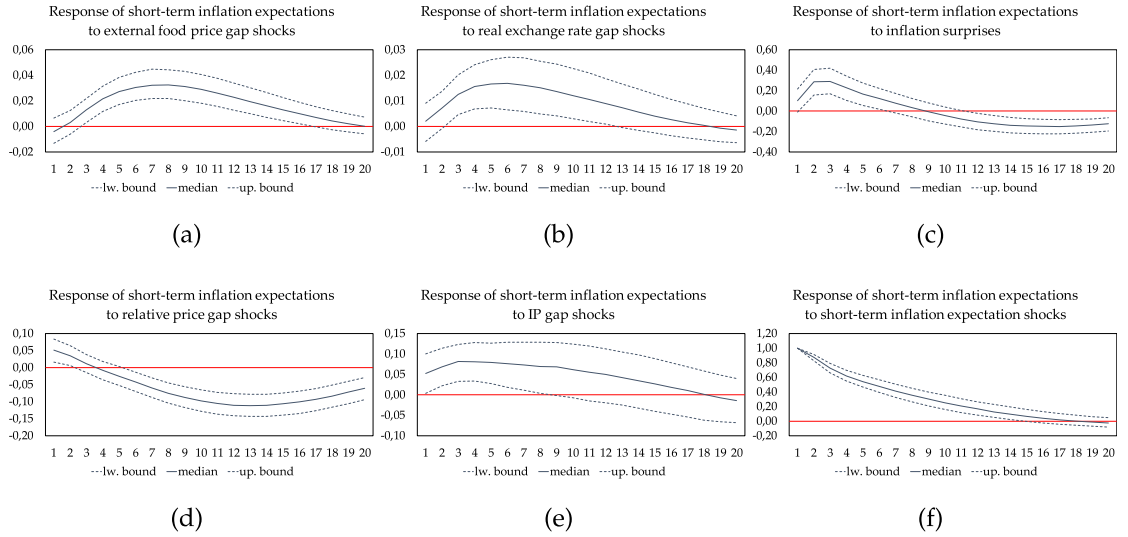


Fig. 8. BVARx impulse responses (endogenous variables) Short-run inflation expectations.

Source: Author's calculations.

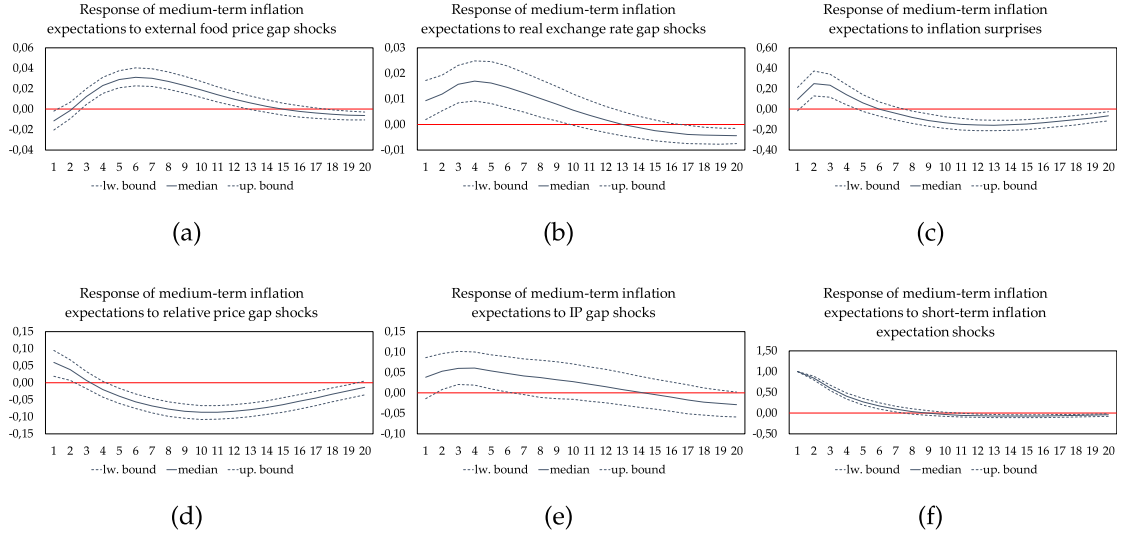


Fig. 9. BVARx impulse responses (endogenous variables) Medium-term inflation expectations.

