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QPM-Based Analysis of Weather Shocks and Monetary Policy in Developing Countries

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Prepared by Valeriu Nalban and Luis-Felipe Zanna

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ABSTRACT: Weather-related shocks are of a supply-side nature and therefore present significant challenges for monetary policy. Using a Quarterly Projection Model (QPM) framework, this paper provides an overview of weather-relevant analytical exercises that help to understand the propagation channels of these shocks, the policy trade-offs they imply, and the ensuing implications for the conduct of monetary policy. The exercises highlight the important role of economic characteristics and frictions, such as the weight of food expenditures in the consumption basket, the GDP share of the agriculture sector, the degree of imports substituting for the damaged domestic agricultural supply, the extent of inflation expectations' anchoring and central bank credibility, and the specific characteristics of the monetary policy framework, including the degree of exchange rate flexibility and the definition of the price stability objective. Overall, the extent of these characteristics and frictions in developing countries render them more vulnerable and constitute bigger challenges in monetary policy conduct relative to developed economies.

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Contents

1. Introduction

Weather-related shocks, such as floods and droughts, are prevalent in developing economies and complicate the conduct of monetary policy. Consequently, there is a need to analyze their macroeconomic effects and transmission mechanisms as integral components of the economic landscape and monetary policy discussions that inform policy decisions in central banks (CBs). This analysis is often supported by models and tools, including Quarterly Projection Models (QPMs) that are at the core of the Forecasting and Policy Analysis Systems (FPAS) that support CBs' policy processes.

The current generation of QPMs represents a semi-structural framework that focuses on the business cycle components—gaps and trends—of key macroeconomic variables. For inflation targeting CBs, this framework also incorporates an endogenous, forward-looking monetary policy response consistent with their objective—e.g., the interest rate path that ensures inflation forecast returns to the target over the medium term. Considerations about exchange rate policies, such as those specific to fixed exchange rate regimes or managed floats, can also be incorporated. Documented examples of the development and policy application of QPMs conducted within the IMF Institute Capacity for Development (ICD) technical assistance (TA) practice include Abradu-Otoo et al. (2022) and Abradu-Otoo et al. (2024) for Ghana, Al-Sharkas et al. (2023) for Jordan, Baksa et al. (2020) for Cambodia, Baksa et al. (2021) for Morocco, Dakila et al. (2024) for the Philippines, Epstein et al. (2022) for Vietnam, John et al. (2023) for India, Musa et al. (2024) for the Democratic Republic of the Congo, and Vlcek et al. (2020) for Rwanda.

While this generation of QPMs has had limited scope for the explicit analysis of weather-related phenomena, some elements are still incorporated into the policy analysis.[2] For example, Dakila et al. (2024) simulate temporary increases in world food prices on account of *El Niño* phenomenon and study their repercussions on the Philippine economy, with second-round effects on domestic inflation prompting a tighter monetary policy stance at the cost of economic deceleration. Abradu-Otoo et al. (2024) use the Bank of Ghana QPM to study the propagation of negative agriculture shocks, their contribution to food price dynamics, and their implications for the monetary policy conduct. John et al. (2023) describe the updated Reserve Bank of India QPM, which features a (moving average polynomial) "monsoon" shock in the dynamics of food inflation.

This paper introduces a QPM-based conceptual framework which on one hand is rather general and captures the key characteristics of low-income developing countries (LIDCs) and emerging market (EM) economies (like a high share of food within the consumption basket), while on the other hand can be easily customized and calibrated to a particular country. The conceptual framework can help provide a macroeconomically consistent narrative behind forecasts that may involve weather-related shocks, which can aid in the communication of the economic outlook and policy decisions. Accordingly, the paper

[2] Even if not explicitly considered in their analytical framework, central banks often make explicit reference to weather-related shocks and their impact on agriculture and food prices. Taking the Bank of Ghana example, before the model extension introduced in Abradu-Otoo et al. (2024), the September 2014 Monetary Policy Report states that "conditioned on good harvests, adequate supply of foodstuffs on the market help to moderate food prices and in turn food inflation" (page 6), while the September 2016 Monetary Policy Report indicates that "the developments in food prices during the harvest season will determine the extent to which food prices will evolve […] as the food season was derailed by the delays in rainfall" (page 15). Both references suggest a negative relationship between agriculture output and food prices, which is the key element in the benchmark QPM used in this paper.

provides a wide range of analytical considerations on how to introduce and analyze weather-related shocks in QPMs. The premise is that QPM-based analytical exercises can approximate the propagation of shocks and inform the decision-making process in a reduced form, without explicit modeling of weather data. The objective is to incorporate these analytical considerations as specific model features while maintaining the parsimonious structure of QPMs to ensure their effectiveness as policy tools and their ability to help inform and communicate policy decisions.

Identifying the analytical considerations for the QPMs is complex due to the multifaceted nature of weather-related shocks. These shocks often impact key macroeconomic variables at the sectoral level, such as reduced agricultural output and subsequent increases in food prices during a drought, directly affecting the central bank objectives and monetary policy formulation. Additionally, they have wide-ranging economic effects. In the short run, extreme weather events (e.g., hurricanes, floods, wildfires, droughts) cause physical damage, infrastructure costs, and supply chain disruptions, with significant implications for the financial sector (insurance claims and premiums, stranded assets, deterioration of balance sheets) and price dynamics. In the long term, gradual increases in temperatures and changes in weather patterns have major implications for natural systems, labor productivity (particularly in outdoor activities), agricultural yields, relative prices, internal and cross-border migration, and energy production and demand.

Policy responses to these disruptions are similarly complex, ranging from fiscal expenditures on rebuilding infrastructure and targeted relief for affected populations, to longer-term strategies regarding the energy transition. While the role of fiscal policy is somewhat evident given its mandate and direct impact on affected agents, the remit of monetary policy is less well-defined. Furthermore, the macroeconomic effects of weather-related shocks may depend on the degree of development of the country. These shocks are likely to be more disruptive in LIDCs and EM economies, where response capacity and resource availability are more limited, compared to advanced economies (AEs).

Despite these challenges, the empirical literature can help guide the identification of key analytical considerations to be introduced in QPMs for an effective analysis of weather-related shocks. NGFS (2020) and NGFS (2023) provide extensive reviews of the impacts of natural disasters and weather-related shocks across time horizons, affected variables, and transmission channels. Moreover, a recent body of works provides strong empirical evidence of their adverse economic effects. For example, Kotz et al. (2023) employ a global dataset to show that air temperature increases lead to higher prices, with food inflation reacting twice as strong as headline inflation. Using vector autoregressions, Ciccarelli and Marotta (2021) estimate that, in OECD countries, physical risk climate shocks resemble negative demand shocks, while transition risk shocks are of a supply-side nature, with climate shocks having overall larger effects in more recent data samples. Kabundi et al. (2022) use local projections to show heterogenous economic impacts, depending on the type and intensity of the shock, country income levels, and monetary policy frameworks. They find that droughts have the highest inflationary impact and propagate through food price increases, especially in LIDCs, where the share of food expenditure is generally higher, suggesting a more cautious monetary policy approach in the face of supply-type shocks and the importance of well-anchored inflation expectations. Cantelmo et al. (2024) analyze IMF reports for disaster-prone countries, finding no systematic central bank response to climate shocks.

Likewise, the macro-modeling literature can provide structural guidance for a proper assessment and disentangling of the various transmission channels operating in the case of weather-related shocks. In this regard, a quickly expanding workstream based on dynamic stochastic general equilibrium (DSGE) models is emerging. Contributions include Gallic et al. (2020), who introduce a weather-dependent agricultural sector, with results pointing to a non-trivial impact of weather shocks to macroeconomic volatility and welfare; McKibbin et al. (2020), who compare a range of monetary policy frameworks (including inflation targeting, nominal income targeting, and price level targeting) to highlight their relative costs and benefits in terms of climate-related trade-offs; and Kara and Thakoor (2023), who consider natural disasters as left-tail productivity shocks to highlight the associated trade-offs for the monetary policy conduct. Ciccarelli et al. (2024) document the on-going experience of the European Central Bank with incorporating climate considerations into their analytical toolkits, showcasing that among a suite of models, the DSGE model extended with a banking sector and financial frictions exhibits the steepest drop in output. Cantelmo et al. (2024) show that in a small-open-economy New-Keynesian model with disaster shocks, inflation targeting remains the welfare-optimal regime. Baksa et al. (forthcoming) analyze the role of existing prevalent frictions in LIDCs (e.g., food subsistence requirements, sectoral labor immobility, and financial frictions where land serves as collateral) for the macroeconomic effects and transmission mechanisms of weather-related shocks.

Building on this empirical and macro-modeling literature, this paper analyzes the monetary policy modeling implications of specific weather-related disturbances within a relatively standard QPM framework. The exercises focus on the monetary policy-relevant horizon and business cycle frequency implications but exclude long-term effects of climate change and big natural disasters. The emphasis is on temporary shocks, with some effects potentially materializing in the medium-term due to macroeconomic persistence and policy transmission lags. Longer-run implications are confined to assessing policy trade-offs caused by permanently more volatile shocks. The monetary policy conduct is restricted to the interest rate dynamics (and nominal exchange rate in the case of specific simulations that assume some degree of exchange rate management by the central bank). The analysis is also silent on other policy considerations that are likely to have important implications: fiscal-related measures, energy transition policies, and other central bank tools, like regulatory or financial stability-related measures.

The analysis and model extensions presented in this paper leverage the QPM structure to identify supply- and demand-side transmission channels and the responses of various variables within a general equilibrium system. This approach recognizes and quantifies key economic characteristics and frictions, such as the weight of food expenditures in the consumption basket, the sectoral weight of agriculture, the trade-off nature of weather-related shocks, external balance implications, the degree of inflation expectations' anchoring, central bank credibility, and specific aspects of the monetary policy framework (e.g., inflation targeting, exchange rate management, relevant price index to define price stability). The exercises demonstrate the adaptability and tractability of QPMs in conducting enhanced policy analysis, including alternative scenarios involving adverse weather-related events. This validates these models as useful tools to support regular policy processes in CBs and follows best practices in the IMF's capacity development and TA in monetary policy analysis and forecasting, as documented in Mæhle et al. (2021).[3]

The core feature of the analytical framework utilized in this paper is the nexus between agriculture production and food prices, as applied in the QPMs of the Bank of Ghana and the National Bank of Rwanda, documented in Abradu-Otoo et al. (2024) and Vlcek et al. (2020), respectively. This link captures, in a reduced-form manner, the economic effect of weather-related shocks such as droughts or floods that directly impact the agricultural production and create inflationary pressures on food prices. The magnitude of these supply-side effects—resulting in increases in headline inflation and declines in aggregate output—are proportional to the weights of food in the consumption basket and of agricultural value added in total GDP. While in AEs these effects are likely to be transitory and may not require a central bank response ("looking through" supply shocks), in LIDCs and EMs, with less-anchored inflation expectations and limited central bank credibility, avoiding second-round effects may require a tighter policy stance. As such, the monetary policy trade-off posed by weather-related shocks is more stringent.

Based on the nexus between agriculture production and food prices, the paper then presents some key analytical considerations to study the implications of critical assumptions, conduct policy scenarios, and evaluate central bank trade-offs while considering the importance of various goals that policymakers take into account. In this context, the analytical exercises are organized across three dimensions that are likely to be critical for assessing the economic impacts of weather-related shocks and their implications for monetary policy conduct.

First, certain economic characteristics or frictions—such as a high share of consumption expenditures devoted to food, high value added and employment shares of agriculture, or food insecurity requiring reliance on imports—are likely to render the effects of weather-related shocks relatively stronger in LIDCs and EMs compared to AEs. Second, the properties of the shocks play a significant role in the propagation of weather-related disruptions and may affect the nature of policy responses. For example, a transitory and geographically isolated event may not affect the formation of inflation expectations, allowing the central bank to "look through" the shock. In contrast, more persistent disturbances can lead to de-anchored inflation expectations and significant second-round effects, requiring policy tightening. Third, the design of the monetary policy framework—including the degree of exchange rate flexibility, the level of central bank credibility, and the definition of the price index (headline versus core) consistent with the price stability objective—are also important considerations for the transmission of weather-related shocks and the profile of monetary policy reactions.

