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Interest Rate Sensitivity Scenarios to Guide Monetary Policy

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ABSTRACT: This paper examines the challenges of formulating monetary policy in the face of heightened uncertainty. We develop a framework to assess the optimal monetary policy path under uncertainty, focusing on four key dimensions: the expectation formation process, inflation persistence, the measurement of the neutral interest rate, and the slope of the Phillips curve. Our framework provides a flexible tool for policymakers to address uncertainty and enhance decision-making in pursuit of economic stability. This framework is helpful to improve the risk management approach to monetary policy by showing how scenarios can quantify different sources of uncertainty faced by the ECB and give market participants an idea of how the ECB would react if those scenarios materialize.

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WORKING PAPERS

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Contents Page

Tables

Figures

I. Introduction

After a long period of low and stable inflation and inflation expectations below target, the COVID shock combined with the large energy shock experienced in Europe, following the aftermath of Russia's invasion of Ukraine, caused inflation to reach levels not seen in decades, peaking in the Euro area at 10.7 percent in October 2022. At the same time, near-term inflation expectations finally increased above the two percent target prompting the ECB to start an unprecedented tightening cycle.

When inflation surged at the beginning of 2021, forecasters assumed that inflation would decrease much faster than it did. When inflation turned out to be more persistent than initially anticipated, forecasters started to make errors in the opposite direction, assuming that inflation would be more persistent than it turned out to be. Overall, there has been great uncertainty about the inflation process and forecasters have misjudged information in both directions. In such circumstances of high uncertainty and large forecast errors, central banks face exceptional difficulties in setting the optimal path for policy. It can also lead to a departure from conventional forward-looking forecast-based approaches to monetary policy and the adoption of a multi-pronged reaction function with emphasis on incoming data. Indeed, such high levels of uncertainty prompted the ECB to adopt in June 2022 the concept of "data dependence", which was initially used to describe a conjunctural environment with a "high learning" setting, where the ECB should use a Bayesian updating on the basis of incoming data for policy calibration.

Another important source of uncertainty in this current period comes from the measurement of the neutral interest rate, defined as the level of policy rate consistent with a closed output gap and inflation at target, i.e. a level at which central bank policy neither stimulates nor constrains the economy. Brand, Noëmie, and Mazelis (2024) use a suite of models to show that the neutral interest rate probably increased after the pandemic. Another important point they make is that there is a large heterogeneity of estimates depending on which model is used to measure the neutral rate. [1]

Setting interest rates in times when the economy is exposed to large idiosyncratic supply shocks introduces new uncertainties that the ECB has to address when formulating its monetary policy. In this short paper, we discuss a framework and some tools that can be used to formulate an optimal policy rate path in the face of forecast uncertainty that could be useful for policy discussions in the context

[1] The measure of the neutral rate is important for a couple of reasons: 1) it measures how much restriction a level of interest rate is imposing; 2) it guides market expectations on medium-term interest rates levels, 3) it affects how one measures monetary policy transmission. All of the previous points highlight that the neutral rate is an important unobserved state variable that the ECB should consider when deciding a policy path.

of the ongoing ECB Strategy Review. With this framework, we show how illustrative sensitivity scenarios can be designed and used to improve the risk management approach to monetary policy. More specifically, the framework computes the optimal monetary policy (one that minimizes a welfare loss function) when private agents form their expectations in different ways (either with the traditional rational expectations framework or with an adaptive learning formulation).

We provide several application examples to show how different sources of uncertainty could be assessed by the ECB when deciding monetary policy. While it is impossible to account for every type of uncertainty the ECB may encounter, we demonstrate how sensitivity scenario analysis can be tailored to address the specific question at hand. In this paper, we look at four possible sources of uncertainty: 1) the expectation formation process. Our flexible framework allows us to analyze policy mistakes if we misjudge how agents form expectations; 2) the inflation persistence; 3) measurements of the neutral rate; 4) uncertainty about the slope of the Phillips curve.

On the expectations process, other than simple adaptive expectations, such as the one from Brayton and others (1997), where the ECB can only affect inflation expectations through realized inflation outcomes, with adaptive learning expectations, ECB can also affect agents' *learning process*. In adaptive learning expectations, agents observe the values of some variables and use them to reassess their backward-looking ”econometric model” to generate expectations. Given the current context of fast changing expectations, this expectations process is of particular interest, as high inflation creates an endogenous bias and increases inflation expectations persistence, increasing the cost of disinflation. What we find is that the policy recommendation under rational expectations and adaptive learning expectations would be similar. The main reason is because inflation and the output gap are not that far from their equilibrium values and the models behave similar around those values.

On inflation persistence, this paper explores the sensitivity of a policy path to different views about the inflation persistence, and by doing so it provides a band of possible responses based on different persistence of the inflationary process. In a practical setting, the Governing Council members could weigh the probability of each of these sensitivity scenarios produced by staff and decide on a policy path.

On the uncertainty about where the neutral rate is, we apply the framework to demonstrate how to construct a sensitivity scenario analysis that yields a robust recommendation for policy rates amid uncertainties surrounding the estimation of the neutral rate. Our objective is to quantify the welfare losses associated with various misjudgments regarding the neutral rate, enabling the ECB to adopt a policy that minimizes potential welfare losses. Although the assessment of welfare losses is inherently model-dependent, our methodology of utilizing sensitivity scenarios to evaluate welfare losses from errors is more general and can be extended to various models. The main conclusion of this exercise is that the optimal monetary policy recommendation would not change much for the range of recently estimated neutral rates, as long as the ECB keeps re-optimizing policy for the new values of inflation and output gap. However, we show that the welfare cost of underestimating the neutral rate is greater than the cost of overestimating it, i.e the cost of following on overly accommodative monetary policy is higher than the cost of following an overly restrictive monetary policy. The result also reflects that the latest data are better accounted for by a higher level of the neutral rate than what was believed to be the case prior to the pandemic

The final section answers the question of how sensitive the optimal interest rate path is to the relative weights in the social welfare loss function. As expected, it shows that the ECB would be a bit more conservative if it only valued inflation, but the recommendations are not dramatically different, only deviating by 25-50bps.