Source: Author's calculations.

The prior distribution for Σ is an inverse Wishart distribution, with scale matrix S_0 and degrees of freedom α_0 :

$$\Sigma \sim JW(S_0, \alpha_0) \quad (22)$$

Thus, the prior density of Σ is given by:

$$\pi(\Sigma) \propto |\Sigma|^{-\frac{(\alpha_0+n+1)}{2}} \exp\left[-\frac{1}{2}\text{tr}\{\Sigma^{-1}S_0\}\right] \quad (23)$$

The following equation lead to a posterior of the following form:

$$\begin{aligned} \pi(\beta, \Sigma | y) &\propto |\Sigma|^{-\frac{T+\alpha_0+n+1}{2}} \exp\left[-\frac{1}{2}(\beta - \bar{\beta})' \bar{\Omega}^{-1} (\beta - \bar{\beta})\right] \\ &\times \exp\left[-\frac{1}{2}\hat{\beta}'(\Sigma^{-1} \otimes X'X)\hat{\beta} + \beta_0' \Omega_0^{-1} \beta_0 - \bar{\beta}' \bar{\Omega}^{-1} \bar{\beta}\right] \\ &\times \exp\left[-\frac{1}{2}\text{tr}\{\Sigma^{-1}[(Y - X\hat{\beta}) + S_0]\}\right] \end{aligned} \quad (24)$$

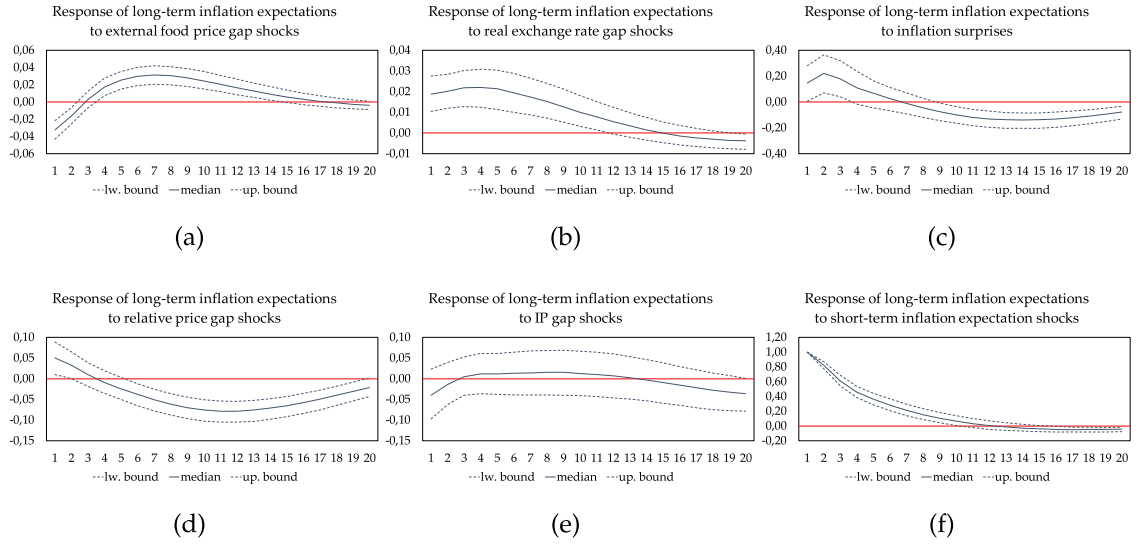


Fig. 10. BVARx impulse responses (endogenous variables) Long-run inflation expectations.
Source: Authors' calculations

Where:

$$\hat{\beta} = (X'X)^{-1}X'Y$$

$$\epsilon \sim \mathcal{N}(0, \bar{\Sigma}) \quad \text{Where } \bar{\Sigma} = \sum \otimes I_t$$

$$\bar{\Omega} = [\Omega_0^{-1} + \sum^{-1} \otimes X'X]^{-1}$$

$$\bar{\beta} = \bar{\Omega}[\Omega_0^{-1}\beta_0 + (\sum^{-1} \otimes X')y]$$

Importantly, it is not possible to derive an analytical marginal distribution for β and Σ from expression (A6). However, it is possible to derive their conditional distributions. To do so, one considers the joint posterior distribution for all parameters and retain only the terms involving parameters whose conditional distribution must be determined. All terms do not involve these parameters and do not contain information about their distribution and thus, are relegated to the proportionality constant. With these conditional distributions it is possible to use Gibbs sampling to obtain random draws from the unconditional posterior distributions of the parameters of interest.