The rest of the paper is organized as follows. Section 2 describes the conceptual framework adopted in the paper. The detailed structure of the main relations underlying the (baseline) QPM is covered in section 3. Next, section 4 presents the set of model-based results, highlighting the importance of certain economic features, properties of weather-related shocks, and characteristics of the monetary policy framework. Section 5 concludes.

[3] In central bank QPM practice, non-model assumptions and impacts, including specific effects of weather-related shocks on key macroeconomic variables estimated using satellite approaches (e.g., econometric nowcasting and near-term forecasting tools), are imposed through expert judgment. This involves pairing structural shocks to be endogenized with variables to be exogenized, along with constructing the associated economic narrative.

2. A Conceptual Framework and Overview of Key Results

Given their multifaceted nature, modeling weather-related shocks in the context of monetary policy analysis and forecasting is inherently challenging. These shocks have both short- and long-run influences, propagating through multiple transmission channels, with potentially opposite effects on key variables, making the identification of combined final effects a priori uncertain. In this context, the approach adopted in this paper is organized across three relevant dimensions specific to the typical structure of QPMs developed to support policy analysis and forecasting at CBs. While these QPMs have a similar New-Keynesian core, as introduced in Berg et al. (2006), sequential extensions and decompositions are typically implemented to make the analytical framework more realistic and to enhance model-based analysis and forecasting in support of the policy making process. The country-specific customizations and extensions introduced with TA from IMF's ICD are documented in various publications, including Abradu-Otoo et al. (2024), Al-Sharkas et al. (2023), Baksa et al. (2020), Baksa et al. (2021), Dakila et al. (2024), Epstein et al. (2022), Musa et al. (2024), and Vlcek et al. (2020).

To structure the paper's conceptual approach, Table 1 summarizes the key results that emerge at the intersection of three relevant dimensions: economic characteristics, the properties of weather-related shocks, and the monetary policy framework and exchange rate policies.[4] The analytical exercises and detailed results are presented in section 4, with Table 1 referencing the corresponding figures.

The first dimension considers economic characteristics, highlighted in the top rows of Table 1 with red shading. Among the key features that enable a meaningful analysis of weather-related disruptions is the interplay between agricultural goods supply and food prices. Accordingly, the QPM extension decomposes aggregate demand into agriculture and non-agriculture sectors and disaggregates the headline consumer price index (CPI) into food and non-food (core) prices. Additionally, it incorporates external balance considerations, allowing to simulate relevant scenarios concerning current account vulnerabilities in the case domestic agriculture production affected by the shock has to be substituted with imports. Given that food products are subsistence goods with low price elasticity, a minimum supply—from domestic and/or imported sources—must be assured.

The second dimension reflects the properties of weather-related shocks, highlighted in the columns of Table 1 with blue shading. In the context of fairly standard medium-size QPMs, the relevant shocks include food inflation Phillips curve shocks and agricultural production shocks. Both are supply-side in nature and propagate in qualitatively similar ways but may result in quantitatively different outcomes and policy implications in the model, depending on certain economic characteristics (first dimension) and model calibration. Another relevant element is the duration of the shocks. In particular, the implications of (permanently) more volatile weather-related shocks and increased frequency of these disturbances, are shown to make the central bank trade-offs more acute.

[4] In this respect, the conceptual approach resembles the IMF's Integrated Policy Framework principles whereby the optimal policy mix depends on the interaction between the nature of shocks and specific country characteristics or frictions; see IMF (2020).

Table 1: Conceptual framework and key results

		(II) Properties of the shocks	
		Shocks to food prices vs agriculture output	Permanent vs transitory; more volatile
(I) Economic characteristics	Sectoral decomposition of GDP (agriculture and non-agriculture) and CPI (food and non-food)	▪ Both food price shocks and agriculture output shocks are of supply-side nature (Figure 2) ▪ They imply trade-offs (Figure 9)	▪ Increased volatility of food price shocks complicates trade-offs (Figure 9)
(I) Economic characteristics	Food share in CPI and agriculture share in GDP	▪ Higher food expenditure shares imply higher vulnerabilities (Figure 3)	
(I) Economic characteristics	Imports substituting for domestic agricultural goods	▪ Substituting damaged agriculture output with imports puts additional pressures on exchange rate and inflation (Figure 4)	
(I) Economic characteristics / **(III) Monetary and exchange rate policies**	CB credibility and anchoring of inflation expectations	▪ Economies with a credible central bank are more resilient (Figure 5) ▪ Anchored inflation expectations minimize second-round effects and allow to “look through” weather-related shocks (Figure 6)	▪ Central bank credibility alleviates the trade-offs implied by more volatile food prices (Figure 9)
(III) Monetary and exchange rate policies	Exchange rate flexibility	▪ Exchange rate flexibility can support the stabilization of the economy after shocks (Figure 7)	
(III) Monetary and exchange rate policies	Targeting CPI vs targeting core inflation	▪ Targeting core inflation allows to “look through” initial food price spikes if credible, but can be costly over the medium run if not credible (Figure 8)	

Source: Based on authors’ results.

The third dimension refers to the monetary policy framework and exchange rate policies, highlighted in the bottom rows of Table 1 with green shading. Relevant considerations include the adopted regime of exchange rate flexibility, the exact definition of the price stability objective (CPI inflation versus core inflation), and central bank credibility or the anchoring of inflation expectations. This later element somewhat overlaps with the first dimension, given its association with the economic agents’ behavior more generally.

The diverse range of considerations and analytical results in Table 1 underscores both the complexity of weather-related phenomena and the flexibility of a relatively standard QPM, which can be tailored to fit the specific characteristics of any economy or institution.

3. Model Structure

The core of the benchmark model structure outlined in this section, which will be used in our analytical exercises, follows to some extent the Bank of Ghana QPM, as described in detail in Abradu-Otoo et al. (2022) and Abradu-Otoo et al. (2024). Certain Ghana-specific elements and parameter values are adjusted to render the model more generally applicable to LIDCs and/or EMs with an inflation targeting regime and floating exchange rate. Additional simulations explore the implications of other monetary policy frameworks.

In line with the canonical QPM specification introduced in Berg et al. (2006), the model consists of four key equations or blocks: aggregate demand, aggregate supply (or Phillips curve), uncovered interest rate parity (UIP), and the monetary policy reaction function, as described in Box 1. However, this canonical configuration is adjusted and extended to better reflect the key mechanisms and channels for the propagation of weather-related shocks. In what follows, variables are expressed in logarithms or gaps (denoted with “hats”), with time subscripts representing quarters.

Box 1. The Canonical QPM

The standard canonical QPM, as described in Berg et al. (2006), is a New-Keynesian model, where nominal prices are sticky, output is demand-determined, and monetary policy is non-neutral. It comprises the following four equations:

- *The aggregate demand curve or open economy IS (investment-savings) curve* for the output gap ($\hat{y}_t$):

$$\hat{y}_t = a_1\hat{y}_{t-1} + a_2 E_t\hat{y}_{t+1} - a_3 rmci_t + a_4\hat{y}_t^* + \varepsilon_t^y, \qquad \text{(B1)}$$

with $rmci_t = a_5\hat{r}_t + (1-a_5)(-\hat{z}_t)$. This curve establishes a relationship between the output gap and its past ($\hat{y}_{t-1}$) and expected future ($E_t\hat{y}_{t+1}$) values. It also incorporates the real monetary conditions index ($rmci_t$), which in turn is a linear combination of the real interest rate ($\hat{r}_t$) and the real exchange rate ($\hat{z}_t$) components, both expressed in deviations from their respective trends. Additionally, the curve accounts for the foreign output gap ($\hat{y}_t^*$) and aggregate demand shocks (ε_t^y).

- *The aggregate supply curve or open economy forward-looking Phillips curve* for inflation (π_t):

$$\pi_t = b_1\pi_{t-1} + (1-b_1)E_t\pi_{t+1} + b_2 rmc_t + \varepsilon_t^\pi, \qquad \text{(B2)}$$

with $rmc_t = b_3\hat{y}_t + (1-b_3)\hat{z}_t$. This curve models the relationship between inflation and its past (π_{t-1}) and expected ($E_t\pi_{t+1}$) values. It also includes the real marginal costs (rmc_t), with the domestic component approximated by the output gap and the imports-related component proxied by the real exchange rate gap. Additionally, it is influenced by cost-push shocks (ε_t^π).

- *The uncovered interest parity (UIP) condition* for the (log) nominal exchange rate (s_t):

$$s_t = E_t s_{t+1} + \frac{i_t^* - i_t + prem_t}{4} + \varepsilon_t^s. \qquad \text{(B3)}$$

This condition relates the nominal exchange rate to its expected future value ($E_t s_{t+1}$), foreign (i_t^*) and domestic (i_t) nominal interest rates, and sovereign risk premium ($prem_t$). It also incorporates exchange rate (or UIP) shocks (ε_t^s). The nominal exchange rate is expressed as units of domestic currency per one unit of foreign currency and its change (Δs_t) is linked to the change in the real exchange rate (Δz_t), domestic inflation and foreign inflation (π_t^*) by $\Delta z_t = \Delta s_t + \pi_t^* - \pi_t$.

- *The monetary policy rule* that determines the path of the policy rate (i_t):

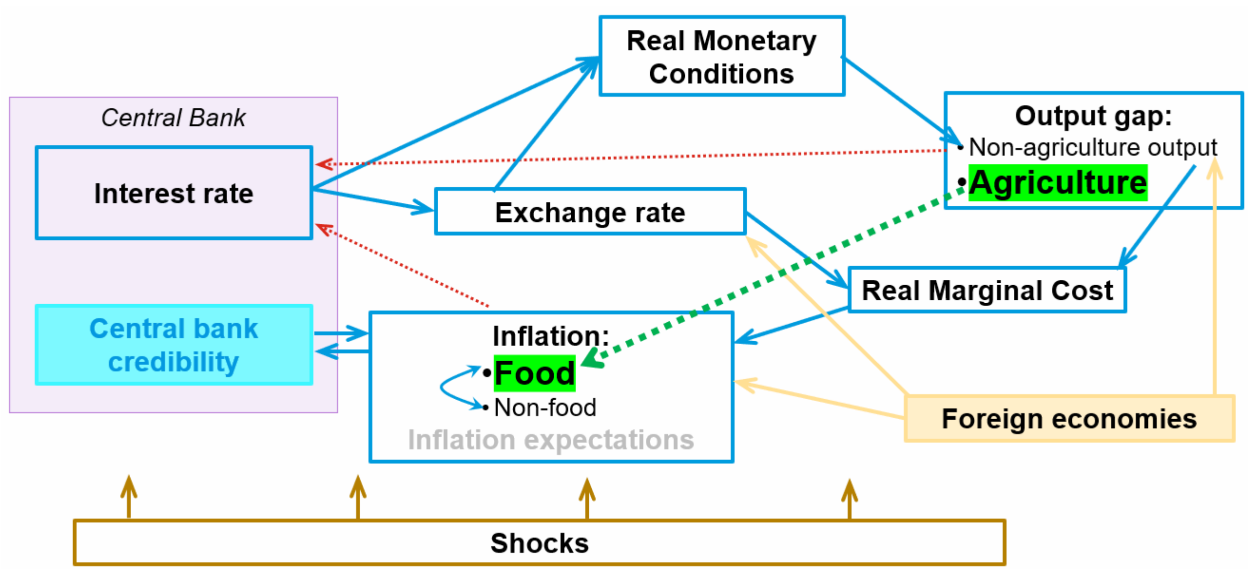
$$i_t = g_1 i_{t-1} + (1 - g_1)\left[i_t^n + +g_2\left(E_t \pi_{t+3}^{yoy} - \bar{\pi}\right) + g_3 \hat{y}_t\right] + \varepsilon_t^i. \quad \text{(B4)}$$

It is a forward-looking monetary policy reaction function aimed at stabilizing inflation, where the policy stance, represented by a short-term interest rate, depends on past values (i_{t-1}), the neutral nominal interest rate (i_t^n), the expected deviation of annual inflation from the target ($E_t \pi_{t+3}^{yoy} - \bar{\pi}$), and the output gap. The rule also incorporates monetary policy shocks (ε_t^i).