The rest of the paper is organized as follows. Section II discusses the related literature, Section III introduces the model focusing on the expectation formation mechanism, and Section IV discusses data and model estimation, Section V discusses the optimal policy methodology, Section VI explores model based monetary policy paths to respond to uncertainties surrounding the inflation trajectory, expectation formation processes, and the neutral interest rate. Section VII discusses implications of different ECB's relative preferences on output gap and inflation deviations. Finally, Section VIII concludes the paper.

II. Literature Review

Forecasts that used pre-pandemic model estimates predicted a much smaller rise in core inflation than has in fact materialized. This could be rationalized as a steeper Phillips curve and falls in potential output (see Gopinath (2022)). Harding, Linde, and Trabandt (2022) argue that a nonlinear Phillips curve could rationalize the failure of existing models to explain the inflation spike. In particular, Erceg (2024) develops a macroeconomic model with nonlinear price and wage Phillips curves, endogenous intrinsic indexation and an unobserved components representation of a cost-push shock where a persistent large adverse supply shock leads to a persistent inflation surge if the central bank follows an inflation forecast-based policy rule and thus abstains from hiking policy rates for some time as it (erroneously) expects inflationary pressures to dissipate quickly. They conclude that such a policy rule is risky when economic activity is strong and large shocks drive inflation well above target. Even though the mechanisms in Erceg (2024) through which inflation rises above target are different than the ones studied here, we reach similar conclusions when facing uncertainty about inflation persistence.

Alvarez and Dizioli (2023) propose a different mechanism that can rationalize steepening inflation-slack relationships during highly inflationary periods: shifts in expectation formation processes. They propose inflation expectations formation mechanisms that can be triggered by highly inflationary episodes and result in longer inflation episodes and steeper inflation-slack curves, with important implications for monetary policy. With adaptive learning expectations, when inflation departs from the target levels, it could be harder to bring it back to target, as expectations are slower to adjust downwards making it more persistent than a rational expectations framework.

Our modelling of adaptive learning expectations and estimation strategy mostly builds on the work by Slobodyan and Wouters (2012a) and Slobodyan and Wouters (2012b). We extend their work in three dimensions. First, we use state-dependent conditional forecasting for our sensitivity scenario analysis. Second, we apply optimal-control monetary policy on the model and compare the policy responses from an estimated reaction function. Third, we estimate a different benchmark model to replicate stylized facts on inflation-unemployment relationships.

The formation of agent's expectations in the model situates our paper in the adaptive learning literature first advocated by Evans and Honkapohja (2001). The main idea from the learning literature is to replace the expected terms in intertemporal optimal conditions with an ad-hoc forecasting model that agents use to form expectations and update in every period using observed data, see also (Cho and Kasa (2015)) and (Eusepi and others (2019)). In this framework, we let the ECB to choose an interest rate path each period to minimize a social welfare loss function.

From the vast literature that covers the impact of ECB credibility on inflation, our paper is most closely related to Erceg and Levin (2003). They develop a model in which agents learn about the ECB's inflation target by observing policy decisions and show that inflation and output responses can be highly persistent. We also show that inflation becomes more inertial with adaptive learning and less anchored inflation expectations.

The illustration of how an adaptive learning model can generate steeper inflation-slack relationships during highly inflationary periods provides an alternative mechanism to research rationalizing steeper inflation-slack relationships using nonlinear Philips curves as in Harding, Linde, and Trabandt (2022). Moreover, the result on adaptive learning models outperforming the standard rational expectations model for both the closed economy model (US) and the open economy (Euro area) is similar to what Milani (2007) and Eusepi, Giannoni, and Preston (2018) show for the US. Unlike these papers, we estimate the model with time-varying beliefs. In addition to better model performance, the adaptive learning model implies that forecast errors are correlated with forecast revisions, a feature of expectations documented empirically by Coibion and Gorodnichenko (2015).

Alvarez and Dizioli (2023) and Orphanides and Williams (2004) find that optimal monetary policy should respond more to inflation under adaptive learning when inflation is away from target. They find that, with non-rational expectations, monetary policy should respond more to inflation in order to subdue volatile expectations. However, when inflation expectations are well-anchored, monetary policy should not respond as much - a result that has similarities with Eusepi, Giannoni, and Preston (2018). They find that monetary policy cannot and should not respond strongly to inflation fluctuations.

We have a discussion of the optimal monetary policy sensitivity to the central bank preferences, but we do not take a stance about the optimal weights. Orphanides and Williams (2008) argue that the optimal control policy can be made more robust by lowering the weight on the output gap and on interest rates and increasing the relative weight to inflation. They argue that learning creates an incentive for a "conservative" central banker.

Our methodology of optimal monetary policy resembles the "flexible inflation target" nomenclature introduced by Friedman and Woodford (2010). The "flexible inflation targeting" term is used to specify that the long-run inflation target does not need to hold at all times, nor is it necessary for the ECB to do all in its power to bring the inflation rate to the long-run target as soon as possible. Temporary departures of the inflation rate are acceptable if they are justified by projected near-term changes in the output gap. de Groot and others (2022) provides a toolkit for generating optimal policy projections under rational expectations assumptions. de Groot and others (2022) is similar to this paper in a sense of using a baseline projection for target and instrument variables, but assumes a rational expectation framework, which is a special case in our framework.

Our work here speaks directly to the seminal paper by Orphanides and Williams (2006), who makes the point that calibrated forms of the Taylor Rule that work well under full information rational expectations perform poorly with imperfect information and uncertainty about the neutral rates. We derive our optimal policy reaction function exactly in this environment, when agents don't have full information and are learning, and we provide illustrative sensitivity scenarios to assess optimal monetary policy under uncertainty about the neutral rates.

Closer to our analysis on optimal policy under adaptive learning, Gaspar, Smets, and Vestin (2006) state that policy reacts in a way to keep inflation expectations' persistence low. Mendes, Murchison, and Wilkins (2017) comment that the level of inflation can matter for monetary policy decisions, because the policy transmission could be different for different levels of inflation. Those are exactly the cases explored in this paper when we derive optimal policy under adaptive learning expectations. Nevertheless, those papers do not explore the learning process in detail, including the possibility of policy mistakes and a comparison of optimal policy under rational expectations. Unlike their analysis, the optimal policy analyzed here is not in steady state, but rather in context of a positive output gap and high inflation, which amplifies the difference in optimal policy reactions.