A.6. Robustness test using the multivariate ENSO index

Given that alternative measures could be used to assess ENSO fluctuations, this appendix re-estimates the BVARx models outlined in Section 4, using the Multivariate ENSO Index (MEI.v2) as a robustness check. According to the National Oceanic and Atmospheric Administration (NOAA), the bi-monthly MEI.v2 is the leading time series of the combined Empirical Orthogonal Function (EOF) of five variables: sea level pressure (SLP), sea surface temperature (SST), zonal and meridional components of the surface wind, and outgoing longwave radiation (OLR) over the tropical Pacific basin (30° S–30° N and 100° E–70° W). Fig. 11 demonstrates that the impulse responses of short-term, medium-term, and long-term synthetic inflation expectations are similar.

Table 9

Unit root test for the series used in the BVARX model.

At Level	UNIT ROOT TEST TABLE (PP)									UNIT ROOT TEST TABLE (ADF)									Decision
	With Constant			With Constant & Trend			Without Constant & Trend			With Constant			With Constant & Trend			Without Constant & Trend			
	t-Statistic	Prob.		t-Statistic	Prob.		t-Statistic	Prob.		t-Statistic	Prob.		t-Statistic	Prob.		t-Statistic	Prob.		
BVARx Variables																			
ENSO	-3.26	0.02	**	-3.25	0.08	*	-3.26	0.00	***	-3.37	0.01	**	-3.52	0.04	**	-3.36	0.00	***	I(0)
Relative price gap	-3.17	0.02	**	-3.16	0.09	*	-3.17	0.00	***	-6.10	0.00	***	-6.09	0.00	***	-6.12	0.00	***	I(0)
Monthly inflation surprises	-11.21	0.00	***	-11.21	0.00	***	-11.24	0.00	***	-5.80	0.00	***	-5.81	0.00	***	-5.82	0.00	***	I(0)
IP Gap	-2.82	0.06	*	-2.78	0.21		-2.82	0.00	***	-3.95	0.00	***	-3.93	0.01	**	-3.96	0.00	***	I(0)
International food prices gap	-3.47	0.01	***	-3.45	0.05	**	-3.47	0.00	***	-4.07	0.00	***	-4.05	0.01	***	-4.08	0.00	***	I(0)
Real exchange rate gap	-4.45	0.00	***	-4.44	0.00	***	-4.46	0.00	***	-5.40	0.00	***	-5.38	0.00	***	-5.41	0.00	***	I(0)
Synthetic inflation expectation index (deviation from the inflation target)																			
Short-term inflation expectations	-3.37	0.01	**	-3.36	0.06	*	-3.14	0.00	***	-3.75	0.00	***	-3.73	0.02	**	-3.05	0.00	***	I(0)
Medium-term inflation expectations	-4.68	0.00	***	-4.68	0.00	***	-3.73	0.00	***	-4.24	0.00	***	-4.23	0.00	***	-3.54	0.00	***	I(0)
Long-term inflation expectations	-4.33	0.00	***	-4.33	0.00	***	-2.81	0.01	***	-4.10	0.00	***	-4.13	0.01	***	-2.44	0.01	**	I(0)
Break-even inflation																			
BEI_1	-3.53	0.01	***	-3.55	0.04	**	-3.52	0.00	***	-3.24	0.02	**	-3.24	0.08	*	-3.27	0.00	***	I(0)
BEI_2	-3.83	0.00	***	-3.85	0.02	**	-3.68	0.00	***	-3.78	0.00	***	-3.79	0.02	**	-3.66	0.00	***	I(0)
BEI_3	-4.15	0.00	***	-4.17	0.01	***	-3.82	0.00	***	-4.10	0.00	***	-4.11	0.01	***	-3.75	0.00	***	I(0)
BEI_4	-4.37	0.00	***	-4.40	0.00	***	-3.79	0.00	***	-4.31	0.00	***	-4.33	0.00	***	-3.69	0.00	***	I(0)