The schematic representation of the extended model is illustrated in Figure 1. It highlights the monetary policy transmission mechanism and key interlinkages between macroeconomic variables, as well as the relevant considerations related to the propagation of weather-related shocks. These include the decomposition of output into agriculture and non-agriculture sectors, and of headline inflation into food and non-food (core) components.

Monetary policy operates as follows. Changes in interest rates, considered the monetary policy instrument, affect the relative value of the domestic currency. Under the assumed nominal price rigidities, interest rate and exchange rate changes impact real monetary conditions. Given that the agricultural sector is primarily driven by weather-related developments—especially in LIDCs and EMs, where the use of modern technology and irrigation is still limited—real monetary conditions primarily affect non-agricultural activities. These demand-side effects reflect domestic cost pressures, which, together with exchange rate dynamics approximating imported cost pressures, impact inflation and inflation expectations, especially for the non-food component.

Figure 1: Schematic representation of the model



Source: Authors' representation, partly based on Abradu-Otoo et al. (2024).

To analyze the importance of central bank credibility and the occurrence of second-round effects, the extended model incorporates a mechanism whereby the formation of inflation expectations takes into account the central bank's historical performance in achieving the inflation target. These considerations are likely to be important for CBs in LIDCs and EMs, where established monetary policy frameworks are relatively weaker compared to CBs in AEs. This is evidenced by the IAPOC index computed in Unsal et al. (2022) and the less-anchored inflation expectations demonstrated empirically in IMF (2018).[5]

3.1. Demand

The total output gap, defined as the difference between (logarithms of) real GDP and trend output, is represented as a weighted sum of the agriculture ($\hat{y}_t^a$) and non-agriculture ($\hat{y}_t^{na}$) sectoral gaps:

$$\hat{y}_t = \omega_a \hat{y}_t^a + (1 - \omega_a)\hat{y}_t^{na}, \tag{1}$$

where ω_a represents the share of agriculture value added in total GDP, which is assumed to be constant. Intuitively, a higher reliance on agriculture (higher ω_a) may render the economy more exposed to weather-related shocks.[6] The agriculture sector is notably volatile due to its reliance on weather conditions. In contrast, non-agriculture activities, which include services and manufacturing, offer a clearer picture of the domestic business cycle position and dynamics. This helps identify domestic demand-side inflationary pressures more accurately, making the non-agriculture gap particularly relevant for monetary policy formulation.[7]

A standard investment-savings (IS) framework is employed to specify the non-agriculture output gap dynamics. Current-period non-agriculture cyclical demand is driven by backward- and forward-looking expectations ($\hat{y}_{t-1}^{na}$ and $E_t\hat{y}_{t+1}^{na}$, where E_t denotes model-consistent rational expectations), the real monetary conditions index ($rmci_t$), foreign demand (captured by the trading partners' output gap, $\hat{y}_t^*$)[8], and sectoral demand shocks ($\varepsilon_t^{y^{na}}$):

$$\hat{y}_t^{na} = a_1\hat{y}_{t-1}^{na} + a_2 E_t \hat{y}_{t+1}^{na} - a_3 rmci_t + a_4 \hat{y}_t^* + \varepsilon_t^{y^{na}}, \tag{2}$$

[5] Some of the major differences vis-à-vis the Bank of Ghana QPM in Abradu-Otoo et al. (2022) and Abradu-Otoo et al. (2024), which are not necessarily relevant for the analysys of weather-related shocks and their implications for the monetary policy conduct, include the absence of direct fiscal effects on aggregate demand and ignoring the further separation of non-agriculture sector into oil and non-agriculture-non-oil activities.

[6] In LIDCs, where formal employment in secondary and tertiary sectors is significantly lower, the employment share of agriculture is typically above its GDP share, highlighting labor income vulnerabilities to weather-related shocks that are likely to be underestimated in our model.

[7] Abradu-Otoo et al. (2022) further decompose the non-agriculture sector into oil and non-agriculture-non-oil GDP, which helps identify the differential cross-sector impacts of the pandemic-related lockdowns introduced in 2020 in Ghana: while oil and agriculture, two strategic activities, were exempt from government restrictions and showed largely neutral output gaps, the non-agriculture-non-oil sector experienced a significantly negative output gap.

[8] The next section describes a model extension to account for external balance considerations more explicitly, which entails a respecification of the non-agriculture output gap equation (2); see subsection 4.3.

where $rmci_t$ is defined as a linear combination of interest rate and exchange rate[9] components, both expressed in real terms and in deviations from their respective trends:

$$rmci_t = a_5\hat{r}_t + (1 - a_5)(-\hat{z}_t), \tag{3}$$

where $\hat{r}_t$ represents the real interest rate (RIR) gap (the deviation of the real interest rate from the real neutral rate) and $\hat{z}_t$ represents the real exchange rate (RER) gap (the deviation of the real exchange rate from its trend, with positive/negative values denoting an undervalued/overvalued domestic currency). An increase in $rmci_t$ denotes a tightening, due to a positive RIR gap (current RIR exceeds its trend) and/or negative RER gap (current RER is below its trend, indicating an overvalued currency).

Given that agriculture output experiences large fluctuations (especially outside AEs) due to its reliance on weather conditions, the assumed data-generating processes is an exogenous autoregressive process:

$$\hat{y}_t^a = a_6\hat{y}_{t-1}^a + \varepsilon_t^{y^a}. \tag{4}$$

The shock, $\varepsilon_t^{y^a}$, is used to simulate agricultural output disruptions due to weather-related events, such as droughts or floods that affect crop volumes. In practice, additional terms can be included in equation (4), such as policy-relevant considerations that affect total supply of agricultural goods on the market, like releases of grain crops from strategic reserves during severe droughts. These elements are highly country-specific and can be incorporated into practical QPM applications using expert judgements.

3.2. Supply

The headline CPI (in log terms) is decomposed into food (p_t^f) and non-food (p_t^{nf}) components:

$$p_t = \omega_f p_t^f + (1 - \omega_f)p_t^{nf}, \tag{5}$$

where ω_f denotes the weight of food expenditures in the consumption basket. A higher expenditure share devoted to food, which is generally inelastic and has a strong subsistence component, may lead to more sizeable fluctuations in inflation due to weather-related shocks. This, in turn, poses additional challenges for the central bank in achieving its price stability mandate.

For each price index, inflation is modeled using a semi-structural Phillips curve approach. Non-food (or core) quarter-on-quarter annualized inflation (π_t^{nf}) is driven by backward- and forward-looking expectations (π_{t-1}^{nf} and $\pi_t^{e,nf}$), real marginal costs (rmc_t^{nf}), and a sector-specific cost-push shock ($\varepsilon_t^{\pi^{nf}}$):

$$\pi_t^{nf} = b_1^{nf}\pi_{t-1}^{nf} + (1 - b_1^{nf})\pi_t^{e,nf} + b_2^{nf} rmc_t^{nf} + \varepsilon_t^{\pi^{nf}}. \tag{6}$$

[9] The exchange rate is expressed as domestic currency units per one unit of foreign currency (e.g., US dollar), so that by convention an increase in the exchange rate, both nominal and real, denotes a depreciation of the domestic currency, which implies looser monetary conditions and a stimulative impact on aggregate demand.

A similar dynamic equation is considered for food inflation, with the critical addition of the agriculture gap ($\hat{y}_t^a$) term:

$$\pi_t^f = b_1^f \pi_{t-1}^f + \left(1 - b_1^f\right)\pi_t^{e,f} + b_2^f rmc_t^f - b^a \hat{y}_t^a + \varepsilon_t^{\pi f}. \tag{7}$$

The inclusion of $\hat{y}_t^a$ captures the key interlinkage between agriculture value added and food price inflation. For example, a weather-related shock that affects agricultural production will reduce food supply and generate upward inflationary pressures, with the strength of this channel measured by the parameter b^a. The sector-specific shock $\varepsilon_t^{\pi f}$ captures additional effects on food inflation, such as the application of regulated prices for specific items, e.g., “minimum support prices” in the QPM developed for India in John et al. (2023).

Real marginal costs for food and non-food producers have similar structures, representing a weighted average of the non-agriculture gap (proxying domestic price pressures), the RER gap (proxying imported price pressures), and the relative prices gap (denoted by $\widehat{rp}_t$ and expressed as food prices relative to non-food prices, thus accounting for inter-sectoral price spillovers):[10]

$$rmc_t^j = b_3^j \hat{y}_t^{na} + \left(1 - b_3^j - b_4^j\right)\hat{z}_t + b_4^j \widehat{rp}_t, \tag{8}$$

for $j \in \{nf, f\}$. While qualitatively food and non-food real marginal costs are similar, the sector-specific parameterization ensures the model incorporates the evidence that core prices better reflect underlying inflationary pressures and fundamental business cycle dynamics. This is captured by having $b_2^{nf} > b_2^f$, so that the transmission from marginal costs to inflation is stronger for non-food inflation. Additionally, the model accounts for the differentiated weights of domestic and imported price pressures across the two sectors. For instance, if most non-food goods and services are domestically produced while a large portion of food is imported, then $b_3^{nf} > b_3^f$.

As motivated in Abradu-Otoo et al. (2022), inflation expectations in both food and non-food sectors feature a monetary policy credibility channel. This specification allows to incorporate, in a linear fashion, second-round effects due to temporarily un-anchored inflation expectations: when CPI inflation deviates from the target—especially due to supply shocks in the food sector—agents may question the central bank’s capacity to achieve its price stability objective and expect inflation to deviate from the target for a longer period. One rationale for this behavior, detailed in Chansriniyom et al. (2020), is the high frequency of elevated inflation episodes in LIDCs. As a result, agents may consider the possibility of near-term inflation reentering a “high inflation regime.”

Formally, inflation expectations in (6) and (7) are specified as

[10] In the case of non-food real marginal costs, the relative price effects incorporate the transmission from prices of fresh food items to processed food items included in the core component, for which the former serve as inputs. Additionally, the presence of the relative price gap as a separate term within the real marginal costs, with the coefficient b_4^j, allows to calibrate the strength of intersectoral relative price effects. Even with b_4^j set to 0 there are spillovers across the sectors via the real exchange rate gap, given its definition uses overal CPI rather than sector-specific prices.

$$\pi_t^{e,j} = E_t \pi_{t+1}^j + b_5^j incred_t, \tag{9}$$

where $j \in \{nf, f\}$, and the lack of central bank credibility, $incred_t$, is common across the two sectors. Credibility is defined as the accumulation of discounted past annual (year-over-year, yoy) deviations of CPI inflation from the target, $\pi_t^{yoy} - \bar{\pi}$:

$$incred_t = \beta_1 incred_{t-1} + (1 - \beta_1)\, \beta_2 \left(\pi_{t-1}^{yoy} - \bar{\pi}\right) + \varepsilon_t^{incred}, \tag{10}$$

where β_1 measures the persistency in the (in)credibility process, β_2 reflects the impact of the latest inflation deviation from the target on current credibility stock, and ε_t^{incred} is a shock. Standard QPM formulations assume only rational expectations and ignore the monetary policy credibility considerations (i.e., $b_5^j = 0$ in (9), so that inflation expectations are fully rational). However, in the case of less firmly established monetary policy frameworks—specifically in LIDCs and EMs, as shown by the multi-dimensional index of Unsal et al. (2022)—the formation of economic agents' expectations is likely to imply more persistence and weaker anchoring (i.e., $b_5^j > 0$). This means that the central bank may have a more limited ability to "look through" supply shocks.[11] Similarly, IMF (2018) provides empirical evidence based on various metrics to show that while inflation expectations have become increasingly anchored across EMs, there are still sizable differences relative to AEs.

