Policy implications of losing credibility: Lessons from Colombia's post-pandemic inflationary surge[*]

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Abstract

Inflationary surges, such as those experienced in the aftermath of the COVID-19 pandemic, can undermine the credibility of central bank inflation targets. Using data from expectations surveys, we test whether credibility losses occurred in Colombia and assess their magnitude. We then use these estimates to inform a Bayesian estimation of a monetary policy model in which such credibility is endogenous, depending on the central bank's past performance in achieving its inflation target. We implement our framework embedded in one of the main semi-structural models for monetary policy analysis in the country, the 4GM-model (Gonzalez et al., 2020). Our implementation is designed such that the 4GM specification is nested within our model as a particular case in which the costs of credibility losses are absent. Our findings indicate that the post-pandemic inflationary surge in Colombia represents the episode with the largest credibility loss in recent decades, and such episodes tend to make inflation stabilization policies more costly in terms of output.

Keywords: Credibility, expectations, inflation, monetary policy, non-linear.
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1 Introduction

The aftermath of the COVID-19 pandemic left an enduring impact on the global economic landscape, presenting several challenges for policymakers. One of the foremost issues that garnered attention in policy discussions was the pervasive inflationary surge recorded in many countries. Among other issues, policymakers faced the intricate tasks of diagnosing the drivers behind that surge, assessing its intensity and duration, and evaluating potential implications for the design of monetary policy. One of these implications includes the possibility of a change in the trade-off between inflation and output stabilization, potentially stemming from the erosion of credibility in central banks' inflation targets, in a context where inflation soared well beyond those targets.

In this study we start by employing data from expectations surveys to assess the magnitude of those credibility losses in Colombia, a country operating under an inflation-target regime that had a significant post-pandemic inflationary surge.[1] We build on Bomfim and Rudebusch (2000), who uses a filtering framework to construct a metric for the time-variant credibility of the inflation target as an anchor for agents' expectations. Armed with that metric of credibility, we proceed to estimate a monetary policy model in which credibility is endogenous and contingent on a loss function that assumes that agents evaluate the central bank's past performance in achieving its inflation target.[2] Notably, our obtained credibility metric from expectations surveys guides the selection of the functional form for the loss function of our model, and the Bayesian estimation of its parameter values.

Similar to recent literature where credibility is endogenous (Hommes and Lustenhouwer, 2019; Park, 2023), in our model agents' expectations about inflation are no longer an invariant combination of their past realizations and those under full-information rational expectations. Instead, the weights of each component endogenously evolve depending on the size of a latent stock of credibility, which, in turn, depends on credibility signals, i.e., the realizations of the loss function. These expectations lead to Phillips curves that have time-variant weights on the backward-looking and forward-looking components. In this way, the extent to which the economy deviates from one with full-information rational expectations —a departure common in the recent behavioral New Keynesian literature — varies endogenously over time. And despite the fact that our approach remains semi-structural (meaning that although our formulation is motivated by theory, we do not identify all primitive parameters of the underlying structural model), this feature of our formulation can be micro-funded by some type of learning dynamics. For example, our Phillips curves' specification is isomorphic to the obtained in "heuristic switching" micro-funded models, where agents are either rational or adaptive/naive, and in

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[1] Inflation in Colombia soared to 13.3% in the first quarter of 2023, a multi-decade high. For a comprehensive review of the determinants of the inflationary surge in Colombia, see Pulido et al. (2023).

[2] The explicit communication of the inflation target by central banks following an inflation targeting strategy allows for this ex-post measurement of monetary policy performance (Svensson, 1997).

which the prevalence of each behavior switches according to their forecasting performance (see e.g. Hommes and Lustenhouwer (2019); Hommes et al. (2019); Cornea-Madeira et al. (2019)).

We integrate our proposed formulation within one of the primary semi-structural models for monetary policy analysis in Colombia, namely, the 4GM-model (Gonzalez et al., 2020). Specifically, our implementation is structured to embed the existing 4GM-model in our framework as a specific case where the costs of credibility losses are absent. This approach provides the monetary authority with a tool tailored to the Colombian economy that is fully compatible with the technology currently used for generating central policy forecasts. In particular, our implementation enables the production of forecasts for endogenous variables in which costs of credibility losses are taken into account, to construct alternative policy scenarios to those generated by the original 4GM-model.

Our endogenous credibility specification within the 4GM-model is estimated as the final outcome of a three-stage approach, informed by the empirical content of the expectations surveys. Specifically, in the first stage we construct an initial credibility metric using only data from expectations surveys and the filtering model proposed by Bomfim and Rudebusch (2000). In the second stage, we choose the functional form of the loss function of the model to generate credibility signals with a distribution whose moments exhibit certain desirable properties, and develop a calibration exercise to obtain, in partial equilibrium, the parameters related to the persistence and bounds of the stock of credibility, using the estimated credibility metric from the first stage. Finally, in the third stage, we estimate the full module of credibility within the 4GM-model using Bayesian techniques, which allow us to account for the effects of general equilibrium channels. In particular, in our (constrained) Bayesian estimation of the model we inform the priors' support of the parameters of the selected loss function and the persistence of the stock of credibility, using the estimated parameters from the calibration exercise in the second stage.

Our results indicate that, in the Colombian case, the post-pandemic inflationary surge represents the episode with the largest credibility loss in recent decades. This is confirmed by both the metric of credibility constructed from the filtering framework and by the endogenous stock of credibility in the model. Moreover, the fact that the Phillips curves have time-variant weights on the backward-looking and forward-looking components means that the trade-off between inflation and output stabilization faced by the monetary authority is no longer fixed over time. In particular, we show that episodes with credibility losses increase the sacrifice ratio of monetary policy, making inflation stabilization policies more costly in terms of output. More importantly, the rate at which the rise in the sacrifice ratio occurs is a non-linear function of the stock of credibility of the central bank's inflation target. Thus, episodes of large and persistent inflationary surges, such as the one followed by the COVID-19 pandemic, require a more restrictive policy stance to achieve inflation convergence, even under the same configuration of shocks of the economy without credibility costs.

The layout of this paper is as follows. Section 2 reviews the related literature. Section 3 presents our empirical motivation, where we construct our off-the-model metric of credibility from expectations surveys. Section 4 introduces our module of endogenous credibility to be incorporated within the the 4GM-model. Section 5 outlines the estimation procedure. Section 6 presents the model impulse-response functions, describes how incorporating endogenous credibility losses affects the transmission channels of the most important shocks, compared to the economy without costs of credibility, and computes the corresponding sacrifice ratios. Finally, Section 7 concludes.

2 Related literature

There is a rich body of literature exploring the consequences of the credibility of central banks' inflation targets for the implementation of monetary policy and its various effects on the economy; see Cepeda et al. (2023) for a comprehensive meta-study. A narrower set of studies has explored these consequences using theoretical frameworks similar to ours. Primarily, our specification aligns with the semi-structural monetary policy models proposed by Argov et al. (2007), Benes et al. (2017), and Chansriniyom et al. (2020) for the economies of Israel, India and the Philippines, and Indonesia, respectively. Similarly to our approach, all these models share three main departures from the workhorse semi-structural specification with constant policy credibility, as enumerated by Alichi et al. (2009): i) an endogenous policy credibility process, by which monetary policy can gain or lose credibility over time; ii) non-linearities in the credibility generating process; and iii) an explicit loss function that recognizes the costs of deviations of inflation from its target.

Our paper distinguishes itself from the aforementioned studies primarily through its empirical focus, that allows us to validate the resulting endogenous stock of credibility in the model with data extracted from expectation surveys. Particularly, in contrast to those studies where the models are fully calibrated for the corresponding countries, we begin by motivating our mechanism with a credibility metric constructed entirely from observed data, building on Bomfim and Rudebusch (2000).[3] This metric enables us first to select the functional form for the loss function of our model and second to inform the priors in our Bayesian estimation. In this way, we discipline the expectation formation process in the model with the help of survey data, an approach that has been documented to improve the fit of standard macroeconomic models (Müller et al., 2022). Moreover, our proposed strategy provides us with an estimation of the credibility loss function in which, unlike several other studies, we do not need to invoke either an ad-hoc penalty for inflation deviation or involve any threshold for its evaluation.[4]

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[3] Bomfim and Rudebusch's (2000) approach is also used in other studies such as Łyziak et al. (2007) and Demertzis et al. (2012) to construct metrics of credibility.

[4] Regarding this issue, refer to Bicchal (2022) for a discussion on the shortcomings of studies that propose credibility indexes based solely on inflation deviations, such as Cecchetti et al. (2002), De Mendonça (2007), De Mendonça and De Guimarães e Souza (2009) or Levieuge et al. (2018).