On the conduct of monetary policy under uncertainty, Brandão-Marques, Meeks, and Nguyen (2024) discusses how monetary policy should take into account high level of uncertainty about wage, profit, and price dynamics when deciding the interest rate path, in particular, they show that monetary policy tightening should be more front-loaded compared to a baseline sensitivity scenario in which the policymaker fully understands monetary policy transmission. Brandão-Marques, Meeks, and Nguyen (2024)'s main point is that if inflation turned out to be more persistent than anticipated, the ECB would have to speedily increase interest rates to high levels to correct the course, and that would be more costly than correcting over tightening by easing policy if inflation turned out to be less persistent than expected. In our framework, the ECB could run sensitivity scenarios mimicking those policy mistakes and doing a welfare loss comparison. In other words, the exercises conducted by Brandão-Marques, Meeks, and Nguyen (2024) could be incorporated in our framework. Ajello and others (2020) study how the high uncertainty about the levels of the natural rate of interest and unemployment, as well as the effect of economic activity on inflation, complicates the achievement of the objectives specified in the dual mandate of the Federal Reserve. They find that these challenges may warrant pursuing more accommodative policy than would be desirable otherwise. Note that we differ from Ajello and others (2020) in the sense that our natural rate of interest is high enough to not bind policy decisions.

Finally, our approach of using formal modelling and simulation exercises in order to support robustness policy decisions under uncertainty was also prescribed by Mendes, Murchison, and Wilkins (2017), who mentions that this approach ensures robustness and consistency in decisions over time.

III. Model environment

A. Benchmark model

Our model is based on Galí, Smets, and Wouters (2012). The main feature of this model is the existence of a union that decides both the wage and household labor supply decisions. In particular, each household has a simple consumption/saving decision to make based on the following problem:

$$\max_{C_t, B_{t+1}} E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{(C_t - 1)^{1-\theta}}{1-\theta} - \int_0^1 \frac{l_{t,j}^{1+\vartheta}}{1+\vartheta} dj \right], \tag{1}$$

subject to the budget constraint,

$$P_t C_t + B_{t+1} + B_{t+1}^* \leq B_t i_{t-1} + B_t^* i_{t-1}^* + \int_0^1 W_{t,j} l_{t,j} dj + prof_t, \qquad \text{for all } t \tag{2}$$

where P_t, is the price of consumption, B_t is savings in domestic bonds, B_t^* is savings in international bonds, i_t is the domestic real gross interest rates, i_t^* is the international real gross interest rates, $W_{t,j}$ for labor type $j \in (0, 1)$ is the wage level chosen by the union, $l_{t,j}$ is the value implied by the demand curve for labor and $prof_t$ are profits net of lump sum government taxes. The consumption C_t is an aggregation of domestic, C_t^H, and external goods, C_t^*:

$$C_t = \left[(1-\omega)^{\frac{1}{\eta}} (C_t^H)^{\frac{\eta-1}{\eta}} + \omega^{\frac{1}{\eta}} (C_t^*)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \quad 0 < \omega < 1 \tag{3}$$

From this problem, the import demand function is derived

$$C_t^* = \omega \left(\frac{P_t^*}{P_t} \right)^{-\eta} C_t = \omega z_t^{-\eta} C_t, \tag{4}$$

where ω is the home bias parameter, P_t^* is foreign price, P_t is domestic price and z_t is the real exchange rate.

After linearizing the Euler equation around the efficient steady state, we obtain the familiar IS curve to be later estimated:

$$\hat{y}_t = \phi^y (E_t[\hat{y}_{t+1}]) - \phi^r (\hat{i}_t - \hat{\pi}_{t+1}) + \phi^z z_t + \phi^{YF} E_t[\hat{y}_{t+1}^F] + shk_t^y, \tag{5}$$

where $\hat{y}$ is the output gap, and $\hat{i}_t$ and $\hat{\pi}_{t+1}$ are the interest rate and price deviations from steady state, respectively, z_t is the real exchange rate gap and $\hat{y}^F_{t+1}$ is the foreign output gap. The shock term, shk^y follows an $AR(1)$ process:

$$shk^y_t = \rho_y shk^y_{t+1} + \varepsilon^y_t, \tag{6}$$

The labor market is operated by perfectly competitive labor contractors that choose N_t and $l_{t,j}$ to maximize profits:

$$\max_{N_t, l_{t,j}} W_t N_t - \int_0^1 W_{t,j} l_{t,j} dj, \quad \text{subject to} \quad N_t = \left[\int_0^1 l_{t,j}^{\frac{\zeta-1}{\zeta}} dj \right]^{\frac{\zeta}{\zeta-1}}, \tag{7}$$

with labor demand:

$$l_{t,j} = N_t \left(\frac{W_t}{W_{t,j}} \right)^{\zeta}, \tag{8}$$

Given this labor demand, each union of type j negotiates wages to maximize the objectives of its members. In order to capture fluctuation in unemployment, we assume Calvo-style frictions to produce wage stickiness. Thus, we assume that there is a fraction $1 - \tau$ of firms that can optimize wages in the current period. For the non-optimizing unions, we assume that they use a simple indexation formula based on lagged nominal wage inflation $\pi_{w,t-1}$ and technology growth $\mu_{a,t-1}$:

$$W_{t,j} = \pi_{w,t-1} \mu_{a,t-1} W_{t-1,j}. \tag{9}$$

Meanwhile, the optimizing unions set $W_{t,j}$ to maximize the present value of the members' objectives:

$$\max_{W_{t,j}} E_t \sum_{i=0}^{\infty} (\beta\tau)^i \left[v_{t+i} W_t l^t_{t+i} - \frac{{l^t_{t+i}}^{1+\vartheta}}{1+\vartheta} \right], \qquad \text{subject to} \qquad l^t_{t+i} = N_{t+i} \left(\frac{W_{t+i}}{W_t} \right)^{\zeta}, \tag{10}$$

In this notation, l^t_{t+i} is employment at time $t+i$ supplied by workers with the wage set in time t. v_{t+i} is household marginal utility of money at time $t+i$.

The solution to this problem is the wage Phillips curve that is used in the simulations we use in the next section.

$$\pi_{w,t} = \kappa_1 y_t - \kappa_2 \hat{\bar{w}}_t + \beta \pi_{w,t+1} + \varepsilon_{pi_w,t}, \tag{11}$$

where $\pi_{w,t}$ is nominal wage inflation, that is $\pi_{w,t} = \hat{\bar{w}}_t - \hat{\bar{w}}_{t-1} + \hat{\pi}_t$. Real wages are measured as deviations from technological growth, that is $\bar{w} = w_t - a_t$, and y_t is output gap.