Given the primary focus of this paper on weather-related shocks that propagate through agriculture production and food prices, we do not consider other potentially relevant aspects that are already included in some central bank QPMs. For instance, Dakila et al. (2024) and Vlcek et al. (2020) decompose headline CPI into core, food and fuel/energy components, while Abradu-Otoo et al. (2024) decompose GDP into agriculture, oil and non-agriculture-non-oil sectors.

3.3. The exchange rate regime and monetary policy

The benchmark model reflects an inflation targeting monetary policy framework with a floating exchange rate regime. Accordingly, a (modified) uncovered interest rate parity (UIP) condition is used to model nominal exchange rate dynamics. The current period exchange rate equals its expected value, corrected for the risk premium-adjusted interest rate differential:

$$s_t = s_t^e + \frac{i_t^* - i_t + prem_t}{4} + \varepsilon_t^s, \tag{11}$$

where s_t and s_t^e are the (log) exchange rate and its expectation for the next period, i_t^* and i_t are the foreign and domestic (policy) interest rates, $prem_t$ is the sovereign risk premium (assumed to be exogenous), and ε_t^s is an exchange rate (or UIP) shock. To accommodate observed deviations from the UIP and somewhat more rigid nominal exchange rate dynamics displayed by the data relative to the theoretical UIP canonical framework, exchange rate expectations are assumed to be formed in a hybrid fashion:

[11] Weakly-anchored inflation expectations constitute one of the possible use cases for Foreign Exchange Interventions within the IMF's Integrated Policy Framework. See IMF (2023) for details.

$$s_t^e = c_1 E_t s_{t+1} + (1 - c_1)\left(s_{t-1} + \tfrac{2}{4}\Delta\bar{s}_t\right). \qquad (12)$$

Accordingly, exchange rate expectations incorporate both pure forward-looking elements, defined by the model-consistent rational expectations ($E_t s_{t+1}$), and backward-looking terms related to the previous period exchange rate (s_{t-1}) adjusted for the trend-consistent exchange rate change ($\Delta\bar{s}_t$, defined as the trend RER depreciation plus the inflation targets differential). By varying the value of c_1, it is possible to capture different degrees of exchange rate flexibility without explicitly considering specific exchange rate policies. Following the Bank of Ghana QPM implemented in Abradu-Otoo et al. (2022), the benchmark model specification assumes a de jure floating exchange rate regime, but with some rigidity to account, inter alia, for occasional targeted central bank operations. These operations aim to minimize excessive exchange rate volatility and avoid disorderly market conditions, while not resisting the medium-term exchange rate tendency aligned with macroeconomic fundamentals (represented by $\Delta\bar{s}_t$).

Following the general QPM practice for interest rate-based monetary policy operational frameworks, the central bank behavior is specified in terms of a Taylor-type reaction function.[12] In this framework, the interest rate is sluggishly adjusted primarily in response to the expected deviation of inflation from its target and the output gap:

$$i_t = g_1 i_{t-1} + (1 - g_1)\left[E_t\pi_{t+1} + \bar{r}_t + g_2\left(E_t\pi_{t+3}^{yoy} - \bar{\pi}\right) + g_3\hat{y}_t\right] + \varepsilon_t^i, \qquad (13)$$

where g_1 controls the degree of interest rate smoothing, $\bar{r}_t$ is the real neutral rate[13] (so that $E_t\pi_{t+1} + \bar{r}_t$ defines the nominal neutral rate), $E_t\pi_{t+3}^{yoy} - \bar{\pi}$ is the three-quarter ahead expected annual (yoy) inflation deviation from the target, $\hat{y}_t$ is the total output gap, and ε_t^i is the monetary policy shock that captures non-systematic interest rate adjustments. Note that the price stability objective is defined in terms of headline CPI, rather than core inflation, while output considerations are specified in terms of total, rather than non-agricultural output.

The rest of the model equations comprise definitions and exogenous autoregressive processes for trends and foreign variables. Their exact specification and calibration do not have any implications for the exercises conducted in the next session.

[12] Our model can be used to assess other monetary policy frameworks. For example, McKibbin et al. (2020) provide theoretical arguments for the relative advantages of various monetary policy regimes. They argue that, in the face of adverse climate disruptions, a central bank implementing inflation targeting would tighten monetary policy to curb inflation, potentially with some considerations for the output gap. Nominal income targeting, however, will prompt the central bank to balance the rise in prices against the losses in real output. On the other hand, Cantelmo et al. (2024) employ a New-Keynesian DSGE model with disaster shocks to show that inflation targeting is welfare-optimal.

[13] The impact of persistent weather-related shocks and natural disasters on the equilibrium interest rate is highly ambiguous. On one hand, factors exerting upward pressures include policies to foster the energy transition that enhance productivity and encourage innovation, increased debt burdens due to fiscal measures, higher expenditures due to health costs and post-disaster reconstruction, etc. On the other hand, interest rates could decline if the weather-related shocks and natural disasters discourage labor supply and affect productivity, while precautionary savings and uncertainty lead to a shift in preferences toward holding safe assets. In this latter scenario, lower equilibrium interest rates also imply a narrowing of the policy space and more frequent occurrence of the effective lower bound constraints, with significant implications for monetary policy. See NGFS (2020), NGFS (2023), IMF (2022a), and Ciccarelli and Marotta (2021) for additional considerations.

3.4. Calibration

The benchmark model described above is calibrated building on the parameterization for the Bank of Ghana QPM presented in Abradu-Otoo et al. (2024). Some specific elements are adjusted to reflect a more generic emerging market and developing economy (EMDE). While the exercises presented in this paper are theoretical, the underlying model also shows a robust data-fit and empirical coherency in the case of Ghana, as shown in Abradu-Otoo et al. (2022) and Abradu-Otoo et al. (2024). In particular, they show that the calibrated model demonstrates theoretically consistent transmission channels in response to key structural shocks, while the out-of-sample forecasting record further confirms the robustness of the QPM's fit to the Ghanaian data. These findings—both theoretical and empirical—are reinforced by well-identified historical business cycle dynamics, their decomposition into underlying driving forces, and relevant counterfactual scenarios to assess policy choices.

The calibrated values for the key parameters are presented in Table 2. Following the semi-structural economic modeling for central bank policy analysis and forecasting, the calibration of model parameters is often favored over estimation due to practical constraints and data limitations. Calibration leverages existing empirical evidence and theoretical knowledge to directly set parameter values, aligning models with observed economic behavior while avoiding the computational challenges and data issues associated with estimation. This also allows for transparent integration of expert insights, especially when certain parameters are hard to estimate due to noisy data, short time series, or regime changes—all relevant considerations for EMDEs. The next section includes a collection of analytical exercises, some of which represent sensitivity analyses concerning specific parameter values and modeling assumptions.

Table 2: Calibrated parameters in key behavioral equations

Non-agriculture gap		Agriculture gap		Output shares	
a_1	0.4	a_6	0.35	ω_a	0.2
a_2	0.3				
a_3	0.2				
a_4	0.1				
a_5	0.5				
Non-food inflation		Food inflation		CPI weights	
b_1^{nf}	0.5	b_1^f	0.3	ω_f	0.4
b_2^{nf}	0.4	b_2^f	0.2		
b_3^{nf}	0.4	b_3^f	0.3	Credibility	
b_4^{nf}	0.3	b_4^f	–0.3	β_1	0.5
b_5^{nf}	0.5	b_5^f	0.25	β_2	0.5
		b^a	1		
Exchange Rate		Interest rate			
c_1	0.6	g_1	0.75		
		g_2	1		
		g_3	0.1		

Source: Based on iterative analysis and partly on Abradu-Otoo et al. (2024).

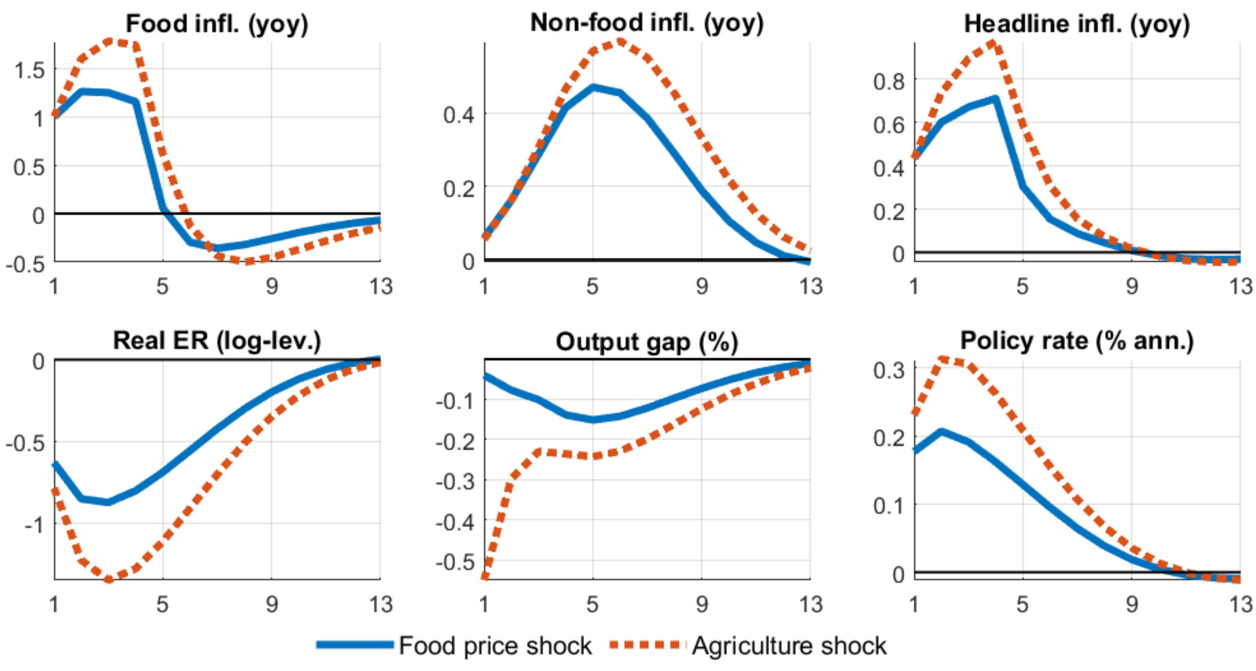
4. Model Results

This section presents the QPM-based analytical exercises and results, aligning them with the conceptual framework outlined in Table 1. The relevant propagation channels in the case of weather-related disruptions pertain to agriculture production and food prices. The introduced sectoral decompositions help to approximate, in a simplified non-structural form, the impact of weather-related shocks, considering the causal relationship between weather events and the fluctuations in agri-food prices and quantities.

4.1. Weather shocks are inherently supply-side

Figure 2 shows the impulse response functions (IRFs) of key macroeconomic variables, expressed in percentage deviations from their steady states, to two weather-related disturbances: a food price shock $\varepsilon_t^{\pi^f}$ in equation (7), and an agricultural production shock $\varepsilon_t^{y^a}$ in equation (4). This exercise does not specify the exact magnitude of the shocks, nor does it establish a direct correspondence between the gravity of the weather event and its impact on food inflation or the agriculture harvest. For the purpose of a meaningful comparison, the shocks are calibrated and normalized such that annual food inflation increases by 1 percentage point above equilibrium in the first quarter.

Figure 2: Food price shocks and agriculture output shocks



Source: Authors' simulations.
Note: The figure depicts the responses of selected macroeconomic variables, expressed in percentage deviations from their steady states. Horizontal axes denote quarters, with the shock occurring in the first quarter.