While we refrain from incorporating micro-foundations into our specification, our model is also related to recent literature in the "behavioral" New Keynesian strand (Jump and Levine, 2019; Gabaix, 2020; Meggiorini, 2023) that incorporates some form of bounded rationality to enhance the fit of the standard New Keynesian model with macroeconomic data.[5] Typically, models within this body of literature deliver a structural specification where all expectations appearing in the optimality conditions are scaled by a factor relative to their standard coefficients. That factor generally corresponds to behavioral parameters of the agents, measuring the strength of cognitive discounting, the degree of level-k thinking or the proportion of rational agents forming expectations under full-information. In certain specifications, this factor can even endogenously vary over time according to some type of learning dynamic, based, for example, on the agents' forecasting performance. Such is the case of the "heuristic switching" models proposed by Hommes and Lustenhouwer (2019), Hommes et al. (2019) or Cornea-Madeira et al. (2019), which, as previously mentioned, feature specifications leading to Phillips curves with time-varying coefficients, similar to those derived from our endogenous credibility mechanism.

Finally, our paper also relates to those studies that, within the context of the Colombian economy, have explored different consequences of credibility losses, and to those that utilize the 4GM model specification to examine its implications when considering additional channels of interest. In the first vein, the study most closely related to ours is González and Hamann (2011), which examines the effects of credibility on inflation persistence and the sacrifice ratios of monetary policy. Their work follows the model by Erceg and Levin (2003), where some components of the inflation target are not perfectly known by the public. Although their conclusions are qualitatively similar to ours, our advantage lies in providing the monetary authority in Colombia with a tool that can be fully integrated with the current model used for generating central policy forecasts, estimated using the empirical content of expectation surveys. In the second category, Romero and Naranjo-Saldarriaga (2023) use the 4GM model to examine the implications of introducing weather shocks into the inflation expectations of agents, while Méndez-Vizcaíno et al. (2021) employ it to endogenously generate risk balances for the forecast paths in the form of predictive densities.

3 Empirical motivation and data

The COVID-19 pandemic and its aftermath have led to renewed interest in the credibility of inflation targets, as both inflation and inflation expectations have increased. Headline inflation in several countries, including the United States and the euro area, reached historically high

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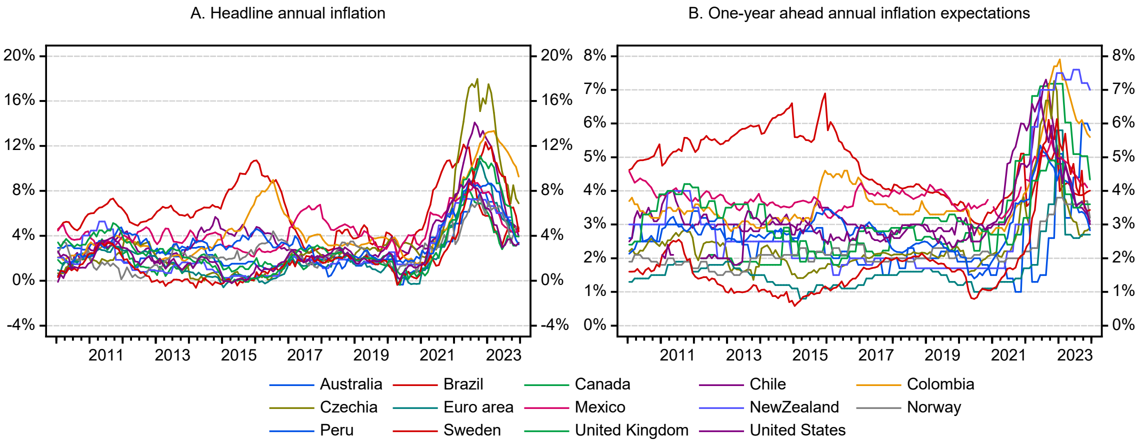
[5] Particularly, to account for empirical regularities of macroeconomic data such as excess kurtosis and stochastic volatility (Jump and Levine, 2019), to attenuate the "forward guidance puzzle" documented by Del Negro et al. (2023) (the fact that with rational agents, forward guidance by the central bank is predicted to work very powerful, see Gabaix (2020)) or to conciliate the estimates of the structural model with microeconomic estimates (Afsar et al., 2023)

Figure 1 – Headline inflation and one-year ahead inflation expectations



Sources: Central banks of each country and expectations surveys carried out by each central bank.

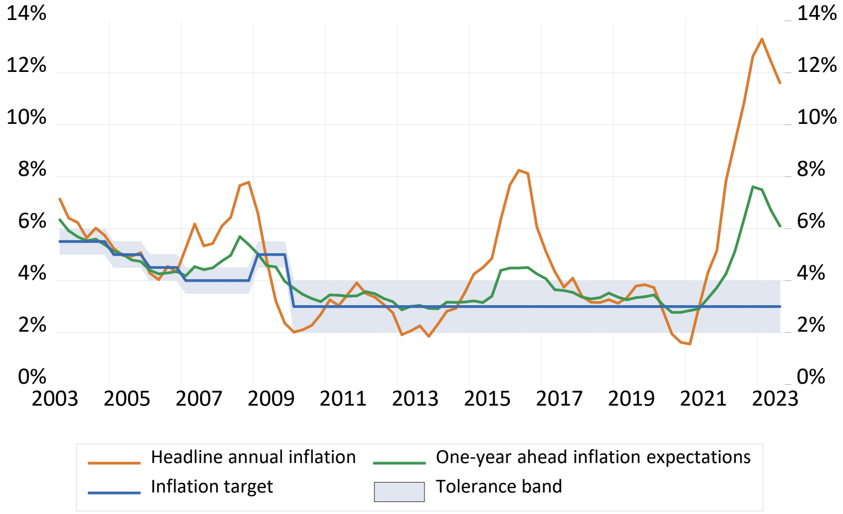
levels in the aftermath of the pandemic (Figure 1A). Headline inflation in the United States, for example, peaked at 9.1% in mid-2022, the highest level since 1980. Similarly, inflation in the euro area rose to 10.6% by the end of the same year. One-year ahead inflation expectations have followed a similar trend. Figure 1B shows that inflation expectations for this group of countries have behaved similarly to headline inflation, although the increases have been somewhat more moderate.

Inflation and inflation expectations in Colombia mirrored global trends. In the first quarter of 2023, Colombia's total annual headline inflation reached 13.3%, above the tolerance band since the end of 2021 (Figure 2). This level is the highest recorded in recent decades and therefore higher than the two peaks observed in 2008 and 2016, when annual inflation was high due to high international food and fuel prices and the El Niño phenomenon, respectively. Inflation expectations have risen moderately relative to overall inflation, peaking at 7.5% in the first quarter of 2023 and remaining above the tolerance band at the end of 2023.

The uncertainty and volatility of the pandemic, coupled with episodes of elevated inflation, may have undermined economic agents' confidence in central banks' ability to achieve their inflation targets, thereby undermining the credibility of monetary policy.

Assessing the credibility of the inflation target is challenging because the stock of credibility is not directly observable. Economic literature offers several methods for estimating this stock of credibility, including credibility measures associated with the anchoring of expectations (Antunes, 2015; Dash et al., 2020; Gefang et al., 2012; Strohsal and Winkelmann, 2015), and ad-hoc functional forms of loss function that penalizes deviations of the observed inflation relative its target (Bicchal, 2022; Cecchetti et al., 2002; De Mendonça, 2007; De Mendonça and De Guimarães e Souza, 2009; Levieuge et al., 2018). The first approach requires to analyze the dynamics of inflation expectations and their sensitivity to inflation shocks, while the second

Figure 2 – Annual inflation, inflation expectations and inflation target of Colombia



Sources: Banco de la República. Annual inflation expectations from the Monthly Expectations Survey of Economic Analysts.

involves specifying and estimating a specific loss function.

We depart from these approaches and instead construct an outcome-based, time-varying credibility measure by adapting the methodology proposed by Bomfim and Rudebusch (2000) using a filtering framework. This methodology has the advantage of being based directly on data from surveys of economic agents' expectations, which allows us to determine credibility based on agents' perceptions. It is intuitive, easy to interpret, and consistent with the credibility measure proposed by Svensson (1997).

Bomfim and Rudebusch (2000) argue that the credibility of the inflation target can be measured by the weight that agents assign to the central bank's inflation target in forming their inflation expectations. The higher the weight given to the target, the greater the credibility of the inflation target. This approach considers that inflation expectations are determined as a weighted average of the current inflation target and past inflation rates, according to:

$$\pi_t^e = \lambda_t \overline{\pi}_t + (1-\lambda_t)\,\widetilde{\pi}_t + \epsilon_t^{\pi^e}, \tag{1}$$

$$\lambda_t = \psi_0 + \psi_1 \lambda_{t-1} + \epsilon_t^{\lambda}, \tag{2}$$

$$\widetilde{\pi}_t = \frac{\pi_{t-1} + \cdots + \pi_{t-q}}{q}, \tag{3}$$

where π_t^e represents the one-year ahead annual inflation expectations, $\overline{\pi}_t$ is the inflation target, π_{t-1} is annual headline inflation in the previous quarter, $\epsilon_t^{\lambda} \sim N\left(0, \sigma^2\right)$ and $\epsilon_t^{\pi^e} \sim N\left(0, \gamma\sigma^2\right)$.[6]

We estimate the state-space system shown in equations (1)-(3) using as observable variables

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[6] We calibrate γ to ensure that the estimated λ_t does not exceed one.