On the production side, we also assume Calvo price-setting frictions. The final good firms are perfectly competitive and maximize profits:

$$\max_{Y_t} P_t Y_t - \int_0^1 P_{i,t} Y_{i,t} dj, \qquad \text{subject to} \qquad Y_t = \left[\int_0^1 Y_{i,t}^{\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}}. \tag{12}$$

The solution to this problem delivers the familiar demand curve for the i^{th} intermediate good monopolist:

$$Y_{i,t} = Y_t \left(\frac{P_t}{P_{i,t}}\right)^{\epsilon}. \tag{13}$$

In this simple model, the production function of the intermediate firm is just $Y_{i,t} = N_{i,t}$. Finally, we assume that at every period there is a fraction of firms $1-\theta$ that can re-optimize their prices while a fraction θ index their prices to past inflation $P_{i,t} = P_{i,t-1}$. The optimizing intermediate good firms then choose a price to solve the following problem:

$$\max_{P_t} \sum_{k=0}^{\infty} \theta^k \mathbb{E}_t \left[Q_{t,t+k}\left(P_t Y^d_{t+k|t} + S_{t+k} P^*_t Y^x_{t+k|t} - MC_{t+k}\left(Y^d_{t+k|t} + Y^x_{t+k|t}\right)\right)\right]$$

Subject to:

- **Domestic demand:**

$$Y^d_{t+k|t} = \left(\frac{P_t}{P_{t+k}}\right)^{-\varepsilon} Y^d_{t+k}$$

- **Foreign demand (in foreign currency):**

$$Y^x_{t+k|t} = \left(\frac{P^*_t}{P^*_{t+k}}\right)^{-\varepsilon^*} Y^*_{t+k}$$

  where $P^*_t = \frac{P_t}{S_t}$ is the price in foreign currency (dividing domestic price by nominal exchange rate S_t).

After log-linearizing the solution to this problem around the steady state, one obtains the NK Phillips curve:

$$\pi_t = \kappa_p \hat{w}_t + (1-\theta)\pi_{t-1} + \theta\pi_{t+1} + \lambda z_t + \varepsilon_{pi,t}, \tag{14}$$

where z_t represents the real exchange rate gap, $\hat{w}_t$ is the real wage gap and inflation is measured as a deviation from target.

Non-arbitrage in bonds trading implies the standard uncovered interest parity condition, which relates domestic and foreign risk free real interest rates:

$$z_t = E_t[z_{t+1}] - \left(\hat{i}_t - \hat{\pi}_{t+1} - (\hat{i}^*_t - \hat{\pi}^*_{t+1})\right) + \varepsilon^z_t, \tag{15}$$

where z is the de-trended real exchange rate and an increase in z means a depreciation. Note that the expected real exchange rate displays the same expectation formation process as in Section III.B. $\hat{i}^*_t$ and $\hat{\pi}^*_{t+1}$ are the foreign interest rate and inflation, respectively.

We close the model with a standard monetary policy reaction function that features interest rate smoothing and estimated responses to inflation and output deviations:

$$\hat{i}_t = \rho \widehat{i_{t-1}} + (1-\rho)[\rho_\pi \widehat{\pi_{t+1}} + \rho_y y_t] + \varepsilon_{i,t}, \tag{16}$$

where $\hat{i}_t$ is the nominal 1-year ahead policy rate as deviation from the neutral rate and ε_i are monetary policy shocks.

B. Expectation formation processes

This section zooms in on the role that expectation formation processes play in shaping macroeconomic dynamics. The strategy is to estimate the model described in III under different expectation formation processes.

We use the standard RE formation process and one "limited rationality model". The rational expectations model assumes that households use all the information available in the model, including all parameters and variables, to form their expectations. In other words, rational expectations forecasts are the conditional expectation under the true distribution expectations $E_t[y_{t+1}] = y_{t+1}$. Monetary policy in the RE version of similar models has been studied extensively, for example in Svensson (1999) and Clarida, Gali, and Gertler (1999). The limited rationality model we use is the adaptive learning expectations as developed in Slobodyan and Wouters (2012b) and Slobodyan and Wouters (2012a). In this model, households use and update statistical models with a smaller set of variables at every period. Households learn from mistakes and use their forecasts errors to update parameter values with a Kalman filter.

In particular, households use a limited information set, X_j, and form their expectations linearly with:

$$a^j_{t+1} = X^j_t b^j_t, \tag{17}$$

for all the variables j that appear with leads in our equilibrium equations. In the terminology of the learning literature, this linear equation is called the Perceived Law of Motion (PLM). While any kind of linear model would work in this framework, the one with the best out-of-sample forecast performance is a simple univariate $AR(2)$ model. That is, the information set X_j contains a constant and two lags of a^j_{t+1}. With this model, the leading variables of the model can be cast in a seemingly unrelated regression equations (SURE) format:

$$\begin{pmatrix} A^1_t \\ A^2_t \\ A^3_t \\ \vdots \\ A^m_t \end{pmatrix} = \begin{pmatrix} X^1_t & 0 & \ldots & 0 \\ 0 & X^2_t & \ldots & 0 \\ 0 & 0 & X^3_t & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & X^m_t \end{pmatrix} \begin{pmatrix} b^1_t \\ b^2_t \\ b^3_t \\ \vdots \\ b^m_t \end{pmatrix} + \begin{pmatrix} \eta^1_t \\ \eta^2_t \\ \eta^3_t \\ \vdots \\ \eta^m_t \end{pmatrix} \tag{18}$$

Where η are the errors with a non-diagonal variance-covariance matrix Σ. In every period, the learning update to the B vector (the stacked vector containing the b for all models) is done with a Kalman filter mechanism:

$$B_{t|t} = B_{t|t-1} + P_{t|t-1} X_{t-1} [\Sigma + X'_{t-1} P_{t|t-1} X_{t-1}]^{-1} \left(a^j_{t+1} - X^j_t B_{t|t-1} \right), \tag{19}$$

with the transition equation

$$B_{t+1|t} = \bar{B} + F \left(B_{t|t} - \bar{B} \right), \tag{20}$$

where F is a diagonal matrix with the estimated parameter $\rho \leq 1$ [2] on the main diagonal. Finally, the corresponding covariance matrix and its transition are given by:

$$P_{t|t} = P_{t|t-1} - P_{t|t-1} X_{t-1} [\Sigma + X'_{t-1} P_{t|t-1} X_{t-1}]^{-1} \left(X'_{t-1} P_{t|t-1} \right), \tag{21}$$

and

$$P_{t+1|t} = F P_{t|t} F' + V. \tag{22}$$

[2] The prior of this parameter is set at 0.5, but results are robust to the prior choice.

