Modernizing Central Banks' Large Semi-Structural Projection Models: The Role of Model-Consistent Expectations*

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We enrich the ECB's modeling toolkit by incorporating model-consistent expectations into the workhorse projection model, ECB-BASE. This enables analysis of announced policy shifts and anticipation effects. We nest VAR expectations, model-consistent expectations and several combinations of the two, termed as hybrid settings. In addition, the Dynare computational environment has been advanced in several dimensions to enable these new modeling capabilities. We then examine monetary policy implications of varying expectation formation. Simulations indicate that forward-looking expectations result in smoother output responses but front-loaded price reactions to policy shocks. By applying the model to assess recent supply shocks that have led to a surge in inflation, we find that forward-looking expectations from the private sector imply increased macroeconomic volatility, necessitating an early policy response.

JEL Codes: C3, C5, E1, E2, E5.

1. Introduction

This paper contributes by modernizing the semi-structural projection model toolkit of the European Central Bank (ECB). We study the transmission of monetary policy in the ECB-(RE)BASE model

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across different expectation formation alternatives. ECB-(RE)BASE is a model-consistent expectations (MCE), or rational expectations (RE), version of the ECB-BASE model, which up until the time of writing operated solely under expectations formed via vector autoregression (VAR). The underlying ECB-BASE model developed at the ECB was introduced by Angelini et al. (2019) as the primary semi-structural macroeconomic model for the euro area. Today, it is instrumental in informing ECB monetary policy preparation by contributing to economic projections, risk and scenario analysis, and quantitative policy evaluations. The main advantage of such models lies in the balance between the theoretically founded structure (and its imposed restrictions) and the empirical validity of captured gradual transmissions. Importantly, expectations also play a critical role in determining macroeconomic dynamics in this class of models. As a functional policy analysis tool, the model features a comprehensive description of the euro-area economy, incorporating a detailed demand breakdown, price and wage developments, forward-looking asset pricing, financing conditions, and future income projections, as well as different roles for policy interventions.

The impetus to explore alternative expectation settings arises from recent supply shocks that have increased energy, production, and consumer prices. These shocks have heightened macroeconomic volatility, underscoring the need to understand the role of expectations as long-term anchors. Induced by such developments, the monetary authorities needed to assess the implications of different degrees of forward-lookingness on macroeconomic volatility. After a prolonged period of low interest rates, the central bank's reaction to the new environment resulted in many instances in a large hiking cycle. In this respect, our work in this paper focuses on understanding the consequences of unexpected and anticipated monetary policy shocks.[1]

At the same time, central bank forecasting models are under increasing scrutiny (see Bernanke 2024). Dynamic stochastic general equilibrium (DSGE) models typically emphasize forward-looking behavior under the rational expectations paradigm. In contrast,

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[1] The accompanying working paper by Adjemian, Bokan et al. (2024) systematically documents the implications of different expectation settings for other main shocks.

the majority of semi-structural projection models rely predominantly on established long-run relationships consistent with data. For pure forecasting purposes, it is often adequate to consider expectations based on historical patterns. However, for analytical purposes, exploring alternative expectation settings that account for policy shifts, evaluate announced changes, and anticipate news would be highly beneficial. We contribute to the ECB's analytical capabilities by integrating these alternative expectation settings into the main projection tool. The implementation also allows for hybrid settings, combining different expectations across various sectors or blocks of the model simultaneously.

Changing expectations from backward-dependent to forward rational expectations affects monetary policy transmission. We find that using the MCE setting leads to a dampened cyclical response because of stronger income smoothing and more gradual transition dynamics. These smoothing forces dominate any implications of the financial sector being forward-looking. We also find that there are front-loading features on prices, especially on HICP (Harmonised Index of Consumer Prices) inflation through the exchange rate effect on imported energy, but less on the GDP deflator. We show that policy announcements lead to partial anticipation of economic dynamics if credibly understood by the private sector. Additionally, we show that recent supply shocks imply more macroeconomic volatility under MCE compared to VAR expectations, highlighting the need for central banks to understand the degree of anticipation of supply pressures to achieve their stabilization objectives.

In its primary role as a forecasting and policy analysis tool, the ECB-BASE model operates under VAR expectations and is estimated accordingly. In this setup, current and past states potentially affect expectations. The VAR provides a reduced-form view of the full economic environment described by the complete macro model and can, loosely speaking, be considered as a "limited or condensed information" expectation formation version. Other forms of restricted information sets used in the forecasting literature are adaptive learning approaches (Slobodyan and Wouters 2012; Warne 2023).

A key challenge in swapping expectations in this class of models is the adjustment costs. These are central for the model to generate empirically plausible transition dynamics. They are modeled via the polynomial adjustment costs (PAC) approach, which is an error-correction-type specification with an explicit role of forward-looking expectations. The Dynare computational environment has been extended to support the reformulation of a VAR-based setup to the MCE setup.