Table 1 – Estimated parameters for partial equilibrium credibility measure λ_t

	Coefficient	Std. Error	p-value
ψ_0	0.107	0.048	0.025
ψ_1	0.842	0.075	0.000
$\sigma^2_{\epsilon^\lambda}$	0.012	0.150	0.000

Sources: Authors' calculations.

the mean of the one year ahead inflation expectations from the Monthly Expectations Survey of Economic Analysts, the annual inflation target in Colombia, and annual inflation up to four quarters in the past ($q = 4$).[7] The stock of credibility is thus the latent variable $\lambda_t \in [0, 1]$, which follows an autoregressive process, with ψ_1 determining its level of persistence (Equation (2)). A level of λ_t close to one in a given period indicates a high anchoring of expectations and, therefore, a high level of credibility in that period. A value close to zero indicates the opposite. Table 1 shows the estimated parameters.

Figure 3 shows the evolution of the resulting latent variable $\lambda_t \in [0, 1]$ over time. Except for the post-Covid episode, the credibility of the inflation target in Colombia has remained relatively stable. The peaks in both headline inflation and inflation expectations that Colombia experienced in 2008 and 2016 led to a decrease in credibility. The persistence of credibility is high, and it typically recovers quickly after a decline. After the pandemic, the loss of credibility of the inflation target was particularly strong, but it did not result in a total loss. Finally, as in previous episodes of credibility loss, credibility rises rapidly from the first quarter of 2023, in tandem with inflation expectations and headline inflation moving closer to the central bank's inflation target.

Finally, it is worth noting that the proposed credibility metric in Figure 3 is a partial equilibrium measure because it does not account for the interaction of credibility with other economic variables beyond expectations, headline inflation, and target inflation. In Section 5, we address this limitation by using this credibility measure to inform the priors in a Bayesian estimation of a credibility measure within a general equilibrium model, the 4GM-model. This approach aims to provide a more comprehensive and accurate measure of credibility.

4 Theoretical framework

In this section, we explore the general equilibrium implications for macroeconomic analysis and forecasting associated with endogenous credibility costs. To achieve this, we extend the 4GM model of Gonzalez et al. (2020) by incorporating an endogenous credibility cost channel and non-linearities. In contrast to the existing literature, we use the initial credibility metric,

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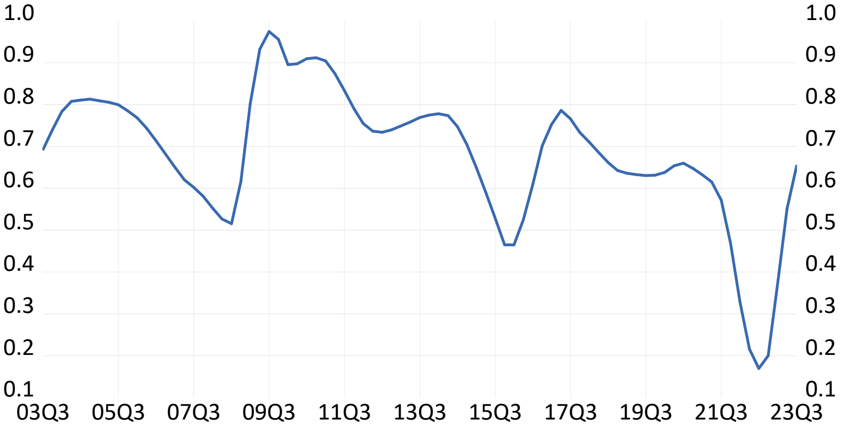
[7] The Monthly Expectations Survey of Economic Analysts, conducted by Banco de la República since September 2003, measures annual inflation expectations one year ahead for Colombia. The survey is aimed at financial institutions or research centers that calculate inflation forecasts. It also inquires about growth, exchange rate, and policy rate expectations, among other variables.

Figure 3 – Colombian partial equilibrium credibility stock measure, λ_t



Note: Credibility measure for Colombia according to the Bomfim and Rudebusch (2000) methodology.
Sources: Authors' calculations.

estimated in Section 3, to inform the functional form of the credibility loss function and its non-linearity. The resulting 4GM-model with credibility costs allows us to treat the current specification of the model as a particular case where costs of credibility are absent. This facilitates the comparison of relevant monetary policy scenarios.

The 4GM-model is a semi-structural New Keynesian model for monetary policy analysis and macroeconomic forecasting in Colombia, used by the Colombian central bank to inform its monetary policy decisions. It is based on a rational expectations framework for a small, open, and oil-exporting economy. The model has four main behavioral equations: an IS curve, a set of four Phillips curves, a UIP condition, and a monetary policy rule. The Phillips curves characterize the inflation of the baskets of goods, services, food, and regulated goods, which have different sensitivities to the output gap and the real exchange rate gap. The oil price plays a fundamental role in the model, affecting both the potential output and the trend component of the real exchange rate. The model is estimated using Bayesian methods and calibrated to reflect some stylized facts of the Colombian economy. The full specification of the 4GM-model can be found in the Appendix B.

In New Keynesian models with rational expectations, the Phillips curve tends to be hybrid, incorporating both backward-looking and forward-looking components of inflation. In these models, inflation expectations entering the Phillips curve are based on rational expectations consistent with the underlying economic framework and with a constant elasticity given by the corresponding parameter. However, this specification overlooks the potential effects of a loss of credibility in the inflation target set by central banks. If credibility in the inflation target falls, agents become more backward-looking, assigning greater weight to past inflation, reducing the influence of rational expectations, and weakening the anchoring of future inflation projections.

To address this limitation, we propose an augmented Phillips curve that partially deviates from the strict rational expectations assumption. Following Argov et al. (2007) and Chansriniyom et al. (2020), our model incorporates a non-linearity that captures the effects of credibility costs. In our model, agents form inflation expectations by considering both rational expectations and past observed inflation. Importantly, the weights assigned to these forward- and backward-looking components vary over time and reflect the central bank's ability to achieve its inflation target-that is, the credibility of the inflation target. Specifically, our augmented Phillips curves have the form:

$$\pi_t^j = \alpha_{\pi^j} \pi_t^{e,j} + (1-\alpha_{\pi^j})\, \pi_{t-1}^j + \alpha_{rmc^j}^{\pi^j} rmc_t^j + \epsilon_t^{\pi^j} \text{ for } j \in \{G, S, F\} \tag{4}$$

$$\pi_t^{e,j} = c_t \mathbb{E}_t \pi_{t+1}^j + (1-c_t)\, \pi_{t-1}^j + \epsilon_t^{\pi ej}, \tag{5}$$

where π_t^j represents annualized quarterly inflation, π_{t-1}^j reflects inflationary inertia, rmc_t^j is the real marginal cost, which in turn depends positively on the output gap $(\hat{y}_t)$, the real exchange rate gap $(\hat{z}_t)$, and the relative price of the same sector. In Equation (5), $\pi_t^{e,j}$ represents inflation expectations that consider a credibility stock and are a weighted average of rational inflation expectations $\left(\mathbb{E}_t \pi_{t+1}^j\right)$ and past inflation $\left(\pi_{t-1}^j\right)$. The model has three such Phillips curves, augmented by a credibility channel, for goods, services, and food.[8]

Equation (5) implies that the weighting of the forward and backward components by the agents depends on a credibility stock, denoted by $c_t \in [0,1]$. When the credibility stock is equal to one, perfect credibility is reached, as in the standard New Keynesian model. However, a credibility stock below one implies an erosion of the credibility of the inflation target.[9] We assume that this credibility stock follows a first-order autoregressive process, that depends on a credibility signal, denoted $s_t \in [0,1]$, which accumulates over successive periods:

$$c_t = \psi c_{t-1} + (1-\psi)\, s_t + \epsilon_t^c, \tag{6}$$

$$s_t = f\left(\pi_{t-1} - \pi_{t-1}^* | \omega\right). \tag{7}$$

The functional form of the credibility signal and the associated parameters in Equation (7) significantly influence the credibility costs. However, these components are not directly observable. Here we introduce an innovative approach to estimate both the functional form of $f(\cdot)$ and its parameters. Particularly, and opposed to the economic literature that relies on restrictive functional forms, often grounded in ad-hoc assumptions specific to the context, we instead advocate for a data-driven strategy. By leveraging historical data, particularly market inflation expectations, we can determine the functional form and estimate the credibil-

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[8] The 4GM-model has a fourth basket for regulated goods. But since regulated goods do not respond to the same market forces as the other three baskets, it is reasonable to assume that the inflation of the basket of regulated goods is not affected by credibility costs.

[9] In the extreme case of zero credibility $(c_t = 0)$, real marginal costs affect changes in inflation rather than its level, $\pi_t - \pi_{t-1} = \alpha_{rmc} rmc_t + \epsilon_t^\pi$. The Phillips curve becomes accelerationist.