BEI_5	-4.50	0.00	***	-4.54	0.00	***	-3.69	0.00	***	-4.66	0.00	***	-4.72	0.00	***	-3.53	0.00	***	I(0)
BEI_6	-4.62	0.00	***	-4.66	0.00	***	-3.53	0.00	***	-4.64	0.00	***	-4.20	0.01	***	-3.33	0.00	***	I(0)
BEI_7	-4.60	0.00	***	-4.64	0.00	***	-3.39	0.00	***	-4.19	0.00	***	-4.22	0.01	***	-3.13	0.00	***	I(0)
BEI_8	-4.21	0.00	***	-4.21	0.01	***	-3.30	0.00	***	-4.22	0.00	***	-4.23	0.00	***	-2.93	0.00	***	I(0)
BEI_9	-4.52	0.00	***	-4.54	0.00	***	-3.14	0.00	***	-4.36	0.00	***	-4.41	0.00	***	-2.76	0.01	***	I(0)
BEI_10	-4.42	0.00	***	-4.42	0.00	***	-3.06	0.00	***	-4.25	0.00	***	-4.28	0.00	***	-2.60	0.01	***	I(0)
Forward Break-even inflation																			
FBEI_1_1	-4.38	0.00	***	-4.38	0.00	***	-4.00	0.00	***	-4.43	0.00	***	-4.42	0.00	***	-4.00	0.00	***	I(0)
FBEI_2_1	-4.80	0.00	***	-4.82	0.00	***	-3.91	0.00	***	-4.88	0.00	***	-4.93	0.00	***	-3.83	0.00	***	I(0)
FBEI_3_1	-4.78	0.00	***	-4.93	0.00	***	-3.58	0.00	***	-4.14	0.00	***	-4.24	0.00	***	-2.47	0.01	**	I(0)
FBEI_4_1	-4.71	0.00	***	-4.42	0.00	***	-3.25	0.00	***	-4.00	0.00	***	-4.08	0.01	***	-2.32	0.02	**	I(0)
FBEI_5_1	-4.54	0.00	***	-4.58	0.00	***	-3.00	0.00	***	-4.04	0.00	***	-4.12	0.01	***	-2.57	0.01	**	I(0)
FBEI_6_1	-4.37	0.00	***	-4.42	0.00	***	-2.75	0.01	***	-3.78	0.00	***	-3.78	0.02	**	-2.29	0.02	**	I(0)
FBEI_7_1	-4.39	0.00	***	-4.38	0.00	***	-2.72	0.01	***	-3.61	0.01	***	-3.60	0.03	**	-2.10	0.03	**	I(0)
FBEI_8_1	-4.41	0.00	***	-4.39	0.00	***	-2.67	0.01	***	-3.56	0.01	***	-3.54	0.04	**	-2.02	0.04	**	I(0)
FBEI_9_1	-4.44	0.00	***	-4.44	0.00	***	-2.76	0.01	***	-3.57	0.01	***	-3.57	0.04	**	-1.81	0.07	*	I(0)
E-BEI (correcting for liquidity)																			
1Y - EBEI	-3.27	0.02	**	-3.25	0.08	*	-3.28	0.00	***	-3.26	0.02	**	-3.27	0.07	*	-3.27	0.00	***	I(0)
2Y - EBEI	-3.07	0.03	**	-3.05	0.12		-3.07	0.00	***	-3.49	0.01	***	-3.60	0.03	**	-3.49	0.00	***	I(0)
3Y - EBEI	-2.97	0.04	**	-2.97	0.14	n0	-2.94	0.00	***	-3.43	0.01	**	-3.58	0.03	**	-3.38	0.00	***	I(0)
5Y - EBEI	-2.85	0.05	*	-2.91	0.16	n0	-2.66	0.01	***	-2.83	0.06	*	-3.50	0.04	**	-2.64	0.01	***	I(0)
8Y - EBEI	-2.70	0.08	*	-2.81	0.19	n0	-2.24	0.02	**	-2.74	0.07	*	-2.87	0.17	n0	-2.28	0.02	**	I(0)
Focus Economics Survey																			
FOCUS_1	-3.04	0.03	**	-3.02	0.13		-2.82	0.00	***	-2.86	0.05	*	-2.84	0.18		-2.71	0.01	***	I(0)
FOCUS_2	-4.36	0.00	***	-4.47	0.00	***	-3.82	0.00	***	-4.33	0.00	***	-4.42	0.00	***	-3.88	0.00	***	I(0)
FOCUS_3	-4.11	0.00	***	-4.28	0.00	***	-3.91	0.00	***	-3.98	0.00	***	-3.02	0.13		-3.80	0.00	***	I(0)
FOCUS_4	-3.59	0.01	***	-4.05	0.01	***	-3.60	0.00	***	-2.17	0.22		-2.69	0.24		-2.19	0.03	**	I(0)
FOCUS_5	-3.66	0.01	***	-4.04	0.01	***	-3.58	0.00	***	-2.01	0.28		-2.50	0.33		-1.99	0.05	**	I(0)
Central Bank Survey																			
End of the current year	-2.85	0.05	*	-2.81	0.19		-2.72	0.01	***	-2.66	0.08	*	-2.63	0.27		-2.59	0.01	***	I(0)
1-year ahead	-3.22	0.02	**	-3.29	0.07	*	-2.76	0.01	***	-3.01	0.04	**	-3.06	0.12		-2.69	0.01	***	I(0)