The two shocks are qualitatively similar and exhibit supply-side effects, yet there are significant quantitative differences. A food price shock (represented by blue solid lines) passes-through to core inflation on account of intersectoral spillovers driven by relative price effects, thereby increasing headline inflation. As a result, inflation expectations temporarily rise above the target—with the credibility channel exacerbating the effects of these one-off shocks as discussed below in subsection 4.4—requiring a monetary policy tightening via higher interest rates. Overall, the real exchange rate (RER) appreciates due to both nominal appreciation (given higher domestic interest rates) and a positive inflation differential (where domestic inflation exceeds foreign inflation). Tighter monetary conditions, through both an overvalued exchange rate and more restrictive interest rates, constrain aggregate demand, resulting in a negative non-agriculture output gap and thereby contributing to the return of inflation to its target.

On the other hand, agriculture (e.g., "harvest") shocks (represented by red dotted lines) imply more persistence and overall larger effects for the same initial increase in food inflation. The total output response includes the direct impact of lower agriculture value added, which is significant on impact but recovers moderately quickly due to the transitory nature of harvest shocks. In contrast, the impact of food price shocks on total output is minimal, arising solely from the policy tightening effect on non-agriculture output, whereas agriculture output remains unchanged. Due to more accelerated inflation dynamics associated with agriculture shocks, a relatively higher interest rate is required, thereby accentuating the inflation-output trade-off. For a model-based quantification of this trade-off, see subsection 4.6.

A key characteristic of most QPMs, particularly those designed for LIDCs and EMs, is the central bank's proactive response to supply shocks. In contexts where there is a limited history of maintaining price stability and central bank credibility is weak—conditions that heighten the risk of unanchored inflation expectations—monetary policy may need to prioritize price stability and address supply-side shocks, even at the cost of incurring output losses, as shown in Figure 2.

4.2. The role of the food weight in the CPI basket

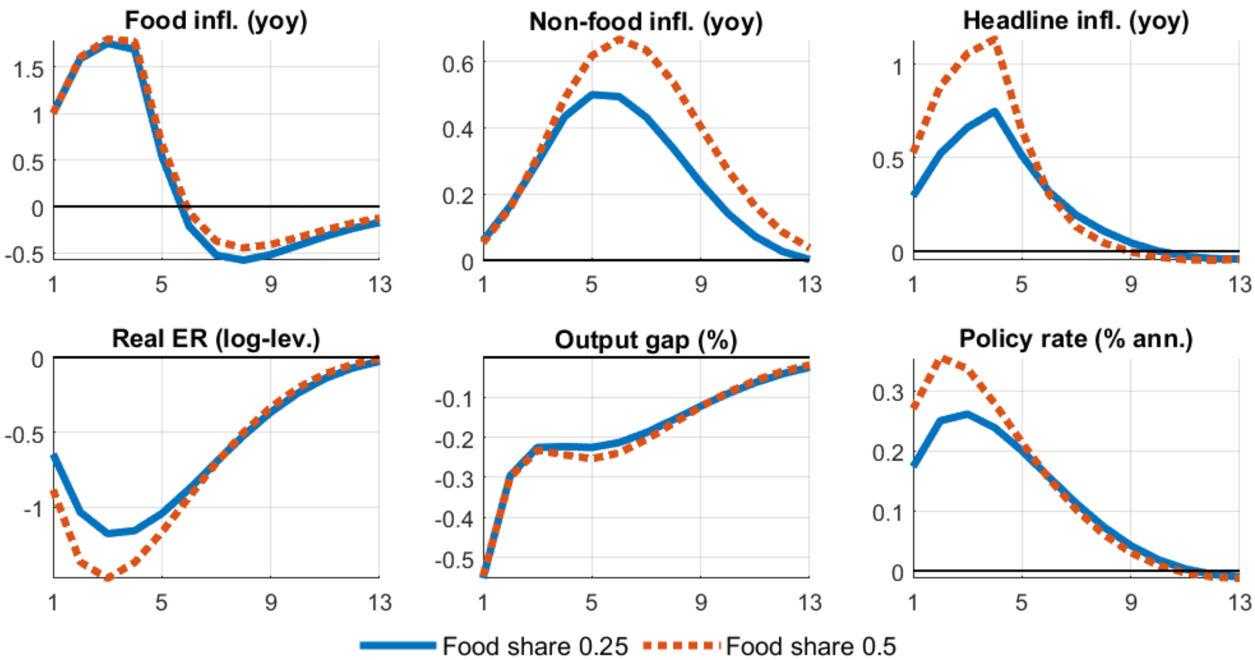
Intuitively, the aggregate effects and monetary policy implications of weather-related shocks depend on the significance of food consumption within total expenditure and the contribution of agriculture value added to total GDP. In this context, Figure 3 presents the IRFs to an agriculture production shock for two different values of food CPI weight: $\omega_f = 0.25$ (blue solid lines) and $\omega_f = 0.5$ (red dotted lines). The results reveal that for the same initial increase in food inflation, the shock has a more pronounced effect on non-food and headline inflation in the economy with a higher food CPI weight. During the first year following the shock, and at its peak in the fourth quarter, annual headline inflation is about one-third higher. This leads to proportionally larger deviations in inflation expectations from the inflation target, resulting in an interest rate response that is 10 basis points higher for the $\omega_f = 0.5$ calibration. The differential impact on output is minimal.

The results suggest that countries with a higher share of household expenditures allocated to food products are more vulnerable to weather-related disruptions. Statistical data indicate that food CPI weights are highest in Sub-Saharan Africa (averaging around 40 percent, as in our baseline calibration) and lowest in AEs (below 20 percent).[14] Accordingly, LIDCs and EMs are more susceptible to weather-

[14] See IMF (2022b).

related shocks and face more acute trade-offs compared to AEs.[15] Although not shown here, the implications of a high versus low agriculture value added share (captured by ω_a, which is set to 0.2 in the baseline calibration) is similar, given the predominance of agriculture activities in less-developed economies.

Figure 3: Agriculture output shocks: the role of the food weight in the CPI basket



Source: Authors' simulations.
Note: The figure depicts the responses of selected macroeconomic variables, expressed in percentage deviations from their steady states. Horizontal axes denote quarters, with the shock occurring in the first quarter.

4.3. The role of imports in substituting domestic agricultural goods

The benchmark model described in the previous section does not explicitly consider external balance effects. Given the subsistence nature of food, the economy may need to offset agricultural losses due to weather-related shocks with imports. These concerns are likely to be more widespread in regions with chronic food insecurity and vulnerabilities to climate shocks, in particular Sub-Saharan Africa, as documented in Baptista et al. (2022), and introduce additional mechanisms with important implications for the aggregate effects and monetary policy conduct. This subsection describes a model extension that allows to simulate such a scenario.

Technically, the model structure is revised in several dimensions, following larger-scale semi-structural models such as FINEX, as detailed in Berg et al. (2023). Additional variables introduced (expressed as GDP ratios) pertain to balance of payments (BOP) positions, including the current account, capital

[15] The higher shares of food expenditure in LIDCs and EMs are related to structural transformation and are associated with food subsistence requirements. For a discussion on the implications of food subsistence for inflation properties and the design of monetary policy, see Portillo et al. (2016).

account, and official reserves. By definition, the BOP implies that international flows of goods and services, i.e., the current account, are matched by financial flows, i.e., the financial account. In gap terms:

$$0 = \widehat{ca}_t + \widehat{fa}_t, \tag{14}$$

where $\widehat{ca}_t$ is the current account to GDP gap and $\widehat{fa}_t$ is the financial account, inclusive of official reserves, to GDP gap. Proper considerations of trade and financial flows require decomposing output into domestic absorption and net exports. To keep the model tractable and as close as possible to the benchmark QPM model presented in the previous section, one can substitute the foreign output gap with a current account gap term, which reflects the cyclical behavior of imports and exports. The current account gap ($\widehat{ca}_t$) dynamic is in turn specified as:

$$\widehat{ca}_t = d_1\widehat{ca}_{t-1} + (1 - d_1)[d_2\hat{y}_t^* - d_3\hat{y}_t^{na} + d_4\hat{z}_t] + \varepsilon_t^{ca}, \tag{15}$$

where $\hat{y}_t^*$ reflects foreign demand for domestically produced goods, $\hat{y}_t^{na}$ captures domestic demand for imports (proportional to non-agriculture GDP), $\hat{z}_t$ approximates the impact of RER gap on the current account, and ε_t^{ca} is a current account shock.

Next, the financial account is decomposed into private sector flows and changes in official reserves. A standard law of motion is assumed for the stock of reserves, reflecting the previous period's stock and adjusting for interest gains expressed in domestic currency (which are proportional to the foreign interest rate and nominal exchange rate changes). It also takes into consideration the foreign exchange operations used to finance current account transactions, given the assumed capital account restrictions that limit the extent of international private capital flows. Accordingly, changes in official reserves reflect primarily the current account transactions and we refrain from discussing the use of foreign exchange interventions (FXI).[16] Private sector capital flows (pf_t) are linked to the sovereign risk premium in the UIP according to:

$$pf_t = \overline{pf} + d_5(prem_t - \overline{prem}) + \varepsilon_t^{pf}, \tag{16}$$

where $\overline{pf}$ and $\overline{prem}$ are the equilibrium values for the private flows and the risk premium, respectively, and ε_t^{pf} represents a private capital flows shock. The elasticity of the private sector capital flows to the risk premium, d_5, allows to approximate various capital account regimes: for an economy with many capital account restrictions, d_5 is (close to) zero, while for a highly liberalized capital account, d_5 is likely to be high, as described in Berg et al. (2023).

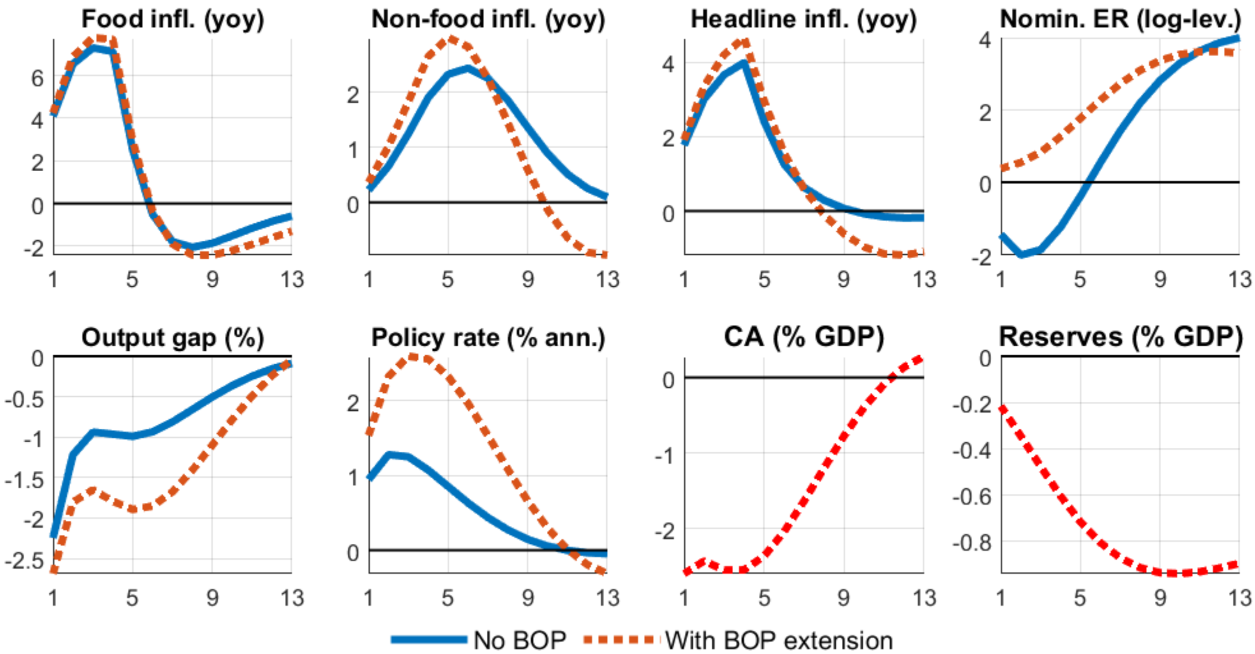
Finally, to incorporate the exchange rate pressures arising from international financial flows that affect the stock of official reserves, the sovereign risk premium is endogenized as follows:

$$prem_t = f_1 prem_{t-1} + (1 - f_1)[\overline{prem} - f_2\Delta res_t] + \varepsilon_t^{prem} \tag{17}$$

[16] For guiding principles on the use of FXI in conjunction with monetary policy and other policies, within the context of the IMF's Integrated Policy Framework (IPF), refer to IMF (2020), Basu et al. (2020), Adrian et al. (2021), and IMF (2023). For modeling FXI policies in a large-scale semi-structural model aligned with the IPF, see Berg et al. (2023).

where Δres_t represents the change in official reserves and ε_t^{prem} denotes the risk premium shock. Equation (17) embeds the mechanism by which a reduction in official reserves (negative Δres_t)—e.g., because of additional foreign exchange payments for imported food in the event of insufficient private sector inflows—deteriorates sovereign risk perceptions. This signals weaker resilience and a diminished capacity to counter exchange rate depreciation pressures.