Table 2 – Estimated parameters for the functional form of the credibility signal

	Coefficient	Std. Error	p-value
ω_1	$ln\left(\frac{1}{1-\omega_3}\right)$		
ω_2	0.062	0.034	0.074
ω_3	0.426	0.066	0.000
$\sigma^2_{\epsilon^{sig}}$	0.018		

Sources: Authors' calculations.

ity signal's parameters. Notably, our method builds upon the metric of credibility previously estimated in Section 3.

We begin by proposing a broadly generic functional form for the credibility signal, as follows:

$$f\left(\pi_{t-1}-\pi^*_{t-1}|\omega\right)=e^{\left(-\omega_1-\omega_2\left(\pi_{t-1}-\pi^*_{t-1}\right)^2\right)}-\omega_3. \tag{8}$$

This function is centered around the announced inflation target, and has three key parameters shaping its profile: ω_1 defines the highest level of the credibility signal achievable by the central bank; ω_2, determines the steepness of the function around the inflation target (where a steeper slope indicates a more rapid erosion of credibility with deviations from the target, while a flatter slope suggests a more forgiving public perception of smaller deviations); and ω_3 represents the lowest possible level of the credibility signal. When $\omega_3 = 0$, the credibility signal can potentially reach a level where the central bank's ability to control inflation has completely eroded. We use this symmetric function for the credibility signal as our baseline, but in Appendix C we examine the robustness of our results when two more generalized asymmetric functions are considered, producing credibility signals that do not differ substantially from the one derived from our symmetric specification.

Our approach to estimating the parameters of the credibility signal is based on the following regression,

$$\lambda_t=e^{\left(-\omega_1-\omega_2\left(\pi_{t-1}-\pi^*_{t-1}\right)^2\right)}-\omega_3+\epsilon^{sig}_t, \tag{9}$$

where the credibility metric λ_t from Section 3 serves as a proxy for the credibility signal s_t. Table 2 presents the estimated parameters, while Figure 4 shows the estimated credibility signal ($\hat{s}_t$) and Figure 5 its associated functional form.[10]

Unsurprisingly the main distinction between the initial measure λ_t and the estimate of the credibility signal s_t lies in their persistence. The initial metric tends to exhibit greater persistence over time. Both measures reveal credibility losses during specific periods. Notably, the years 2008 and 2016 witnessed substantial declines in credibility, which were subsequently recovered. However, the post-Covid-19 era stands out as a critical juncture. The loss of

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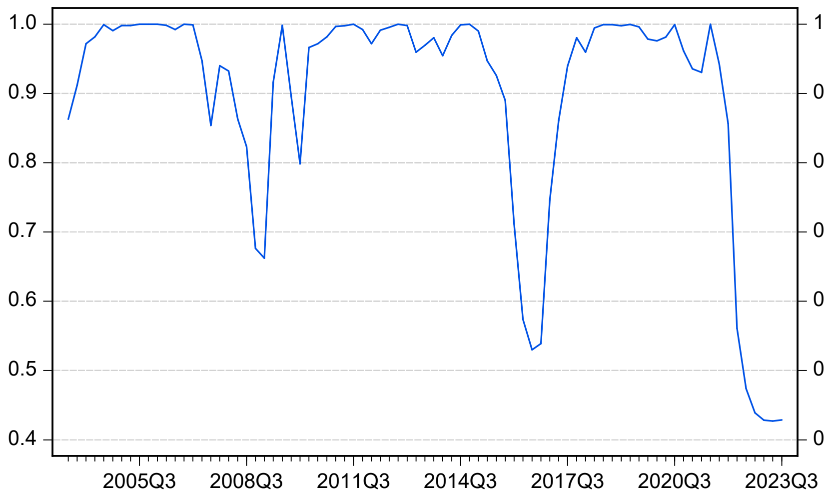
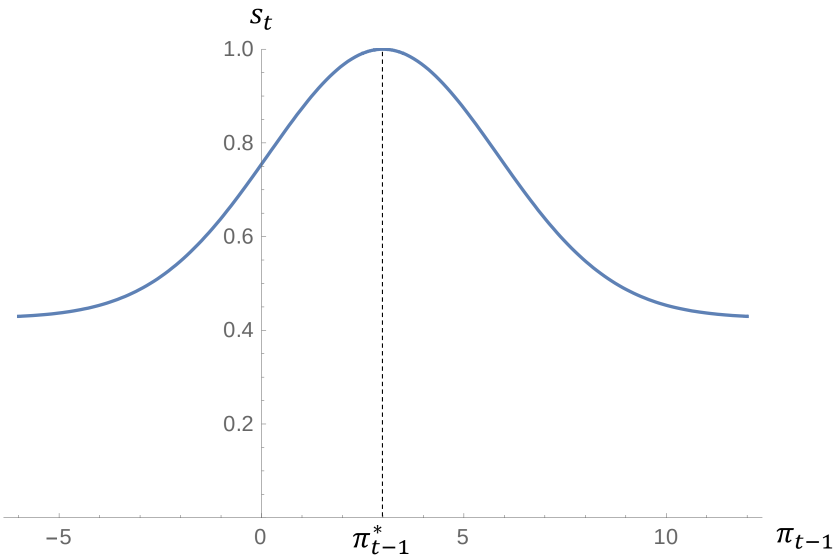
[10] In Appendix B, we examine the robustness of our results when asymmetric credibility signals are considered.

Figure 4 – Estimation of the credibility signal $\hat{s}_t$



Sources: Authors' calculations.

Figure 5 – Functional form of the credibility signal s_t



Note: This figure assumes that the inflation target in quarter $t-1$ is 3%.
Sources: Authors' calculations.

credibility observed during this period surpasses any previous episode since 2003. However, throughout the analysis period, the credibility of the target remained high. Even during the post-Covid episode, credibility was never reduced to zero.

Finally, notice that as in the case of the initial measure λ_t the credibility signal s_t is estimated without considering general equilibrium channels. However, this estimate of the credibility signal and the values found for its persistence and bounds, that depend on the estimated parameters of the functional form of the loss function, will be used as priors in the Bayesian estimation of the full general equilibrium model in Section 5.

5 Estimation

To recap, our estimation of the final credibility stock unfolds in a three-stage process, with each stage building upon the insights gained from the previous one. In the initial stage, detailed in Section 3, we focus on estimating an empirical measure of credibility (λ_t). This initial measure captures the key relationship between the observed inflation expectations and the inflation target, providing a data-driven foundation for our analysis. Armed with this measure, we proceed in Section 4 to utilize λ_t as a proxy for the credibility signal of the model to obtain, in partial equilibrium, a starting point to estimate the parameters associated with its persistence and with the loss function that shape the evolution of the credibility stock. Finally, in this section, we now incorporate the estimates from the second stage into a Bayesian estimation of the 4GM-modified model.

We estimate the 4GM-modified model assuming that the other components of the structure of the model and its estimated parameters remain unchanged. In particular, i) the IS curve:

$$\hat{y}_t = \beta_1 \hat{y}_{t-1} + \beta_2 \mathbb{E}_t \hat{y}_{t+1} - \beta_\Phi \Phi_t + \beta_{\hat{y}^*} \hat{y}^*_t + \beta_{\hat{rp}_t} \hat{rp}^{oil}_t + \eta^{\hat{y}}_t \tag{10}$$

where $\hat{y}_t$ is the output gap, $\Phi_t = \beta_{\hat{r}} \hat{r}_t - (1 - \beta_{\hat{r}})\, \hat{z}_t$ is the real index of monetary conditions, which in turn depends on the real interest rate gap ($\hat{r}_t$) and the real exchange rate gap ($\hat{z}_t$); ii) the UIP condition:

$$i_t = i^*_t + \varphi_t + \Delta \mathbb{E}_t s_{t+1} + \epsilon^s_t, \tag{11}$$

where i_t is the nominal interest rate, i^*_t is the external nominal interest rate, φ_t is the country risk premium, and s_{t+1} is the exchange rate; and iii) the monetary policy rule:

$$i_t = \rho_i i_{t-1} + (1 - \rho_i) \left(\bar{i}_t + \varphi_\pi \left(\mathbb{E}_t \pi^A_{t+3} \text{-} \mathbb{E}_t \bar{\pi}^A_{t+3} \right) + \varphi_{\hat{y}} \hat{y}_t \right) + \epsilon^i_t, \tag{12}$$

where $\bar{i}_t$ is the nominal neutral interest rate and $\left(\mathbb{E}_t \pi^A_{t+3} \text{-} \mathbb{E}_t \bar{\pi}^A_{t+3} \right)$ is the deviation of annual inflation expectations from the target three quarters ahead; all remain unchanged. This assumption allows us to generate a tool that is able to produce forecasts in which costs of credibility losses are taken into account, but that at the same time, are totally compatible to those generated by the original 4GM-model, the current tool for monetary policy analysis.

This procedure facilitates the construction of consistent alternative policy scenarios.

We thus estimate the parameters ω_2, ω_3, ψ and σ^c in the system of equations (4)-(8) and (10)-(12) using Bayesian techniques,[11] in which we inform the priors of ω_2 and ω_3 with the results presented in Table 3 and the prior of ψ with the obtained persistence of the credibility signal estimated in the second stage.[12] Table 3 presents the prior distributions and posterior values of the key parameters associated with the credibility dynamics. As expected, incorporating the general equilibrium channels has non-negligible effects on the obtained estimates of the parameters of interest, compared to their priors. In particular, compared to the values used as priors, the parameter ω_2 is slightly lower, while the parameter ω_3 is higher.