*MacKinnon (1996) one-sided p-values.

Notes: (*)Significant at the 10%; (**)Significant at the 5%; (***) Significant at the 1%, and (no) Not Significant.

Source: Authors' calculations.

A.7. Complete model structure

IS Curve and potential GDP growth

$$\begin{aligned}
\bar{y}_t &= \bar{y}_{t-1} + \frac{\Delta \bar{y}_t}{4} \\
\Delta \bar{y}_t &= \rho_{\Delta \bar{y}} \Delta \bar{y}_{t-1} + (1 - \rho_{\Delta \bar{y}})(\Delta \bar{y}_{ss} + \kappa_{\Delta \bar{y}}(\Delta \bar{r}_{ss}^{oil} - \Delta \bar{r}_{ss}^{oil})) + \epsilon_t^{\Delta \bar{y}} \\
\hat{y}_t &= \beta_1 \hat{y}_{t-1} + \beta_2 E_t \hat{y}_{t+1} - \beta_\phi \phi_t + \beta_{\hat{y}^*} \hat{y}_t^* + \beta_{\hat{r}_{ss}^{oil}} \hat{r}_{ss}^{oil} + \eta_t^{\hat{y}} \\
\phi_t &= \beta_{\hat{r}} \hat{r}_t - (1 - \beta_{\hat{r}}) \hat{z}_t \\
\eta_t^{\hat{y}} &= \beta_{\eta^{\hat{y}}} \eta_{t-1}^{\hat{y}} + \epsilon_t^{\hat{y}}
\end{aligned}$$

Phillips Curves, Relative Prices and CPI aggregation

$$\pi_t^j = \alpha_{\pi^j} \pi_{t-1}^j - (1 - \alpha_{\pi^j}) \pi_t^{e,j} + \alpha_{rmc^j}^{\pi^j} rmc_t^j + \epsilon_t^{\pi^j}$$