Figure 4: Agriculture output shocks: imports substituting domestic agricultural goods



Source: Authors' simulations.
Note: The figure depicts the responses of selected macroeconomic variables, expressed in percentage deviations from their steady states. Horizontal axes denote quarters, with the shock occurring in the first quarter.

Figure 4 compares the propagation of a 10 percent agriculture production shock ($\varepsilon_t^{y^a} = -10$) in the benchmark model without BOP considerations (blue solid lines) to the extended model incorporating the aforementioned BOP channels (red dotted lines) and assuming that the agricultural losses are substituted with imports.[17] The results indicate that, despite having a similar impact on food inflation, which is more directly affected by the shock, the two models exhibit significantly different macroeconomic and policy implications. Substituting agriculture output damaged by the weather-related shock with imports leads to weaker current account and official reserves positions. These changes deteriorate the sovereign risk perceptions and exert depreciation pressures on the exchange rate (note that the nominal exchange rate depreciates immediately despite a tighter interest rate trajectory). A weaker currency implies higher (imported) inflationary pressures and requires a tighter interest rate stance, which further dampens

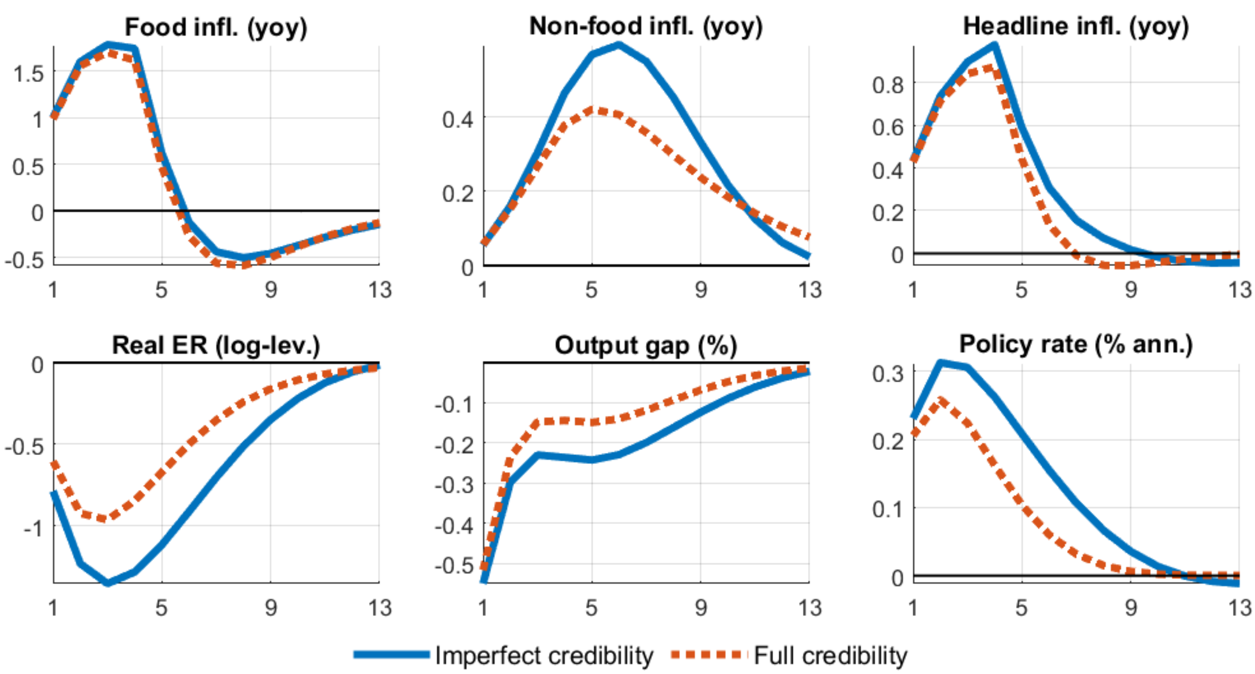
[17] Technically, in the extended BOP model, to capture imports substituting for domestic agricultural goods, a current account gap shock from equation (15) of the same magnitude as the negative agriculture shock from equation (4) is introduced. The extended model parametrization considers: $d_1 = 0.5$, $d_2 = 1$, $d_3 = 0.4$ and $d_4 = 1$ in (15); $d_5 = 1$ in equation (16); and $f_1 = 0.5$ and $f_2 = 4$ in equation (17). Additionally, the foreign output gap in equation (2) is turned off by setting $a_4 = 0$, and a current account gap term is added in equation (2) with an elasticity of 0.25.

aggregate demand. These results highlight some of the vulnerabilities associated with food import dependence, including terms-of-trade shocks originating from global weather disruptions.

4.4. The role of monetary policy credibility

Second-round effects and entrenched supply shocks, manifesting through inflation expectations persistently deviating from the inflation target, partly drive the monetary policy tightening in response to inflationary weather-related shocks in the simulations above. The benchmark model accounts for these effects via the monetary policy credibility channel by calibrating b_5^{nf} and b_5^{f} in equation (9) to positive values. In the benchmark model, credibility is more significant for non-food inflation expectations ($b_5^{nf} = 0.5$ and $b_5^{f} = 0.25$), given that agents are assumed to partly recognize that food prices are affected by unpredictable weather events. Various metrics to proxy for the degree of anchoring of inflation expectations, as computed in IMF (2018), suggest that these mechanisms are relevant for EMs. Abradu-Otoo et al. (2022) conduct a series of counterfactual simulations to analyze the implications of central bank credibility and inflation expectations anchoring in the context of the Bank of Ghana QPM.

Figure 5: Agriculture output shocks: the role of monetary policy credibility



Source: Authors' simulations.
Note: The figure depicts the responses of selected macroeconomic variables, expressed in percentage deviations from their steady states. Horizontal axes denote quarters, with the shock occurring in the first quarter.

Figure 5 compares the responses to an adverse agriculture shock in the benchmark calibration featuring imperfect monetary policy credibility (blue solid lines) to a model version that assumes full credibility by setting $b_5^{nf} = b_5^{f} = 0$ (red dotted lines).[18] While the directions and shapes of the IRFs are similar, the

[18] The results for a food price shock are qualitatively the same and therefore not presented.

relative magnitudes underscore the importance of strengthening central bank credibility and keeping inflation expectations anchored at the announced inflation target. A more credible monetary policy framework limits the extent of second-round effects and relative price spillovers from food inflation (which is quasi-directly affected by the weather-related shock) to non-food inflation. As a result, the interest rate response indicates a milder tightening cycle, with less adverse impact on aggregate demand. Accordingly, the inflation-output trade-off posed by the shock is partly mitigated. Central bank credibility is particularly important for vulnerable economies. For example, as shown above, a higher food CPI share (Figure 3) and/or the need to substitute damaged crops with imports (Figure 4) amplify the aggregate effects of weather-related shocks. In these contexts, building credibility helps to ease the adverse outcomes and alleviate central bank trade-offs. For a quantitative assessment of these aspects, see subsection 4.6.

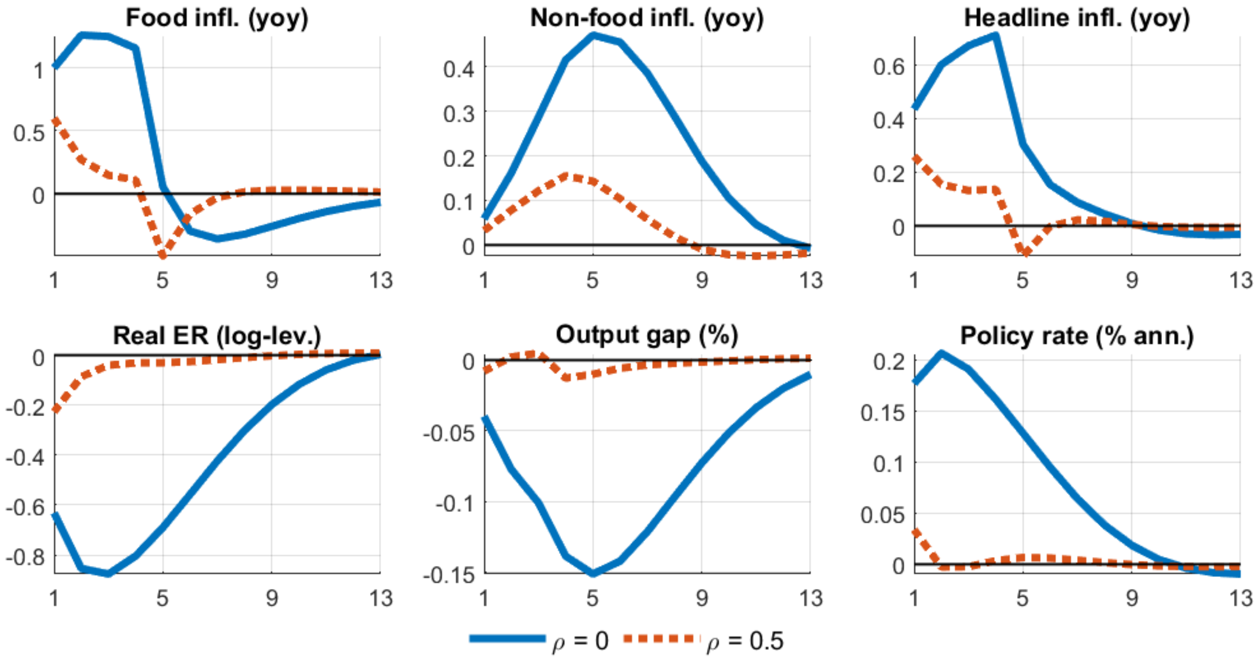
The persistent effects of supply-type shocks presented above are partly due to the assumed backward-looking elements in the key behavioral equations, approximated by autoregressive (lag) terms. Specifically, as per the food inflation Phillips curve (7), the presence of the $b_1^f \pi_{t-1}^f$ term implies that a one-unit period-*t* food price shock has a mechanical impact of b_1^f units in period *t*+1. However, in cases where the shock is considered purely transitory, it may be more sensible to disregard this mechanical impact via the lagged term. One approach to "neutralize" the effects of previous-period shocks is to model the innovation as a moving average process. In the case of food price shocks, this involves substituting $\varepsilon_t^{\pi^f}$ in equation (7) with $\varepsilon_t^{\pi^f} - \rho \varepsilon_{t-1}^{\pi^f}$, where ρ controls the extent to which the shocks affect adaptive expectations.[19] The Central Bank of Colombia uses this approach to incorporate the expected strength of *El Niño* and *La Niña* phenomena on inflation expectations; see Banco de la República (2023).[20]

Figure 6 presents the propagation of a food price shock in the benchmark model ($\rho = 0$, blue solid lines) compared to an alternative calibration featuring moving average shocks ($\rho = 0.5$, red dotted lines). The latter assumes that the shock is purely transitory and that agents' expectations remain well-anchored. Consequently, the shock has only minimal effect on key macroeconomic variables, including no reaction from the central bank, consistent with the "look through" supply shocks approach.