Table 3 – Parameter estimates

Par.	**Description**	**Prior distribution**	**Posterior distribution**		
			Mean	10%	90%
ω_2	Steepness of the signal function	beta(0.062,0.05)	0.041	0.01	0.13
ω_3	Lower bound credibility signal	beta(0.43,0.2)	0.66	0.17	0.70
ψ	Credibility stock persistence	beta(0.84,0.1)	0.84	0.83	0.86
σ^c	Std. of credibility shock	gamma(0.05,0.05)	0.02	0.018	0.021

Source: Authors' calculations.

Armed with these estimates, in the following section we explore the implications for monetary policy of including an endogenous credibility channel in the model, focusing on how the costs of the stabilization process, in terms of output, change under different credibility values.

6 Policy implications

To understand the response of the economy to inflationary shocks under endogenous credibility, the simulation depicted in Figure A.4 presents two contrasting scenarios that illustrate the importance of the initial state of credibility in the economy's response to supply shocks. In both scenarios, a shock to the services' Phillips curve is considered, with a deviation of 100 basic points (b.p hereafter) from the steady state. In the first scenario, characterized by the absence of credibility losses ("high initial credibility"), we observe that monetary policy successfully anchors expectations and controls inflation with relative efficiency.[13] Although a monetary policy effort is required to counteract the shock's impact, the absence of credibility

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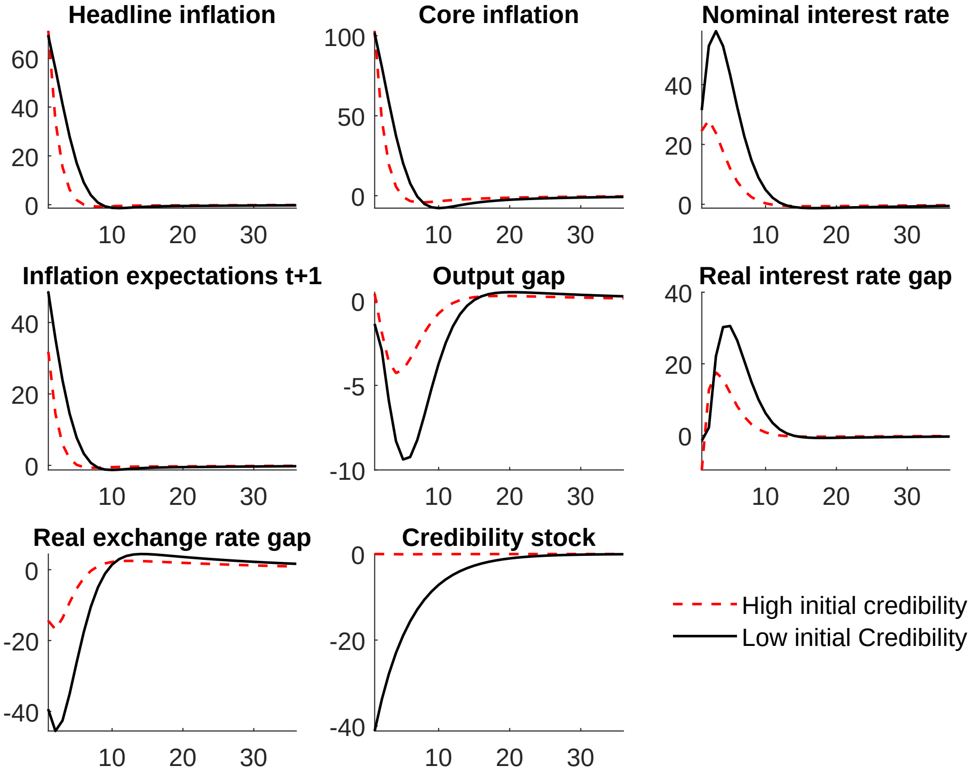
[11] Particularly, we approximate the posterior distributions using a MCMC Metropolis-Hastings algorithm, with 10000 draws where 20% of those are discarded as burn-in draws

[12] The standard deviation of the shock on credibility stock σ^c has a non-informative prior.

[13] In some way, the absence of credibility costs make the model to deliver the "forward guidance puzzle" documented by Del Negro et al. (2023), i.e. the fact that with rational agents, forward guidance led by the central bank target is predicted to work very powerful.

losses allows for a moderate response, minimizing distortions in the economy. In this context, the loss of output is limited, and the economy swiftly recovers from the shock's effects.

Figure 6 – Impulse-response functions of a cost-shock under different values of credibility



Note: Response of selected variables to a 100 basic points (b.p) supply shock. The responses of the endogenous variables are in basic points (b.p).
Source: Authors' calculations

The scenario labeled "low initial credibility" simulates the same supply shock, but with an initial stock of credibility 40% smaller than in the first scenario.[14] The results are markedly different. Monetary policy faces greater challenges to anchor expectations and contain inflation. A higher monetary policy effort is required to counteract the impact of the inflationary shock, resulting in a greater loss of output and a larger appreciation effect in the real exchange rate inflationary gap. Thus, the lack of credibility limits the effectiveness of policy measures, prolonging the recovery of the economy. These results are qualitatively similar (although with differences in their magnitudes) when a goods' Phillips curve cost shock is considered (see Figure A.1 in Appendix A); while in the case of demand shocks the implications of lower

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[14] This is achieved through a simultaneous shock to the stock of credibility ϵ_t^c. An alternative way to recreate an economy that starts in a low-credibility regime is through multiple sequential shocks. For example, Figure A.3 in Appendix A shows the impulse response functions to several sequential supply shocks and their cumulative impact on the credibility stock.

credibility are more attenuated (see Figure A.2 in Appendix A).

Therefore, by relaxing the assumption of no credibility losses, the optimal response of the monetary authority and its corresponding costs in terms of output depend on the degree of credibility in the inflation target of the monetary authority. The absence of credibility losses not only facilitates a more efficient response by monetary policy, but also mitigates the costs in terms of economic growth. To better understand the latter costs associated with inflationary supply shocks, we proceed to evaluate the sacrifice ratio in response to various increases in headline inflation (100 basis points, 1000 basis points, 10000 basis points), a simulation that also illustrates the non-linear effects on the costs associated with the output gap.

Table 4 presents the sacrifice ratios, calculated as the present value of the quarterly output gap under the different simulated inflationary episodes, providing a measure of the economic losses incurred. This approach captures both the immediate and long-term effects of monetary policy decisions on the quarterly output gap. In the model with no credibility costs, the sacrifice in terms of the output gap is proportional to inflation increases, indicating that significant deviations from headline inflation do not impose additional costs on the monetary authority. Thus, the (relative) monetary effort required to anchor expectations remains constant. However, when credibility is endogenous, the sacrifice ratio increases more than proportionally, implying that substantial deviations from the announced inflation target impose additional stabilization costs on the central bank.

Table 4 – Policy responses to rises in headline inflation under endogenous and constant credibility

Scenarios: Increases in headline inflation	100 (b.p)	1000 (b.p)	10000(b.p)
Endogenous credibility	31.08	411.68	6217.08
Constant credibility (ss)	30.67	306.72	3067.23

Source: Authors' calculations

In conclusion, our simulations highlight the nuanced dynamics of credibility and its implications for the effectiveness of monetary policy. Specifically, our quantitative exercises reveal that fluctuations in credibility significantly magnify the challenges policymakers face in anchoring inflation expectations while minimizing output losses, particularly in the presence of supply shocks. The comparative analysis between high- and low-credibility scenarios underscores the importance of building credibility to reduce stabilization costs after inflationary surges, such as the one triggered by the COVID-19 pandemic. Finally, from a practical perspective, an important aspect of the design of our tool is its ability to create alternative policy scenarios to those generated by the primary semi-structural model currently used for forecasting and monetary policy analysis, accounting for the additional costs of credibility losses. This capability allows policymakers to isolate the general equilibrium effects of credibility losses by comparing model outcomes with and without these losses.[15]

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[15] For example, Figure A.4 in Appendix A shows the differences between the forecast scenario with endogenous credibility losses and the scenario without credibility costs generated in mid-2023.

7 Conclusions

In this study, we delved into one of the many repercussions of the COVID-19 pandemic: the potential erosion of central bank credibility due to the significant inflationary surge that followed the pandemic. Using data from expectation surveys in Colombia, we constructed a time-variant credibility metric based on a filtering framework, which served as a cornerstone for our model estimation. We embedded endogenous credibility into the 4GM-model, one of the main tools for monetary policy analysis in the country, providing a nuanced tool for forecasting and scenario analysis that accounts for the intricate interplay between credibility losses and monetary policy effectiveness.