Once the coefficients for the believes are updated, $B_{t|t-1}$, the households form their expectations for the lead variables as in (17). If we replace these lead variables in the model solution, we obtain a time-dependent backward-looking representation of the model:

$$\begin{bmatrix} a_t \\ \omega_t \end{bmatrix} = \alpha_t + T_t \begin{bmatrix} a_{t-1} \\ \omega_{t-1} \end{bmatrix} + R_t \epsilon_t, \tag{23}$$

where y_t includes the model variables and ω_t are the shocks.

Differently from the rational expectations solution, the matrices α_t, T_t and R_t are time dependent and can be quite different if the model is far from steady state. They depend on the parameters that define policy function and on the forecast model summarized by the vector B_t. The system described in (23) is the Actual Law of Motion (ALM) of the model.

IV. Data and Model Estimation

The deep parameters of the model described in Section IV are estimated with quarterly macroeconomic data from 2008Q1 to 2019Q4 for the Euro area and the US. After that, this parameters are fixed but the learning parameters, the ones that affect expectations in the model, are re-estimated at every quarter using actual data from 2019Q4 to 2024Q3. October 2024 WEO forecasts are then used in the illustrative sensitivity scenarios in section VI. The set of variables included in the estimation are the output gap, the real wage gap, annualized quarterly price inflation deviation from target[3], the real exchange rate gap and the policy rate.

As previously documented by Howard, Rich, and Tracy (2022), measures of average wage per worker in the US suffered from changes in workforce composition. Lower wage workers suffered larger employment losses than high wage workers. That created an artificial composition-driven increase in the average wage. A similar qualitative change in workforce composition happened in Euro area. Since our model does not have enough structure to explain this workforce composition change, we use the composition-constant real wage calculated by Howard, Rich, and Tracy (2022) for the US and use the same logic to create a composition-constant real wage for Euro area. The adjustment at this aggregate level does not completely correct for the workforce composition change, but it lessens its effect on the real average wage series that we use.

[3]For the US, we use the core personal consumption expenditures (PCE). For the Euro area, we use the HICP excluding energy and unprocessed food

There are many possible filters to calculate the output gap and to detrend real wage from its labor productivity trend. We use the output gap as calculated by IMF staff and an HP filter to detrend real wage. Since the model is a gap model, it abstracts to study issues related to productivity change. That relates not only to labor productivity, but also TFP, trends in the neutral interest rate and trends in the real exchange rate.

The model is estimated using the Bayesian likelihood methods with standard priors as in Smets and Wouters (2007). Some parameters have weak identification and are calibrated using standard values in the literature. Those parameters that are related to the steady-state values of the observed variables of the model are also calibrated. The foreign block is assumed to follow US variables. We first estimate a closed economy model for the US and use this parameters as priors when we estimate jointly the parameters for the US and euro area. Some of the parameters of the foreign block are also calibrated because of poor joint identification.

V. Optimal monetary policy rule methodology

Our optimal monetary policy methodology proceed in the following steps: 1) produce a forecast for output gap and inflation; 2) find the structural shocks that explain this forecast; 3) find the optimal monetary policy response, given those shocks. This section covers in detail how steps 2) and 3) are conducted.

After solving and estimating the model, the Actual Law of Motion, equation (23) can be used to find the most likely structural shocks that can explain the history of the macroeconomic variables included in the model. Similarly, using a Kalman smoother the ALM can provide us with the most likely structural shocks that can explain any macroeconomic outlook forecast. In other words, the ALM can tell us the combination of supply and demand shocks necessary to generate any forecast for the output gap and inflation. The limitation of this approach is that the structural shocks found this way would be different than they would be if the social welfare loss function was used instead of the monetary policy reaction function in equation III.A. This approach implicitly assumes that agents don't know that the ECB changed its monetary policy reaction function. This limiting assumption was introduced to reflect a situation where the ECB decides in the current period to adopt a policy to minimize the social welfare loss.

The question we explore is the policy path that the ECB would select if it had complete knowledge of the future structural shocks that will hit the economy. We answer this question using the same strategy as in Alichi and others (2015). Instead of using the estimated monetary policy function as in equation (16), we assume that the ECB chooses the path for interest rates that minimizes the following welfare loss function:

$$\min_{\hat{i}_t} E_t \sum_{t=0}^{\infty} \beta^t \left(k_i (\hat{i}_t - \hat{i}_{t-1})^2 + k_y \hat{y}_t^2 + k_\pi \hat{\pi}_t^2 \right) \tag{24}$$

Note that k_i, k_y, k_π give the relative weights that this ECB assigns to interest rate smoothing, output gap and inflation deviations from target, respectively. The interest rate smoothing tries to capture, in a reduced form way, the ECB concerns about financial stability. this is a reduced form welfare loss function, as it includes the interest rate smoothing term and the coefficients k_y and k_π are not directly mapped to household's welfare. For the reminder of the paper, we will assume that the ECB assigns equal weights to the deviations of the inflation and the output gap and that the smoothing of the interest rate has a weight of 0.95 (also used in Alichi and others (2015)). We also define as the optimal monetary policy path the interest rate path that minimizes this welfare function.

In the rational expectations model, agents are forward-looking and have perfect knowledge of how monetary policy shocks affect future marginal costs and inflation. In the adaptive learning model, agents are backward looking and need to see inflation fall to adjust expectations. In particular, the ECB has three channels to influence inflation: The first is the standard direct channel in which a tighter policy cools off demand, lowering the output gap and hence inflation. The other two channels operate through inflation expectations. By tightening policy, the ECB lowers current inflation, which enters in the $AR(2)$ inflation expectations equation. This lowers next period expectations. We call this the direct inflation expectation channel. The ECB can also affect households' learning process through indirectly altering the coefficients in the $AR(2)$ equation. By seeing less inflation this period than they had expected, households update their model of how past inflation matters for future inflation. We call this the learning channel.