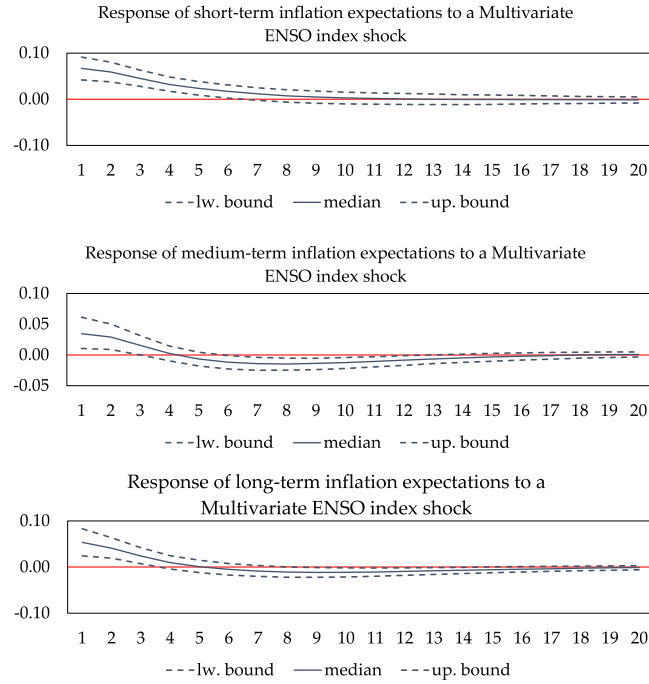


Fig. 11. BVARx impulse responses to a Multivariate ENSO Index shock.
Source: Authors' calculations.

For $j = \text{Goods (g), Services (s), Regulated (r), and Food (f)}$.

$$rmc_t^j = \begin{cases} \alpha_{\hat{y}}^{rmc^j} \hat{y} + (1 - \alpha_{\hat{y}}^{rmc^j})(\hat{z}_t - \hat{r}p_t^j) \text{ for } j = g, s \\ \alpha_{\hat{y}}^{rmc^j} \hat{y} + (1 - \alpha_{\hat{y}}^{rmc^j})(-\hat{r}p_t^{F*} + \hat{z}_t + \lambda^f ENSO_t - \hat{r}p_t^j) \text{ for } j = f \\ \alpha_{\hat{y}}^{rmc^j} \hat{y} + (1 - \alpha_{\hat{y}}^{rmc^j})(-\hat{r}p_t^{oil} + \hat{z}_t + \lambda^f ENSO_t - \hat{r}p_t^j) \text{ for } j = r \end{cases}$$

$$\hat{r}p_t^j = rp_t^j - \bar{r}p_t^j$$

$$rp_t^j = p_t^j - p_t$$

$$\bar{r}p_t^j = \bar{r}p_{t-1}^j + \frac{\Delta \bar{r}p_t^j}{4}$$

$$\Delta \bar{r}p_t^j = \rho_{\Delta \bar{r}p^j} \Delta \bar{r}p_{t-1}^j + (1 - \rho_{\Delta \bar{r}p^j}) \Delta \bar{r}p_{ss}^j + \epsilon^{\Delta \bar{r}p^j}$$

$$p_t = \omega^G p^G + \omega^S p^S + \omega^R p^R + \omega^F p^F + \eta_t^{p_t}$$

$$\eta_t^{p_t} = \eta_{t-1}^{p_t} + \epsilon_t^{p_t}$$

$$0 = \omega^G \hat{r}p_t^G + \omega^S \hat{r}p_t^S + \omega^R \hat{r}p_t^R + \omega^F \hat{r}p_t^F$$

Inflation Expectations and credibility

$$\pi_t^{e,j} = c_t \pi_t^j + (1 - c_t)(\pi_{t+1}^j + \psi ENSO_t) + \epsilon_t^{\pi^{e,j}} \text{ for } j = f, r$$

$$\pi_t^{e,j} = c_t \pi_t^j + (1 - c_t)(\pi_{t+1}^j) + \epsilon_t^{\pi^{e,j}} \text{ for } j = g, s$$

$$c_t = \rho^c c_{t-1} + (1 - \rho^c) \xi_t$$

$$\xi_t = \frac{(\epsilon_t^{bad})^2}{(\epsilon_t^{bad})^2 + (\epsilon_t^{good})^2}$$

$$\epsilon_t^{bad} = \pi_t - [\rho^e \pi_{t-1} + (1 - \rho^e) \pi_t^{bad}]$$

$$\epsilon_t^{good} = \pi_t - [\rho^e \pi_{t-1} + (1 - \rho^e) \pi_t^{good}]$$

To control for boundary conditions, we set $\xi_t = 0$ if $\epsilon_t^{bad} > 0$ and $\xi_t = 0$ if $\epsilon_t^{good} < 0$.