[19] The same approach to "neutralize" shocks' persistence is implemented in practice for modeling indirect tax changes. For example, in the case of a value added tax increase, inflation will rise in the quarter when the new measure takes effect, but it is likely to return (ceteris paribus) to "normal" values in the very next quarter, without affecting inflation persistence and the formation of inflation expectations. John et al. (2023) use a polynomial specification for "monsoon" shocks affecting food prices, which can encompass these aspects.

[20] We thank our colleague Alexander Guarin for pointing out and explaining the approach followed by the Central Bank of Colombia.

Figure 6: Agriculture output shocks: modeling anchored inflation expectations



Source: Authors' simulations.
Note: The figure depicts the responses of selected macroeconomic variables, expressed in percentage deviations from their steady states. Horizontal axes denote quarters, with the shock occurring in the first quarter.

4.5. The role of the degree of exchange rate flexibility and the monetary policy framework

The benchmark model assumes an inflation targeting regime and exchange rate flexibility. In practice, however, the parameters of the monetary policy framework vary significantly and include inflation targeting with a free-floating exchange rate, standard pegs, and a continuum of intermediate regimes.

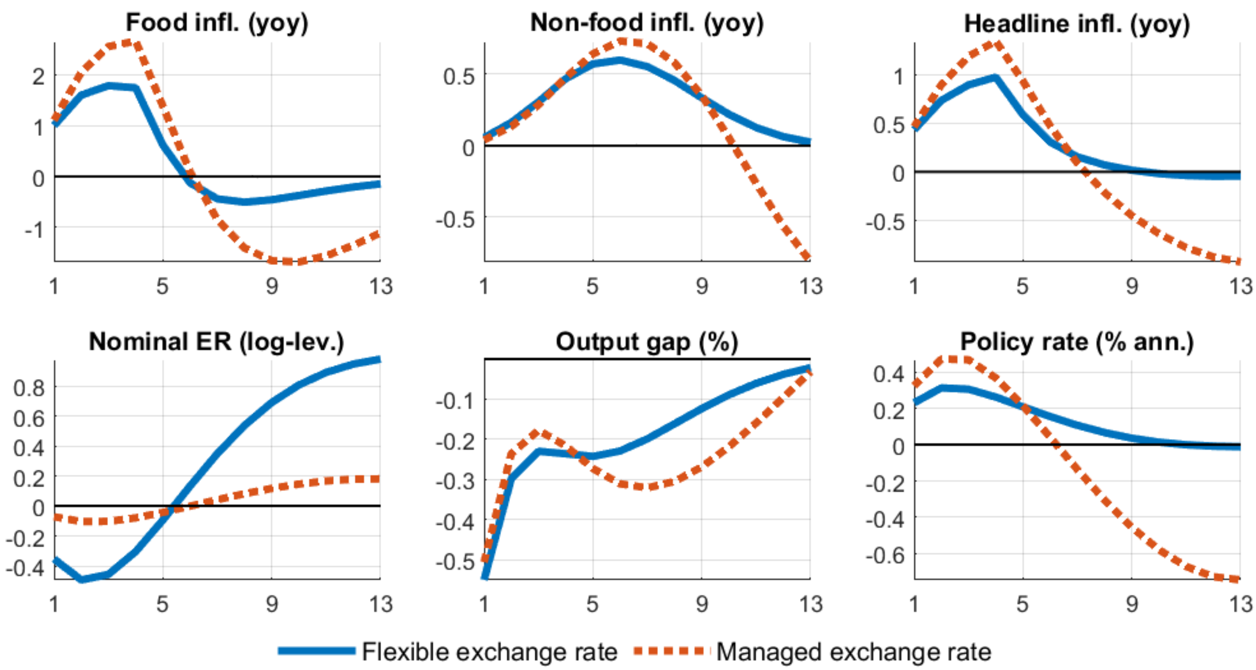
To analyze the transmission of weather-related shocks affecting agriculture production across different assumptions regarding the degree of exchange rate management, the benchmark UIP condition (11) is modified to:

$$s_t = \omega_s(s_{t-1} + \Delta\bar{s}) + (1-\omega_s)\left(s_t^e + \frac{i_t^* - i_t + prem_t}{4}\right) + \varepsilon_t^s, \qquad (11')$$

where $\Delta\bar{s} = \Delta\bar{z} + \bar{\pi} - \bar{\pi}^*$ represents the fundamentals-consistent nominal exchange rate change, that is, the real exchange rate trend depreciation, $\Delta\bar{z}$, adjusted for the inflation target differential between domestic and foreign economies, $\bar{\pi} - \bar{\pi}^*$. The parameter ω_s controls the weight of exchange rate peg considerations. In the benchmark model, exchange rate flexibility was ensured by setting $\omega_s = 0$. Conversely, for a hard peg regime, $\omega_s = 1$.

Figure 7 illustrates the propagation of an adverse agriculture shock in the benchmark model (blue solid lines, with $\omega_s = 0$) compared to an alternative calibration that approximates a managed exchange rate regime (red dotted lines, with $\omega_s = 0.5$).[21] The latter model displays more volatile and pronounced fluctuations in response to weather-related shocks, despite a quasi-fixed nominal exchange rate. Due to limited expenditure switching and exchange rate pass-through effects, the interest rate initially needs to increase significantly. However, this stronger monetary policy reaction is reversed over the medium run, as the nominal exchange rate anchor implies a form of *price level* targeting, in contrast to *inflation* targeting in the baseline model. Overall, the simulations highlight the benefits of exchange rate flexibility in delivering important shock-absorbing effects, including a smoother interest rate path and a sustained return of inflation to the target.

Figure 7: Agriculture output shocks: the role of exchange rate flexibility



Source: Authors' simulations.
Note: The figure depicts the responses of selected macroeconomic variables, expressed in percentage deviations from their steady states. Horizontal axes denote quarters, with the shock occurring in the first quarter.

Another important consideration in specifying the monetary policy framework is the definition of the price index consistent with the objective of price stability.[22] In the benchmark model, in line with the mandate of most inflation targeting CBs, we use the headline CPI inflation in the policy reaction function (13). While in practice policy makers often emphasize core (non-food) inflation as a more accurate indicator of underlying price pressures—including in analytical notes and external communications—the evaluation of the central bank's fulfillment of its price stability objective is typically made against CPI inflation. This

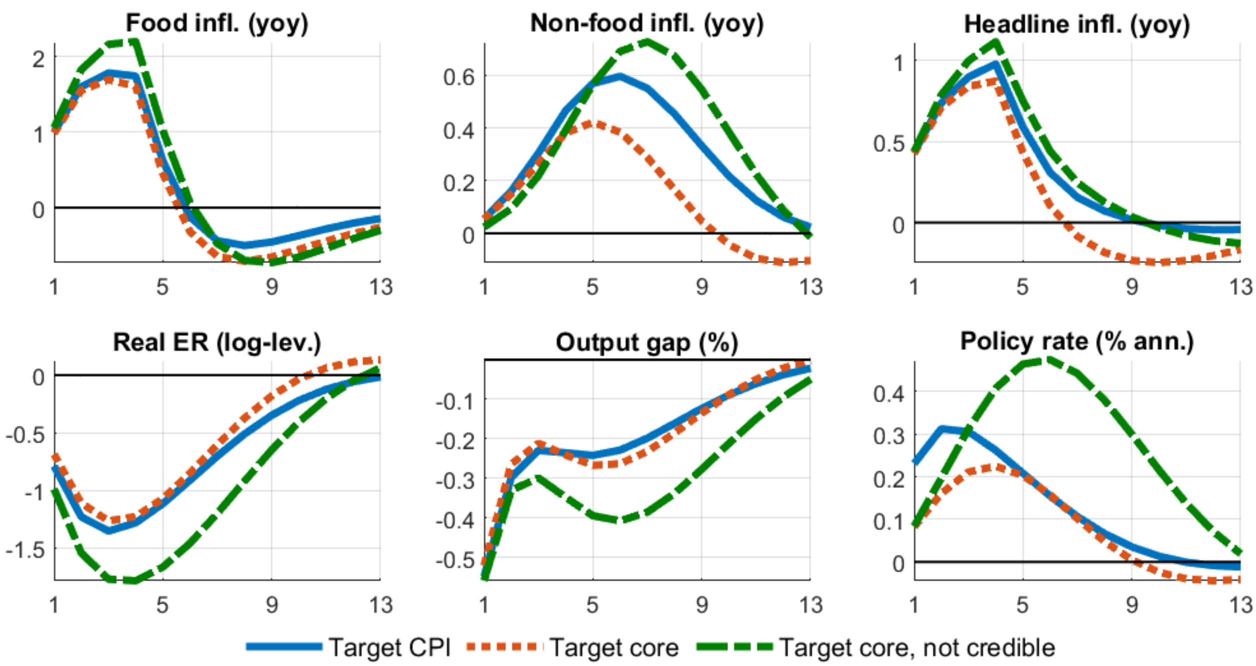
[21] Some degree of capital controls is implicitly assumed, allowing the central bank to continue using the interest rate policy. The alternative model also incorporates the assumption that, in the absence of a full exchange rate adjustment (due to $\omega_s > 0$), inflation processes become more persistent. Consequently, the parameters b_1^{nf} and b_1^{f} are increased by 50 percent relative to the baseline calibration, to 0.75 and 0.45, respectively.

[22] This specification and its implications for the monetary policy are extensively discussed in the academic literature. See, for instance, Aoki (2001), Mankiw and Reis (2003), and Airaudo and Zanna (2012).

approach is recognized for its simplicity and relevance for the general population. However, given that food prices are largely beyond the central bank's influence, targeting core inflation—i.e., using core inflation in the monetary policy reaction function (13)—could be a viable alternative.[23] IMF (2024) presents a similar exercise in the context of the recent global monetary policy tightening episode, comparing macroeconomic outcomes under a variety of interest rate reaction functions.

Figure 8 compares the effects of a negative agriculture shock in the benchmark model, which uses the headline CPI inflation target as the monetary policy objective (blue solid lines), against two alternative frameworks that use the non-food (i.e., core) inflation target. In the scenario of a credible core-based inflation targeting regime (red dotted lines), the extent of inter-sectoral relative price effects is more limited, resulting in significantly moderated interest rate tightening relative to the benchmark CPI-based inflation targeting. Both non-food and headline inflation rates are lower than in the baseline model, with roughly the same trajectory for the output gap. This suggests that a credible core inflation targeting framework can alleviate the trade-offs arising from weather-related shocks.

Figure 8: Agriculture output shocks: alternative price stability objectives



Source: Authors' simulations.
Note: The figure depicts the responses of selected macroeconomic variables, expressed in percentage deviations from their steady states. Horizontal axes denote quarters, with the shock occurring in the first quarter.