Our estimated model revealed the dynamic nature of the trade-off between inflation and output stabilization, contingent on the central bank's credibility. Particularly, a crucial insight from our analysis is the non-linear relationship between the stock of credibility and the sacrifice ratio. This relationship suggests that restoring inflation to target levels before the pandemic requires a more aggressive policy stance than would be inferred under scenarios devoid of credibility considerations. Our results highlight the importance of maintaining a robust level of central bank credibility to mitigate costs in terms of output of the stabilization process.

Considering these findings, policymakers are encouraged to prioritize the usual measures that bolster central bank credibility, especially in the aftermath of large-scale shocks. Such measures may include transparent communication strategies, adherence to inflation targets, and incorporation of credibility considerations into policy models. Future research could enhance our model to include mechanisms currently not represented in the 4GM-model, such as the interaction between the goods and labor markets, the explicit modeling of weather shocks, or financial sector considerations.

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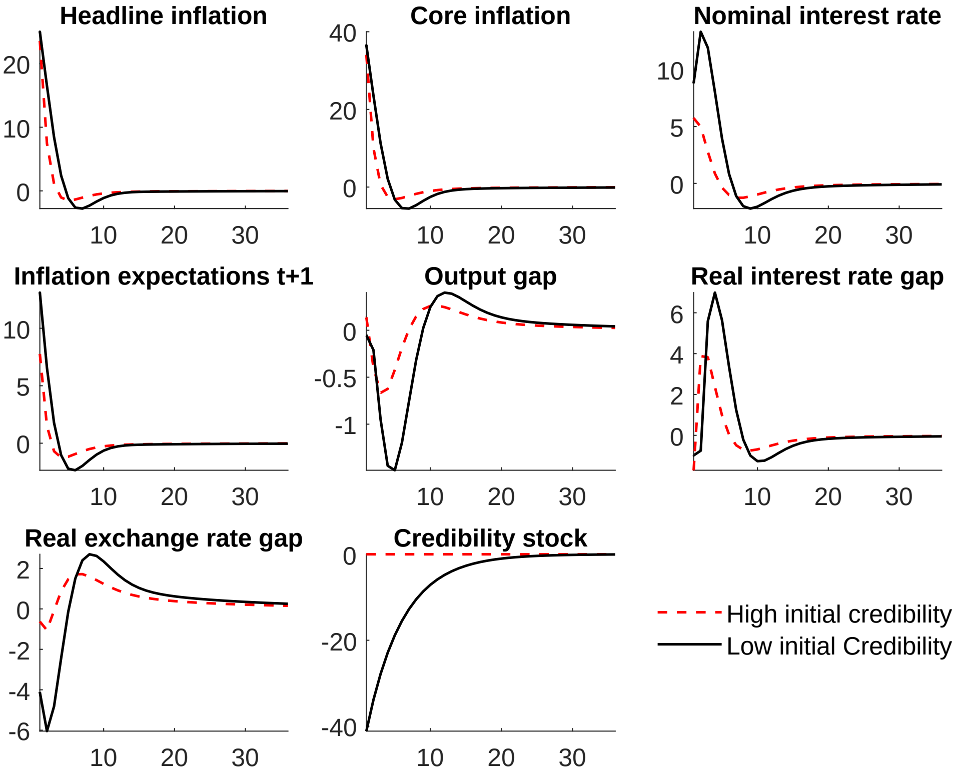
Appendix

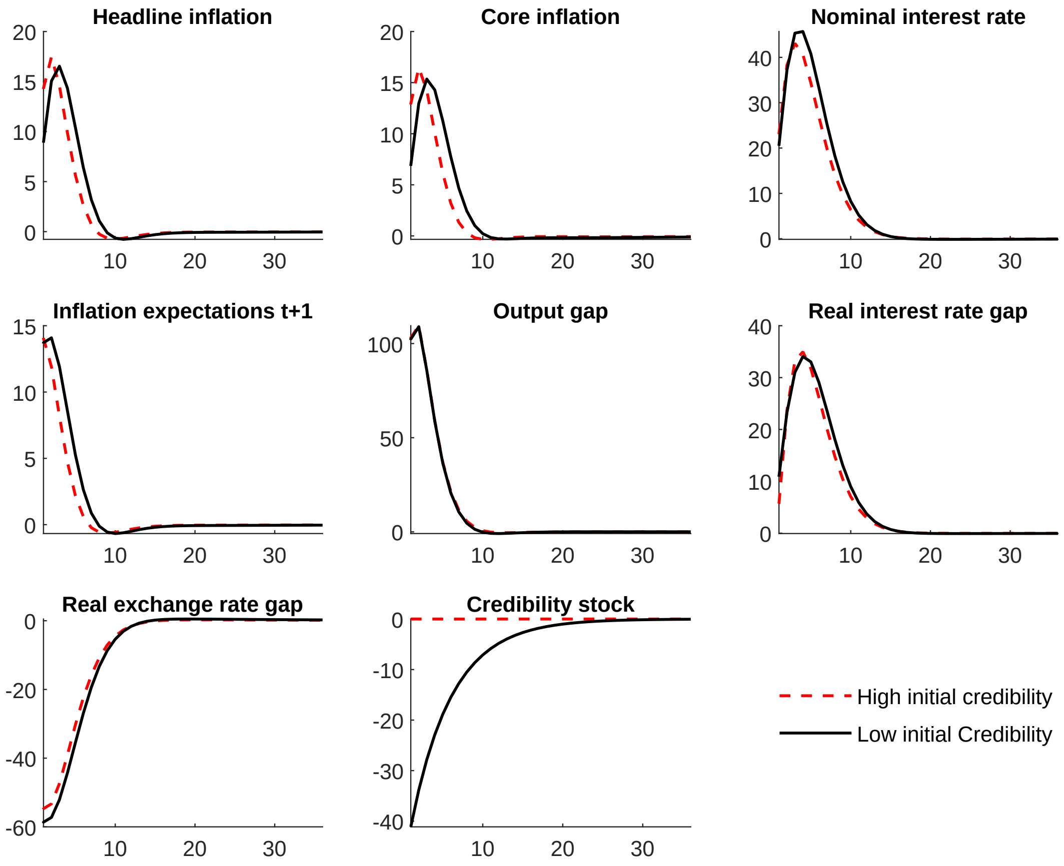
A Additional Figures

Figure A.1 – Impulse response function to a tradable goods cost shock



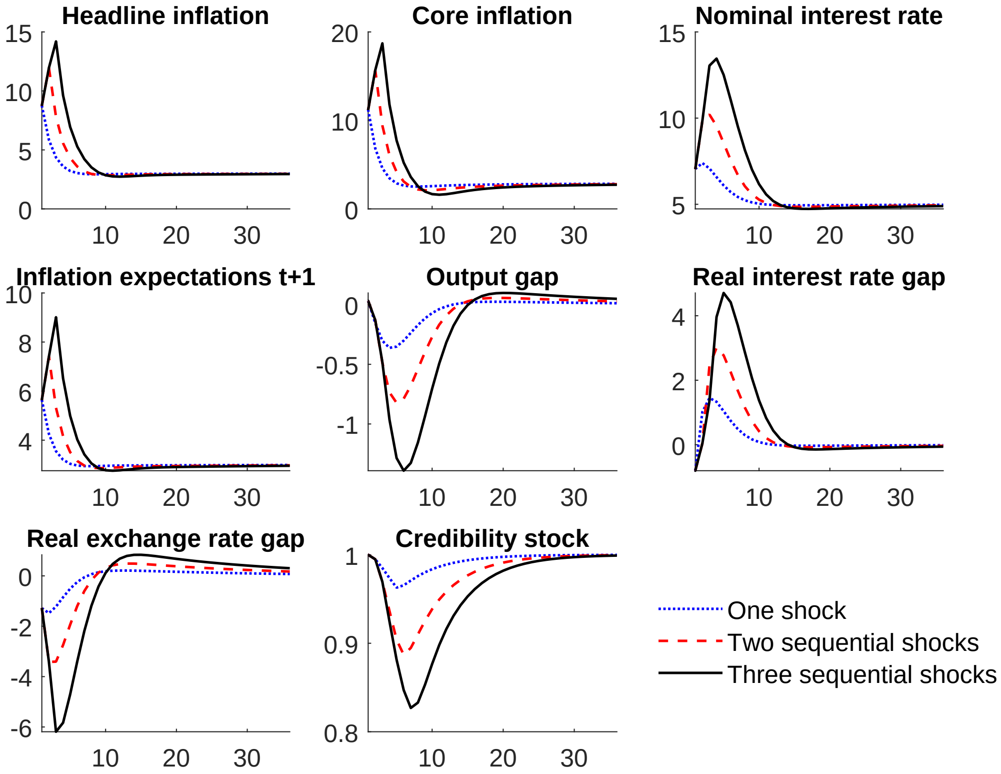
Note: Response of selected variables to a 100 basic points (b.p) supply shock. The responses of the endogenous variables are in basic points (b.p).
Source: Authors' calculations