Monetary Policy Rule and Interest Rates

$$\begin{aligned}
i_t &= \rho_i i_{t-1} + (1 - \rho_i) \left[\bar{i}_t + \psi_\pi (E_t \pi_{t+3}^A - E \bar{\pi}_{t+3}^A) + \psi_y \hat{y}_t \right] + \epsilon_t^i \\
\bar{\pi}_t^A &= \rho_{\bar{\pi}^y} \bar{\pi}_{t-1}^A + (1 - \rho_{\bar{\pi}^y}) \bar{\pi}_{ss}^A + \epsilon_t^{\bar{\pi}^A} \\
\bar{i}_t &= \bar{r}_t + E_t \pi_{t+1} \\
\bar{r}_t &= \bar{r}_t^* + \overline{CDS}_t + \Delta \bar{z}_{ss} \\
\hat{r}_t &= r_t - \bar{r}_t \\
r_t &= i_t - E_t \pi_{t+1}
\end{aligned}$$

Determination of the foreign exchange rate

$$\begin{aligned}
\Delta s_{t+1} &= i_t^* - i_t + prem + \epsilon_t^{ls} \\
\Delta E_t s_{t+1} &= 4(E_t s_{t+1} - s_t) \\
z_t &= \bar{z}_t + \hat{z}_t \\
z_t &= s_t + p_t^* - p_t \\
\hat{z}_t &= \hat{z}_{t-1} + \frac{\Delta \bar{z}_t}{4} \\
\Delta \bar{z}_t &= \rho_{\Delta z} \Delta \bar{z}_{t-1} + (1 - \rho_{\Delta z})(\Delta \bar{z}_{ss} - \epsilon_{\Delta \bar{z}}(\Delta \bar{r}_{ss}^{oil} - \Delta \bar{r}_{ss}^{oil})) + \epsilon_t^{\Delta \bar{z}}
\end{aligned}$$

Exogenous variables

$$\begin{aligned}
\hat{r}_{p_t}^{oil} &= r p_t^{oil} - \bar{r}_{p_t}^{oil} \\
r p_t^{oil} &= p_t^{oil} - p_t^* \\
\bar{r}_{p_t}^{oil} &= \bar{r}_{p_{t-1}}^{oil} + \frac{\Delta \bar{r}_{p_t}^{oil}}{4} \\
\Delta \bar{r}_{p_t}^{oil} &= \rho_{\bar{r}^{oil}} \bar{r}_{p_{t-1}}^{oil} + (1 - \rho_{\bar{r}^{oil}}) \Delta \bar{r}_{ss}^{oil} + \epsilon_t^{\Delta \bar{r}^{oil}} \\
\hat{r}_{p_t}^{oil} &= \rho_{\hat{r}^{oil}} \hat{r}_{p_{t-1}}^{oil} + \epsilon_t^{\hat{r}^{oil}} \\
y_t^* &= \rho_{y^*} y_{t-1}^* + \epsilon_t^{y^*} \\
p_t^* &= p_{t-1}^* + \frac{\pi_t^*}{4} \\
\pi_t^* &= \rho_{\pi^*} \pi_{t-1}^* + (1 - \rho_{\pi^*}) \pi_{ss}^* + \epsilon_t^{\pi^*} \\
i_t^* &= \rho_{i^*} i_{t-1}^* + (1 - \rho_{i^*}) i_{ss}^* + \epsilon_t^{i^*} \\
\bar{i}_t^* &= \bar{r}_t^* + E_t \pi_{t+1}^* \\
\bar{r}_t^* &= \rho_{\bar{r}^*} \bar{r}_{t-1}^* + (1 - \rho_{\bar{r}^*}) \bar{r}_{ss}^* + \epsilon_t^{\bar{r}^*} \\
\overline{CDS}_t &= \rho_{\overline{CDS}} \overline{CDS}_{t-1} + (1 - \rho_{\overline{CDS}}) \overline{CDS}_{ss} + \epsilon_t^{\overline{CDS}} \\
\overline{CDS}_t &= \rho_{\overline{CDS}} \overline{CDS}_{t-1} + (1 - \rho_{\overline{CDS}}) \overline{CDS}_{ss} + \epsilon_t^{\overline{CDS}} \\
\hat{r}_{p_t}^{F*} &= \rho_{\hat{r}^{F*}} \hat{r}_{p_{t-1}}^{F*} + \epsilon_t^{\hat{r}^{F*}}
\end{aligned}$$