The preference of core inflation targeting over CPI inflation targeting outlined above hinges on the rational expectations assumption of the QPM. Economic agents are characterized by having a perfect understanding of the model equations and policy reaction functions, including credible beliefs in the

[23] The practice of using core inflation to define price stability is still observed. For example, the Bank of Uganda's objective is defined as "5 percent core inflation in the medium term (2-3 years ahead)", where core prices exclude crops, oil, and administered items (source: Bank of Uganda website).

central bank's commitment to price stability (i.e., core inflation at target), which are only partially impacted by the monetary policy credibility mechanisms. This implies that a relatively small interest rate change is sufficient to steer the economy back to equilibrium. However, if these conjectures are not met—such as when the central bank reacts to core inflation (expectations) while the declared objective is headline inflation target—it is likely that once the agents "learn" about the inconsistency between stated objectives and operational targets, the credibility of the monetary policy framework will be compromised, leading to elevated risks of un-anchored inflation expectations.[24]

In the non-credible core inflation targeting simulation (green dashed lines), the initial interest rate response is similar to the credible counterpart. However, over time, agents realize that the central bank is focused on core inflation while the objective is headline inflation. This credibility damage leads to larger above-target inflation deviations, prompting the central bank to extend the tightening cycle both in amplitude and duration, with adverse consequences on output. Overall, the simulations highlight the importance of consistent monetary policy frameworks, with a coherent relationship between objectives, actions, and communications.

4.6. An assessment of the central bank policy trade-offs

QPMs can be used to investigate the multidimensional trade-offs faced by the central bank in responding to shocks. In this subsection, we deploy the extended QPM to construct the policy frontiers for weather-related supply shocks propagating through food prices. These frontiers can inform policy makers' reactions with respect to inflation relative to output, given stated policy objectives and preferences. The results underscore the complex trade-offs posed by supply shocks and the need for a well-calibrated balance between the inflation target objective and the stability of output and the exchange rate.

To visualize the trade-offs implied by weather-related shocks, we compute the volatility of key macroeconomic variables, measured by standard deviations (SDs), in the baseline QPM. The baseline calibration sets the SDs of all shocks to zero, except for the shocks in the Phillips curves for the non-food and food CPI components—i.e., $\varepsilon_t^{\pi^{nf}}$ and $\varepsilon_t^{\pi^f}$ in equations (6) and (7), respectively—, which have unit SDs. To elucidate the role of central bank preferences, the volatilities are computed for a range of parameter values for the response coefficient in the interest rate reaction function (13) associated with the expected inflation deviation from the target, i.e., g_2.[25] The policy frontiers are then constructed by plotting the SDs of inflation against the SDs of the output gap and against the SDs of the exchange rate change. The literature typically focuses only on inflation and output volatility, as exemplified by Gali (2015). However, for small open LIDCs or EMs, the exchange rate can also be an important policy variable or

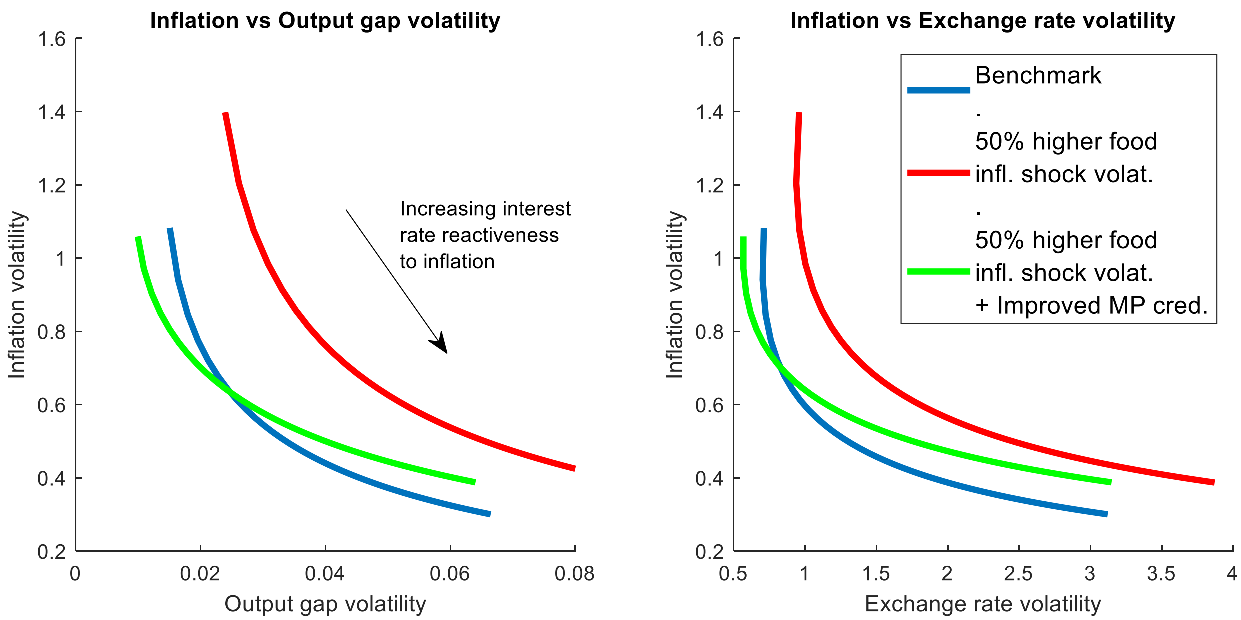
[24] Formally, the non-credible core inflation targeting calibration consists of the following parameter changes: $\beta_2 = 1$ (against 0.5) to account for more rapid credibility losses; b_1^{nf} and b_1^f are increased by 25 percent, to 0.625 and 0.375, respectively, to allow for more persistent inflation dynamics; and $c_1 = 0.7$ (against 0.6) to allow for larger exchange rate reactions to shocks.

[25] The values range between 0.5 and 5, with a step of 0.1. Other parameters, such as on the interest rate lag, g_1, and on the output gap, g_3, are kept at their baseline calibration values. Note that because of the specification of the interest rate rule in (13), a below-one value for g_2 can be still consistent with model stability (Taylor principle).

even a secondary objective. This motivates the assessment of the potential trade-off between avoiding exchange rate volatility and achieving the inflation target that certain shocks can imply.

For the benchmark calibration, the blue curves in Figure 9 illustrate the set of policy options available to the central bank—specifically, the relative weight of inflation versus the output gap in the interest rate reaction function (13). These options are depicted in terms of the variability of inflation against the output gap (left panel) and against the exchange rate change (right panel).[26] The downward-sloping policy frontier in the left panel indicates that as the central bank reduces the output gap variability by implementing a softer response to inflation (lower g_2), this leads to higher inflation volatility. If policymakers focus primarily on permanently keeping inflation close to the target—by assigning a large weight to inflation in the Taylor rule equation (13), i.e., increasing g_2—it results in elevated output gap volatility (lower-right corner). In contrast, if the focus is on the output gap stability, then the central bank must tolerate higher inflation variability (upper-left corner). A similar trade-off is observed in the inflation versus exchange rate space (right panel): a policy framework that reacts strongly to inflation manages to ensure price stability, but at the cost of excessive exchange rate volatility. This volatility is necessary to allow the exchange rate to act as a shock absorber.

Figure 9: Policy trade-offs in reacting to food price shocks



Source: Authors' simulations.
Note: The figure depicts the policy frontiers constructed for various values for the coefficient of expected inflation deviation from the target in the interest rate rule. Volatility of each variable is measured as its model-based unconditional standard deviation.

[26] In central bank practice, QPMs are primarily used for forecasting and policy scenario analysis. Being not fully micro-founded, they are somewhat inadequate for optimal policy analysis based on welfare criteria. Therefore, we refrain from normative analyses. While one could follow a reduced-form "loss function" approach, there is significant uncertainty regarding the relevant weights that the policy makers assign to price stability against economic growth or other secondary objectives.

We can also study the consequences of higher volatility of weather-related shocks. In this context, the red curves in Figure 9 illustrate the policy trade-offs in a hypothetical scenario where the standard deviation of the food price shock is 50 percent higher, while the standard deviation of the non-core price shock remains unchanged. The rightward shifts of the policy frontiers in both the inflation-output and inflation-exchange rate spaces highlight the increased stringency of weather-related trade-offs. Quantitatively, with 50 percent more volatile food price shocks, maintaining stable headline inflation requires a tighter interest rate reaction, which increases output and exchange rate volatility by a factor of approximately two.

Increased monetary policy credibility and better-anchored inflation expectations can significantly ameliorate these trade-offs. The green curves in Figure 9 represent the policy frontiers for 50 percent more volatile food price shocks (as depicted by the red curves), but also assume an improvement in central bank credibility by setting $\beta_2 = 0.25$ in the credibility process equation (10), instead of the baseline value of $\beta_2 = 0.5$. The results suggest that the initial trade-off (before increased volatility, shown by the blue curves) can be essentially restored by building a credible monetary policy framework and keeping inflation expectations aligned with the target, thus minimizing the incidence of second-round effects.

Overall, the exercises conducted in this subsection underscore the importance of carefully designing the monetary policy framework and properly calibrating the interest rate response to weather-related shocks. Supply-type shocks create a trade-off between bringing inflation to the target and stabilizing the business cycle, with additional complications potentially arising from exchange rate-related vulnerabilities. In this context, the IMF's Integrated Policy Framework (IPF) discusses the appropriateness of using additional tools—such as foreign exchange interventions, macroprudential policy measures, and capital flow measures—in specific cases and under certain conditions, to complement conventional monetary policy and mitigate trade-off situations.[27]

5. Conclusion

Weather-related shocks are an important source of disturbance and uncertainty, presenting significant challenges to economic policymakers, including central banks (CBs). In this context, the paper provides an overview of weather-relevant analytical exercises using an extended Quarterly Projection Model (QPM), whose canonical version is at the core of many Forecasting and Policy Analysis Systems (FPAS) in many CBs. These exercises help to understand the propagation channels of weather-related shocks, the policy trade-offs they imply, and the ensuing implications for the conduct of monetary policy. The extended model's simplicity, tractability, and adaptability in creating these scenarios reaffirm the QPM's role as a useful tool in supporting the monetary policy process in CBs within a continuously evolving economic landscape.

At the core of our analytical exercises is the nexus between agricultural production and food prices, as food inflation is significantly influenced by agricultural supply, which is partly driven by unpredictable

[27] See IMF (2020) and Basu et al. (2020) for the IPF conceptual framework; Adrian et al. (2021) for a quantitative DSGE-based analysis; IMF (2023) for the guiding principles on the use of foreign exchange interventions; and Berg et al. (2023) for a large-scale semi-structural model.

weather-related events such as rainfall patterns and droughts. One of the salient results of the analysis is that weather-related shocks are of a supply-side nature and present challenging trade-offs for policymakers, potentially requiring a monetary policy response if there are risks of second-round effects. For example, if agricultural production drops due to a poor harvest, it results in lower overall output and higher food and headline inflation. To prevent inflation expectations from becoming unanchored and to minimize second-round effects—which is more likely in LIDCs and EMs—the central bank may initiate a tightening cycle and raise the interest rates, with further adverse impacts on aggregate demand.

Our QPM-based analytical exercises demonstrate that the magnitude and duration of the monetary policy response to weather-related supply shocks depend on the key characteristics and frictions of the economy. These include the CPI weight of food expenditures, the GDP share of the agriculture sector, the degree of imports substituting for damaged domestic agricultural supply, the extent of inflation expectations' anchoring and central bank credibility, and the specific characteristics of the monetary policy framework, including the degree of exchange rate flexibility and the definition of the price stability objective. Overall, our analysis also suggests that because of existing economic characteristics and frictions, less-developed economies are more vulnerable and may face bigger policy challenges in responding to weather-related shocks than advanced economies.

Considering the inherent complexity of modeling weather-related phenomena—such as distinguishing between short-term and long-term events, multiple propagation channels, relevancy of fiscal policy, and the challenging identification of demand- versus supply-side effects—the approach presented in this paper has important limitations. These include not explicitly considering non-linearities (e.g., asymmetric effects of shocks and "tipping points"); ignoring fiscal policy responses; not modeling the direct link between weather-related variables and economic data; lacking granular assessment at sectoral or geographical levels and other heterogeneities; and having limited modeling structure of the financial sector, which can act as a shock amplifier through macro-financial linkages. These aspects are left for future research.

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