Figure A.2 – Impulse response function to a demand shock



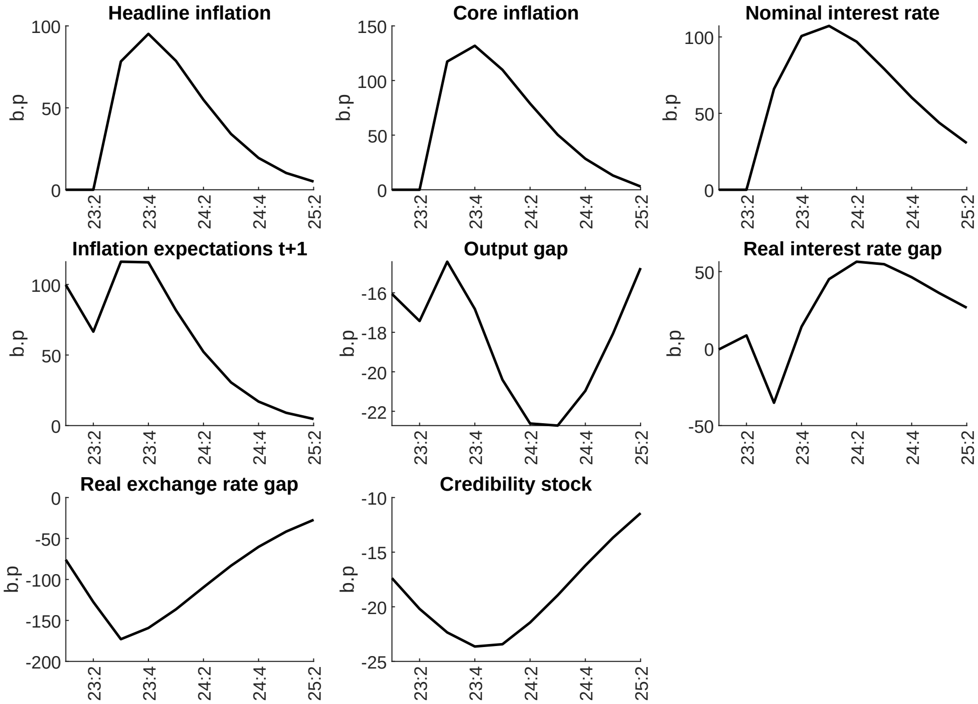
Note: Response of selected variables to a 100 basic points (b.p) demand shock. The responses of the endogenous variables are in basic points (b.p).
Source: Authors' calculations

Figure A.3 – Impulse response function to multiple supply shocks



Note: Response of selected variables to one, two and three sequential supply shocks of 800 basic points (b.p)
Source: Authors' calculations

Figure A.4 – Differences between escenarios with and without endogenous credibility



Note:The results represent the differences between the forecast scenario with endogenous credibility costs and the scenario without credibility costs, both with information up to July 2023 and without additional judgments in the forecast horizon (2 years).
Source: Authors' calculations

B The Full 4GM-model (Gonzalez et al., 2020)

The model structure can be divided into four main blocks: 1) The IS Curve and potential output growth; 2) the Phillips curves for each CPI basket; 3) the monetary policy rule and definitions of other interest rates; and 4) the uncovered interest parity (UIP) and the process for foreign variables. Shocks are denoted by ε_t and are normally distributed.

1) IS Curve and Potential GDP Growth

The output level in logarithmic terms y_t is defined in terms of a cyclical component $\hat{y}_t$ (output gap) and a trend $\overline{y}_t$ (potential output):

$$y_t = \overline{y}_t + \hat{y}_t \tag{A.1}$$

$$\overline{y}_t = \overline{y}_{t-1} + \frac{\Delta\overline{y}_t}{4} \tag{A.2}$$

$$\Delta\overline{y}_t = \rho_{\Delta\overline{y}}\Delta\overline{y}_{t-1} + (1-\rho_{\Delta\overline{y}})\left(\Delta\overline{y}_{ss} + \kappa_{\Delta\overline{y}}\left(\Delta\overline{pr}_t^{oil} - \Delta\overline{pr}_{ss}^{oil}\right)\right) + \varepsilon_t^{\Delta\overline{y}} \tag{A.3}$$

$$\hat{y}_t = \beta_1\widehat{y}_{t-1} + \beta_2 E_t\hat{y}_{t+1} - \beta_{\Phi}\Phi_t + \beta_{\hat{y}^\star}\hat{y}_t^\star + \beta_{r\hat{p}_t^{oil}}\widehat{rp}_t^{oil} + \eta_t^{\widehat{y}} \tag{A.4}$$

$$\Phi_t = \beta_{\hat{r}}\hat{r}_t - (1-\beta_{\hat{r}})\hat{z}_t \tag{A.5}$$

$$\eta_t^{\widehat{y}} = \beta_{\eta^{\widehat{y}}}\eta_{t-1}^{\widehat{y}} + \varepsilon_t^{\widehat{y}} \tag{A.6}$$

where Φ_t is the real monetary condition index that captures the effect of the real interest rate gap $\hat{r}_t$ and the real exchange rate gap $\hat{z}_t$; $\hat{y}_t^*$ is the foreign output gap; $r\hat{p}_t^{oil}$ is the real oil price gap; and $\eta_t^{\widehat{y}}$ is a demand shock that follows an AR(1) process. Notice that the law of motion of potential growth $\Delta\overline{y}$ depends on its lagged value, the long-term growth rate (steady state) $\Delta\overline{y}_{ss}$, and deviations of the trend growth of the real oil price from its steady state rate $(\Delta\overline{rp}_t^{oil} - \Delta\overline{rp}_{ss}^{oil})$.

2) Phillips Curves and CPI Aggregation

The model considers four CPI baskets j, namely Goods (G), Services (S), Food (F), and Regulated goods (R). Each of them has a Phillips curve of the hybrid form:

$$\pi_t^j = \alpha_{\pi^j}\pi_{t-1}^j + (1-\alpha_{\pi^j})E_t\pi_{t+1}^j + \alpha_{rmc^j}^{\pi^j} rmc_t^j + \varepsilon_t^{\pi^j} \quad \text{for } j = G, S, F, R \tag{A.7}$$

where π_t^j is the annualized quarterly inflation and rmc_t^j is the real marginal cost, given by:

$$rmc_t^j = \begin{cases} \alpha_{\hat{y}}^{rmc^j}\hat{y}_t + (1-\alpha_{\hat{y}}^{rmc^j})(\hat{z}_t - p\hat{r}_t^j) & \text{for } j = G, S \\ \alpha_{\hat{y}}^{rmc^j}\hat{y}_t + (1-\alpha_{\hat{y}}^{rmc^j})(p\hat{r}_t^{F^\star} + \hat{z}_t - p\hat{r}_t^j) & \text{for } j = F \\ \alpha_{\hat{y}}^{rmc^j}\hat{y}_t + (1-\alpha_{\hat{y}}^{rmc^j})(p\hat{r}_t^{oil} + \hat{z}_t - p\hat{r}_t^j) & \text{for } j = R \end{cases} \tag{A.8}$$

Thus, real marginal costs depend positively on the output gap $\hat{y}$, the real exchange rate gap $\hat{z}_t$, and each basket relative price $r\hat{p}_t^j$ gap. In addition, the Phillips curves for food and regulated items include the real relative price gaps of world food prices $r\hat{p}_t^{F*}$ and oil $r\hat{p}_t^{oil}$, respectively. Relative prices and the aggregation of CPI are given by:

$$\hat{pr}_t^j = pr_t^j - \overline{pr}_t^j \quad \text{for } j = G, S, F, R \tag{A.9}$$

$$pr_t^j = p_t^j - p_t \tag{A.10}$$

$$\overline{pr}_t^j = \overline{pr}_{t-1}^j + \frac{\Delta\overline{pr}_t^j}{4} \tag{A.11}$$

$$\Delta\overline{pr}_t^j = \rho_{\overline{pr}^j}\Delta\overline{pr}_{t-1}^j + \left(1 - \rho_{\overline{pr}^j}\right)\Delta\overline{pr}_{ss}^j + \varepsilon_t^{\Delta\overline{pr}^j} \quad \text{for } j = S, F, R \tag{A.12}$$

$$p_t = \omega^G p_t^G + \omega^S p_t^S + \omega^F p_t^F + \omega^R p_t^R + \eta_t \tag{A.13}$$

$$0 = \omega^G \hat{pr}_t^G + \omega^S \hat{pr}_t^S + \omega^F \hat{pr}_t^F + \omega^R \hat{pr}_t^R \tag{A.14}$$

Thus, relative prices pr_t^j are the difference between the price index of sector j, p_t^j, and the consumer price index (CPI), p_t. Each relative price is decomposed in a long-term trend component $\overline{pr}_t^j$ and a gap component $\hat{pr}_t^j$, which enter into each corresponding Phillips curve.