Finally, other important implicit assumptions are that the ECB has full knowledge of the current and future shocks hitting the economy and also has full knowledge of how their actions impact expectations.

The methodology described in this section is flexible and can be used with different benchmark models and expectation formation processes. So, while the results presented in the next section are model specific and are derived from the standard DSGE model described in section III, the methodology presented here is broader and can be applied to different contexts.

VI. Incorporating uncertainty on monetary policy decisions

The ECB can produce alternative macroeconomic sensitivity scenarios to incorporate different sources of uncertainty and use the framework described in section V to prescribe how monetary policy should respond under different sensitivity scenarios. While we cannot cover all sorts of uncertainties that the ECB can encounter, in this section we build a couple of illustrative sensitivity scenarios to show in practice what could be done.

We explore 4 possible sources of uncertainty: 1) the ECB is unclear about the expectation formation process. Our flexible framework allows us to analyze policy mistakes induced by ECB who misjudge how agents form expectations; 2) uncertainties about inflation persistence; 3) uncertainty about the neutral rate; and 4) uncertainty about the slope of the Phillips curve;

A. Uncertainty about expectation formation process

Many traditional macroeconomic models assume full information rational expectations (FIRE), in which agents use all the information available to form model consistent expectations. Many new empirical papers started to challenge this assumption, by showing that agents' expectations display large deviations from FIRE, such as Albrizio and Simon (2023), Baumann and others (2024) and Andrade and others (2022), just to mention a few studies looking at firms' inflation expectations.

Since expectations in the Euro area were so sticky to change, we use the adaptive learning expectations model (AL model) as the benchmark used in the rest of the paper. In this subsection, we will not go in detail about the many different ways to model expectations, but just want to illustrate how sensitive the optimal monetary policy path is to the assumption on how agents form expectations.

Using the same macroeconomic forecast for the output gap and inflation, and the same benchmark model, we find the most likely structural shocks that can explain the forecast under adaptive learning and rational expectations (in other words, we use equation (23) to find the structural shocks). Then, the ECB chooses the interest rate path to minimize exactly the same social welfare loss function but with different expectation processes.

Table 1 summarizes what the policy path would be if the ECB were setting the optimal policy path at the start of 2024 with a social welfare loss function with equal weights on the output gap and inflation deviations. The optimal policy path under rational expectations would prescribe one less cut in 2024 compared to the adaptive learning model, and the same path for 2025 and 2026. Since inflation has been in a downward trend since 2022, the AR component of the inflation expectations under the AL model extrapolates recent past trends, and inflation expectations under AL are lower than under the RE model, which is model consistent and forward looking, contributing to disinflation and allowing the ECB to be slightly looser under AL expectations.

Table 1. Sensitivity of the recommended MP paths to different expectation formation models

	2024	2025	2026
Adaptive learning expectations	Four 25 bps cuts (June, Sep, Oct and Dec).	Three 25 bps cuts (Mar, Jun and Sep)	No change
Rational expectations	Three 25 bps cuts (June, Sep and Dec).	Three 25 bps cuts (Mar, Jun and Sep)	No change

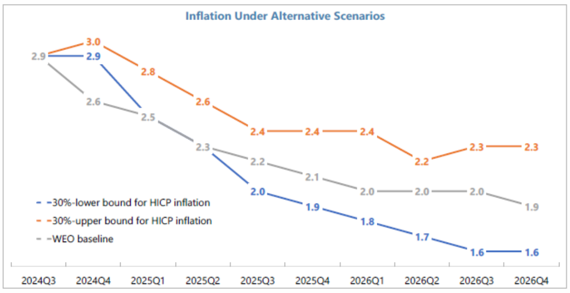
B. Uncertainty about inflation persistence

At the beginning of the inflation surge, forecasters assumed that inflation would have been more temporary than it was. Then, inflation turned out to fall faster than expected in 2023. Overall, core and services inflation remain sticky, with significant uncertainty surrounding their persistence.

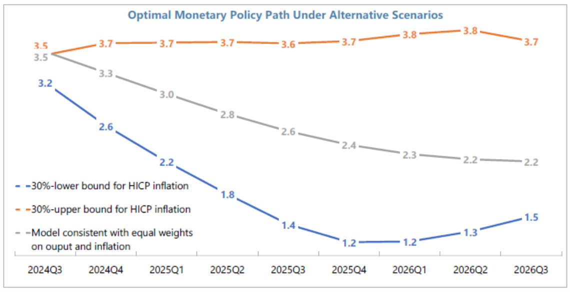
We can use the September ECB staff's core inflation fan chart to assess how robust the recommended monetary policy path is given different inflation persistence paths. In other words, the exercise asks what the MP path would be if inflation is in the 30% lower/upper bound for core inflation.

In the ECB staff's 30% lower bound fan chart, core inflation goes back to target in 2025Q3 and core inflation undershoots to 1.6% over most of 2026. In the 30% higher bound, core inflation does not go back to target and hovers around 2.3%.

In the case where core inflation is in the 30% lower bound, the model indicates that ECB should cut rates by 25bps in December 2024, and cut it twice by 50bps in 2025 (March and June), with a final cut of 25bps in September 2025. In the case where core inflation is in the upper band, the model indicates that the ECB should tighten MP by 25bps in December and keep the rate broadly unchanged all the way to 2026Q4



(a) Inflation under alternative scenarios.



(b) Optimal policy.

Figure 1. Optimal policy under alternative scenarios about inflation persistence.

C. Uncertainty about the neutral rate

One important source of uncertainty at all times is the interest rate level that keeps inflation stable when the output gap is closed. The uncertainty arises for two main reasons: First, this rate is not observable, so it needs to be inferred from observing other variables. Second, it changes overtime due to many factors, including some that are beyond the domestic economy. The ECB needs to know where this rate is to properly calibrate monetary policy.

Recent work by the ECB Brand and Mazelis (2024) suggests that the neutral rate might have increased from its pre-pandemic levels. Although Brand and Mazelis (2024) highlight that there is large measurement dispersion, their median across models moved from around -1% to a number slightly positive in real terms.

But what if these models are capturing noise and the neutral rate has not moved from pre-pandemic levels? The simulations in this sub-section will explore the costs of making mistakes about the neutral rate.