A.8. Credibility mechanism in the semi-structural model

In this annex, we explore the dynamics of the model in response to a 1-unit increase in the ENSO shock under two different scenarios.¹⁷ Both scenarios start from a steady state for all variables, with the exception of the “low credibility” scenario, where the initial point is 50 basis points lower than the steady state.

The ENSO shock directly affects food and regulated inflation. This increase in these specific baskets is a direct consequence of adverse weather’s impact on the marginal costs for these baskets and its effect on inflation expectations, which also rise as a result of the shock. As a consequence, both headline inflation and total inflation expectations increase. In this setting, the monetary policy authority must react by increasing interest rates to anchor inflation expectations. The output gap decreases as a result of the tighter monetary policy (see Fig. 12).

When credibility starts from a lower initial point, the impact of the ENSO shock on inflation and inflation expectations is both higher and more persistent. Consequently, more substantial efforts from monetary policy are required to stabilize the situation.

¹⁷ This is equivalent to 1 degree Celsius anomaly in the ENSO index.

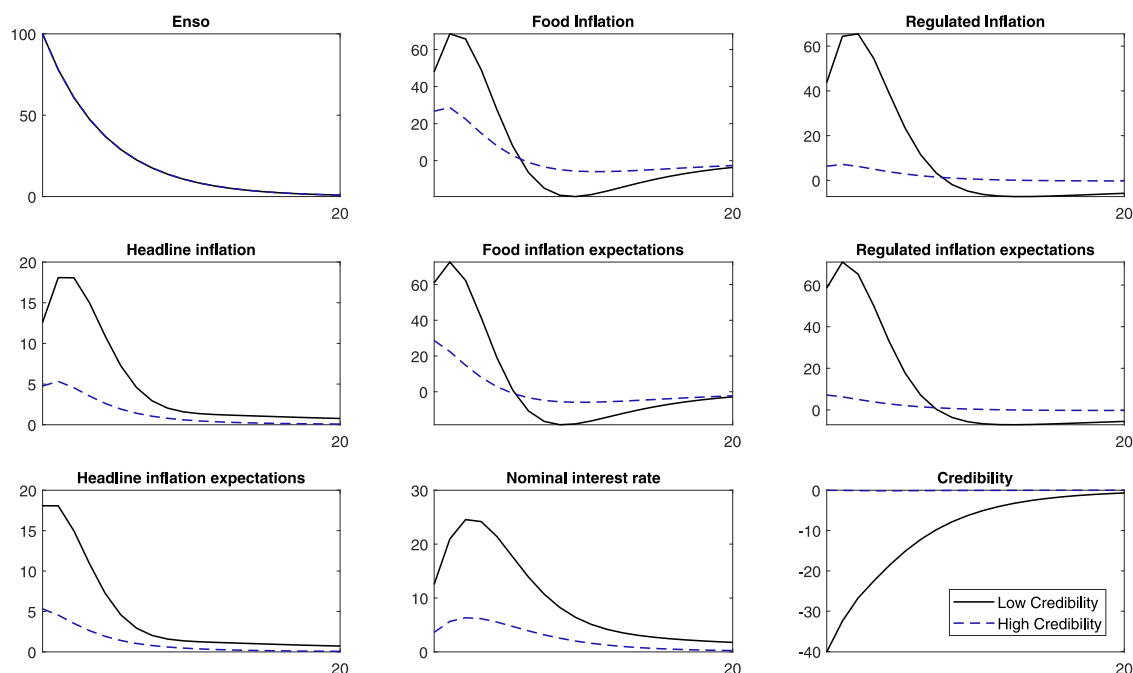


Fig. 12. Response of selected variables (deviation from the steady state) to an ENSO shock under low and high credibility.

Source: Authors' calculations.

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