3) Monetary Policy Rule and Interest Rates

The monetary policy rate i_t is given by a Taylor rule:

$$i_t = \rho_i i_{t-1} + (1 - \rho_i)\left(\bar{i}_t + \varphi_\pi(\mathbb{E}_t\pi_{t+3}^A - \mathbb{E}_t\bar{\pi}_{t+3}^A) + \varphi_{\hat{y}}\hat{y}_t\right) + \varepsilon_t^i \tag{A.15}$$

where $\bar{i}_t$ is the neutral nominal interest rate and $(E_t\pi_{t+3}^A - E\bar{\pi}_{t+3}^A)$ captures the deviation of annual inflation expectations from the three periods ahead target. 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 that is determined by:

$$\Delta\bar{z} = \bar{r} - \bar{r}^* + \overline{prem}_t \tag{A.16}$$

where $\bar{r}^*$ is the neutral real interest rate of the US, $\overline{prem}_t$ is the country's long-term trend risk premium, and $\Delta\bar{z}$ is the long term real depreciation that is in the steady state.

4) Uncovered Interest Parity (UIP) and Foreign Variables

One-period ahead expectations of depreciation $\Delta\mathbb{E}_t s_{t+1}$ are determined by the UIP:

$$\Delta\mathbb{E}_t s_{t+1} = i_t^* - i_t + prem_t + \varepsilon_t^{ls} \tag{A.17}$$

$$z_t = s_t + p_t^\star - p_t \tag{A.18}$$

$$\hat{z}_t = z_t - \bar{z}_t \tag{A.19}$$

$$\bar{z}_t = \bar{z}_{t-1} + \frac{\Delta\bar{z}_t}{4} \tag{A.20}$$

$$\Delta\bar{z}_t = \rho_{\Delta\bar{z}}\Delta\bar{z}_{t-1} + (1 - \rho_{\Delta\bar{z}})\left(\Delta\bar{z}_{ss} - \nu_{\Delta\bar{z}}(\Delta\overline{pr}_t^{oil} - \Delta\overline{pr}_{ss}^{oil})\right) + \varepsilon_t^{\Delta\bar{z}} \tag{A.21}$$

where Δs_t is the nominal depreciation, i_t^* is the FED funds rate, and $prem_t$ is the risk premium. The real exchange rate, z_t, is decomposed into a long-term component $\bar{z}_t$ and a cyclical component $\hat{z}_t$.

Finally, the model has a set of exogenous paths for the following foreign variables: the world oil relative price gap $\hat{pr}_t^{oil}$, the world food relative price gap $\hat{pr}_t^{\star F}$, the foreign output gap $\hat{y}_t^{\star}$, the foreign headline inflation $\pi_t^{\star}$, the nominal foreign interest rate $i_t^{\star}$, the foreign real neutral interest rate $\bar{r}_t^{\star}$, the country risk premium $prem_t$, and the long-term trend country risk premium $\overline{prem}_t$. All of them follow an AR(1) process:

$$(\cdot)_t = \rho_{(\cdot)}\,(\cdot)_{t-1} + \left(1-\rho_{(\cdot)}\right)\tilde{(\cdot)} + \varepsilon_t^{(\cdot)} \tag{A.22}$$

for $(\cdot) = \left\{\hat{pr}_t^{oil}, \hat{pr}_t^{\star F}, \hat{y}_t^{\star}, \pi_t^{\star}, i_t^{\star}, \bar{r}_t^{\star}, prem_t, \overline{prem}_t\right\}$, where $\rho_{(\cdot)}$ is the persistence and $(1-\rho_{(\cdot)})$ represents the speed of adjustment towards the corresponding steady-state value $\tilde{(\cdot)}$.

Our specification with credibility costs modifies the 4GM model by incorporating equations (6) - (8) that define our credibility metric depending on the selected loss function, and changes the system of equations (A.8) by (4) - (5) to incorporate the effects of credibility costs into the Phillips curves.

C Asymmetry of the Credibility Signal

The response of credibility to deviations of observed inflation from target inflation may not be symmetric. Specifically, credibility might decline more significantly - or only - when observed inflation exceeds the target, whereas it may decrease less severely or remain unaffected when inflation falls below the target. Determining whether the credibility response to inflation deviations is symmetric or asymmetric is an empirical question. This appendix explores the potential for an asymmetric credibility response in Colombia during the period 2003-2023.

To examine this, we consider two asymmetric non-linear functional forms for the credibility signal as alternatives to the symmetric nonlinear form used in Section 4 (Equation (8)). In the first alternative, we impose asymmetry by assuming that credibility is not affected when the observed inflation is below the target. This specification is shown in Equation (A.23) below, where the asymmetry assumption is achieved by setting $\omega_5 = 0$:

$$\lambda_t = \begin{cases} e^{\left(-\omega_1-\omega_2\left(\pi_{t-1}-\pi_{t-1}^*\right)^2\right)} + \omega_3 + \epsilon_t^{sig} & \text{if } \pi_{t-1}-\pi_{t-1}^* \geq 0 \text{ with } \omega_2 \geq 0 \\ e^{\left(-\omega_4-\omega_5\left(\pi_{t-1}-\pi_{t-1}^*\right)^2\right)} + \omega_6 + \epsilon_t^{sig} & \text{if } \pi_{t-1}-\pi_{t-1}^* < 0 \text{ with } \omega_5 = 0. \end{cases} \tag{A.23}$$

The second alternative is more general, estimating all parameters so that the data determine the potential asymmetry of the credibility response. This specification corresponds to:

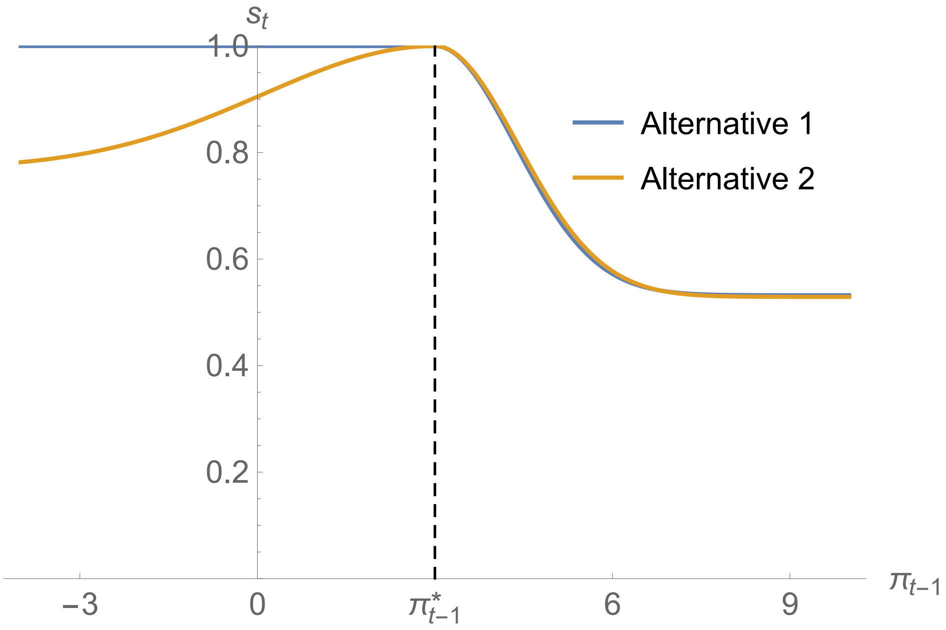
$$\lambda_t = \begin{cases} e^{\left(-\omega_1-\omega_2\left(\pi_{t-1}-\pi_{t-1}^*\right)^2\right)} + \omega_3 + \epsilon_t^{sig} & \text{if } \pi_{t-1}-\pi_{t-1}^* \geq 0 \text{ with } \omega_2 \leq \omega_3 \\ e^{\left(-\omega_4-\omega_5\left(\pi_{t-1}-\pi_{t-1}^*\right)^2\right)} + \omega_6 + \epsilon_t^{sig} & \text{if } \pi_{t-1}-\pi_{t-1}^* < 0 \text{ with } \omega_5 \leq \omega_6. \end{cases} \tag{A.24}$$

Table A.1 presents the estimation results for the two alternatives, while Figure A.5 shows the functional form associated with the two alternative specifications. The data suggest that the credibility response is indeed asymmetric, with credibility declining less when observed inflation is below target than when it is above target. However, when comparing the estimates of the common parameters for these two alternatives, the differences between the first alternative, where the asymmetry is imposed, and the second alternative, where the data determine the magnitude of the asymmetry, are relatively small.

Table A.1 – Estimates of asymmetric credibility signals

Parameter	Alternative 1	Alternative 2
ω_1	$\ln\left(\frac{1}{1-\omega_3}\right)$	$\ln\left(\frac{1}{1-\omega_3}\right)$
ω_2	0.273	0.253
ω_3	0.532	0.529
ω_4	$\ln\left(\frac{1}{1-\omega_6}\right)$	$\ln\left(\frac{1}{1-\omega_6}\right)$
ω_5	0	0.059
ω_6	0.777	0.769

Figure A.5 – Estimates of asymmetric credibility signals. Functional forms of alternative asymmetric credibility signals



These small differences translate into comparable credibility signals for the two asymmetric alternatives, which, in turn, closely resemble the signal obtained using the symmetric specification in Equation (9) (Figure A.6). This similarity indicates that our estimation of the credibility signal remains robust even when considering asymmetric loss functions.

Figure A.6 – Credibility signals with different specifications