The ECB can make two sorts of errors with the neutral rate, it can either underestimate it (let's say the ECB assumes that the neutral rate is still at -1%, but it is actually at 0.5%), or the ECB can overestimate the neutral rate (to make it symmetrical, let's say the ECB assumes that the neutral rate is at 0.5%, but it is actually still at -1%).

The way we implement these errors is the following: 1) we use the 2024 October WEO forecast for inflation and output gap; 2) we find the most likely structural shocks that explain this forecast with two versions of the model that use different neutral rates (in other words, we use equation (23) to find the structural shocks); 3) the ECB uses those shocks and find the optimal monetary policy path for each of those models in the "incorrect model"; 4) in every quarter, we use structural shocks from the "correct" model and the monetary policy shock derived in 3) to produce new output gap and inflation numbers; 5) we repeat steps 2-4 in every quarter. Since the ECB uses the "incorrect" model for filtering and estimating the shocks, it doesn't learn the true shocks and it makes the repeated mistake in the next period.

With this approach, the ECB can observe the actual values for inflation and output gap in each period and re-optimize, so it is a discretionary optimal policy and the only mistake is to assume the wrong neutral rate when finding the structural shocks. In other words, the ECB makes a mistake about the size of the relative structural shocks driving the economy at every quarter.

The results of the policy mistakes are summarized in table 2. The first column shows the situation when the ECB underestimates the neutral rate, thus being overly accommodative, (neutral rate is 0.5 but the ECB wrongly assumes it to be -1%). The second column shows the situation when the ECB overestimates neutral rate, thus being overly restrictive, (where neutral rate has never changed, and it is still -1%, but the ECB wrongly assumes it to have increased to 0.5%).

As expected, when the ECB underestimates neutral rate, the economy runs hot, with inflation above target and positive output gap. While inflation is at the target when the ECB overestimates neutral rate, the output gap is negative

When the ECB is overly accommodative, by underestimating neutral rate, it sees the most likely sensitivity scenario as one where inflation is driven more by supply. When it is overly restrictive, by overestimating neutral rate, the ECB sees inflation relatively to be more driven by demand.

Overall, the welfare cost, as measured by the ECB's social welfare loss function, of underestimating the neutral rate is 13% larger than the cost of overestimating it. This welfare cost of mismeasuring the neutral rate is consistent with the welfare cost of misjudging the inflation persistence, calculated in Brandão-Marques, Meeks, and Nguyen (2024). Brandão-Marques, Meeks, and Nguyen (2024)'s result reflects that ex post it is costlier to correct (with rapid interest rate increases) a policy mistake. Note that this result is not necessarily true at all times and at all levels. Part of why we obtain this result is the fact that the model performs better, in terms of out-of-sample forecast in the recent period, with a neutral rate of 0.5%. In other words, according to this model, the neutral rate is closer to 0.5% than it is to -1%.

Table 2. Comparison of economic outcomes with policy mistakes about the neutral rate

	Overly accommodative	Overly restrictive
Core inflation in 2026	2.4	2.0
Output gap in 2026	0.4	-0.2
Interest rates by the end of 2026	1.9	2.1
Welfare loss	4.5	4.0

D. Uncertainty about the slope of the Phillips curve

After a long period where the literature consensus was that the slope of the Phillips curve had flattened, the recent inflation spike, and the failure of existing models to predict the rise in inflation, there have been a couple of papers Harding, Linde, and Trabandt (2022), arguing that the slope of the Phillips curve has changed fact.

Given this uncertainty about the current slope of the Phillips curve, the ECB can make two sorts of errors , it can either underestimate it (let's say the ECB assumes that the Phillips curve is 50% lower than the baseline estimation), or the ECB can overestimate the neutral rate (to make it symmetrical, let's say the ECB assumes that it is 50% higher than the baseline estimation).

The way we implement these errors is the following: 1) we use the 2024 October WEO forecast for inflation and output gap; 2) we find the most likely structural shocks that explain this forecast with two versions of the model that use different slopes for the Phillips curve (the coefficient κ_p in equation 13); 3) the ECB uses those shocks and find the optimal monetary policy path for each of those models; 4) in every quarter, we use structural shocks from the "right" model and the monetary policy shock derived in 3) to produce new output gap and inflation numbers; 5) we repeat steps 2-4 in every quarter.

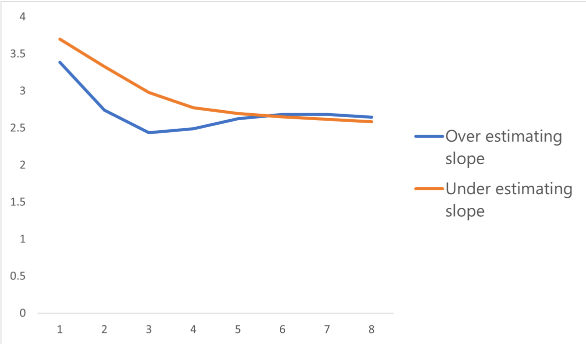
With this approach, the ECB once again can observe the actual values for inflation and output gap in each period and re-optimize, so it is a discretionary optimal policy and the only mistake is to assume the wrong slope of the PC when finding the structural shocks.

The results of the policy mistakes are summarized in table 3. The first column shows the situation when the ECB underestimates the slope, and the second column shows the situation when the ECB overestimates it.

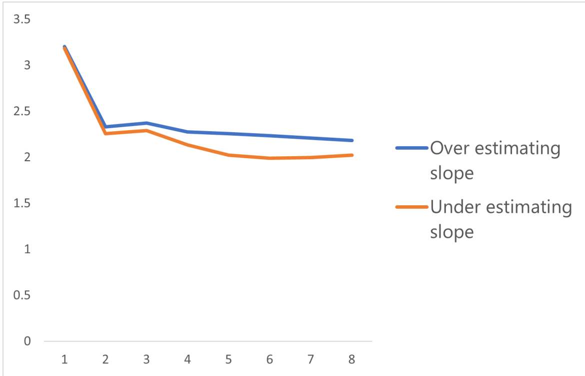
As expected, when the ECB underestimates the slope of the PC, it keeps policy rate tighter for longer (see yellow line in figure 2a). That drives inflation back to target more quickly (figure 2b), but delays the return of the output gap back to zero by 1 quarter. Conversely, if the ECB over estimates the slope of th Phillips curve, it quickly lowers interest rate (blue line in figure 2a), but it is required to tighten policy again, as the ECB sees inflation persistently higher than target (figure 2b). In fact, inflation does not return to target even after 2 years. At the same time, output gap more quickly closes back to zero.

Table 3. Comparison of economic outcomes with policy mistakes about the Phillips curve

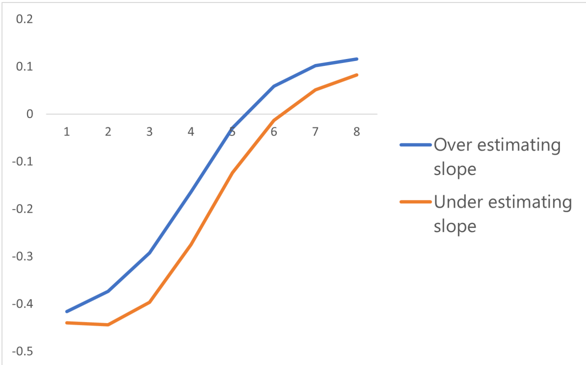
	Underestimating Slope	Over estimating Slope
Core inflation in 2026	2.1	2.2
Output gap in 2026	0.1	0.1
Interest rates by the end of 2026	2.6	2.7
Welfare loss	5.5	6.1



(a) Interest rates



(b) Inflation



(c) Output gap

Figure 2. Macroeconomic outcomes under different mistakes regarding the slope of the PC

Note: It is assumed that the ECB either overestimates or underestimates the slope of the Phillips curve by 50%.

Overall, this interest rate correction and with inflation never going back to target result in higher welfare loss cost, as measured by the ECB's social welfare loss function, of over estimating the slope of the Phillips curve is about 10% larger than the cost of underestimating it. Once again, if the ECB were uncertain about the slope of the Phillips curve, or were uncertain how the slack would feed into inflation, it would be better off by erring on the side of being a bit more conservative.

VII. Central bank preferences

When we discussed the social welfare loss function in section V, we mentioned the role of the relative weights k_y, k_π that the ECB assigns to the output gap and inflation deviations from target, respectively. We do not take a view on the appropriate relative weights, but our framework is flexible to incorporate any preference that a central bank can have. However, how sensitive is the optimal interest rate path to the relative weights in the social welfare loss function? This final section answers this question. To provide a range of possible estimates, we rely on the October WEO inflation and output gap forecasts to determine the optimal policy as if the ECB were setting it at the start of 2024. By assigning extreme weights to the social welfare loss function, we examine how the optimal policy would adjust if the ECB prioritized either inflation or the output gap exclusively.

Table 4 summarizes the results. All the results are intuitive. With zero weight on the inflation gap, so the ECB only values the output gap deviations, the prescribed policy would be 4 rate cuts in 2024 and 3 more cuts in 2025, and 1 25bps cut in March 2026, with the DFR ending 2026 at 2%. With zero weight on output gap, so the ECB only values inflation deviations from target, The recommendation is for 3 rate cuts in 2024, and 3 more cuts in 2025 and no cuts in 2026, ending the DFR at 2.5%. Overall, while small, there would be some differences in the policy rate depending on the ECB's preferences.

Table 4. Sensitivity of the recommended MP paths to different central bank preferences

	2024	2025	2026	DFR by end of 2026
Only value output gap	Four 25 bps cuts (June, Sep, Oct and Dec).	Three 25 bps cuts (Mar, Jun and Sep)	One 25 bps cut in Mar	2%
Equal weights	Four 25 bps cuts (June, Sep, Oct and Dec).	Three 25 bps cuts (Mar, Jun and Sep)	No change	2.25%
Only value inflation	Three 25 bps cuts (June, Sep and Dec).	Three 25 bps cuts (Mar, Jun and Sep)	No change	2.5%

VIII. Conclusion

After a long period of low and stable inflation and inflation expectations below target, the COVID shock combined with the large energy shock experienced in Europe, following the aftermath of Russia's invasion of Ukraine, caused inflation to reach levels not seeing in decades, peaking in the Euro area at 10.7 percent in October 2022. At the same time, near-term inflation expectations finally increased above the two percent target prompting the ECB to start an unprecedented tightening cycle.

Setting interest rates in times when the economy was exposed to large idiosyncratic supply shocks introduces new uncertainties that the ECB have to address when formulating its monetary policy. In this short paper, we introduced a framework and some tools that can be used to formulate policy rate paths given different sensitivity scenarios on the macroeconomy. While we did not cover all kinds of uncertainty that the ECB could encounter, we showed how to use and design sensitivity scenarios to study the question in mind. In other words, we show how these illustrative sensitivity scenarios can be used to improve the risk management approach of monetary policy.

sensitivity scenario analysis is useful for risk management, and can help improve decision-making and communications, reduce interest rate volatility and strengthen monetary transmission. The ECB's staff could conduct and possibly publish some of the realistic sensitivity scenarios studied in this paper, but publish the different interest rate paths. Such practice would help markets better predict how monetary policy would react if the ECB were surprised by the macroeconomic outlook. By improving markets' understanding of the monetary policy reaction function, the ECB could lower unnecessary interest rate volatility and enhance monetary policy transmission.

Four possible uncertainty sensitivity scenarios are studied in this paper: 1) uncertainty about the expectation formation process; 2) uncertainty about the inflation persistence; 3) uncertainty about the measurement of the neutral rate; 4) uncertainty about the slope of the Phillips Curve. We show that, at the current juncture with inflation close to target, the policy recommendation is not that different if we assume RE or AL expectations. We also show somewhat large degree of uncertainty about the future policy rate path, given the still large uncertainty on the inflation process. Our model predicts that, at our current juncture, the welfare cost of underestimating the neutral rate, by assuming no change in the neutral rate compared to pre-pandemic levels is larger than the cost of overestimating it. Similar result is obtained in exercise relating the uncertainty about the slope of the Phillips curve, where it is better for the ECB to be more conservative about how slack feed into inflation.

While the results are model dependent and could differ under a different benchmark model, the methodology used in this paper is broader and can be applied in many different contexts and with different benchmark models. While it is impossible to predict all possible shocks that the economy could face, the practice of simulating the cost of policy mistakes could better elicit the trade-offs of policy actions and lead to better informed decisions.

In the IMF, some form of this sensitivity scenario analysis is used as part of our surveillance work and it helps us to more objectively measure risks to our baseline projections.

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