This paper also relates to the literature on different expectation formation models, in particular in the context of semi-structural models as used in central banks. The main reference point is the work around the FRB/US model (Brayton and Tinsley 1996; Brayton et al. 1997), which served as inspiration in the development of the underlying ECB-BASE model. In their analytical work, Federal Reserve staff have also occasionally compared the impulse responses the model produces under different expectation settings. Brayton, Laubach, and Reifschneider (2014) show that VAR-based expectations can imply high inertia that differs from the inertia implied by the Taylor rule. In this case, the model-consistent expectations imply a softer price response to a monetary policy rate shock than under VAR expectations.

Numerous FRB/US simulations with an emphasis on the role of expectations have been used for monetary policy analysis (e.g., Reifschneider and Williams 2000; Chung et al. 2012, among others). Kiley and Roberts (2017) evaluate the frequency and potential costs of Lower Bound incidences, showing that clear commitment strategies by the central bank to maintain lower interest rates until it achieves the inflation objective are highly effective under MCE in the FRB/US model. Bernanke, Kiley, and Roberts (2019) find that MCE can imply lower output volatility than hybrid expectations when there is a risk of hitting the Lower Bound, as private-sector expectations regarding the inflation anchor help alleviate the constraint. Tetlow (2022) uses FRB/US to assess the costs of disinflation, showing that a persistent reduction in inflation can be achieved under MCE via a credible announcement of shifting the inflation anchor without sharply decreasing demand. Conversely, VAR expectations require a more aggressive policy adjustment, causing a more significant decline in demand to achieve the same outcome.

The remainder of our paper is structured as follows. Section 2 lays out the strategy to solve a model under rational expectations. It describes the role of expectations in ECB-(RE)BASE while broadly outlining its main features and shows the details necessary to convert

BASE into a forward-looking expectation model. Section 3 examines impulse responses to monetary policy shocks, comparing different expectation modalities, and discusses some key contributing factors. Section 4 examines the inflation surge across different expectation settings. Finally, Section 5 concludes.

2. ECB-(RE)BASE

This section discusses the modifications to the ECB-BASE model to convert it into a model-consistent expectations variant.

Before delving into the model details, it is useful to generally recall the treatment of expectations in solving dynamic macro models. Consider the following type of model:

$$\mathbb{E}_t[f(y_{t+1}, y_t, y_{t-1}, \epsilon_t)] = 0, \tag{1}$$

where y_t is a vector of endogenous variables, ϵ_t is a vector of structural shocks with $\mathbb{E}_t[\epsilon_{t+1}] = 0$ and $\mathbb{E}_t[\epsilon_{t+1}\epsilon'_{t+1}] = \Sigma$. Under backward expectations, the terms $\mathbb{E}_t[y_{t+1}]$ are replaced by[2] VAR forecasts: $y_{t+1} = h'x_t$, where x_t is a set of explanatory variables that may include y_t and lags thereof. The solution then amounts to solve for y_t, in each period given $\underline{y_{t-1}}$ and ϵ_t. Formally, the following nonlinear problem arises:

$$f(h'x_t, y_t, y_{t-1}, \epsilon_t) = 0. \tag{2}$$

In this case, the paths for the endogenous variables are the unknown object of interest that we want to solve for. Contrary to that strategy, under rational expectations, we solve Equation (1) for an invariant mapping between the endogenous variables and the state variables. Let this mapping be $y_t = g(y_{t-1}, \epsilon_t)$. We can then reformulate Equation (1) as

$$\mathbb{E}_t\left[f\left(g(g(y_{t-1}, \epsilon_t), \epsilon_{t+1}), g(y_{t-1}, \epsilon_t), y_{t-1}, \epsilon_t\right)\right] = 0, \tag{3}$$

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[2] Assuming the model exhibits linearity with respect to the forward terms, the conditional expectation can be accurately transferred under the function f. In contrast, for nonlinear models, this operation results in an approximation due to Jensen's inequality. Semi-structural models are typically linear with respect to the forward variables.

which is typically solved by perturbation techniques around the deterministic steady state. If we consider a first-order approximation, the solution is a linear reduced-form model: $y_t = Ay_{t-1} + B\epsilon_t$.

Let us now recall the basics of the ECB-BASE model. Figure 1 gives a bird's-eye view of the model structure. The rich structure of the model enables us to incorporate various mechanisms behind economic forces and policy channels. More specifically, the wage-price block is based on a simple auxiliary New Keynesian model used to estimate the model's main price and wage Phillips curves (see Appendix B.4 in Angelini et al. 2019).

The model's domestic demand structure features private consumption, business and housing investment, and government expenditures. Global forces, captured in the foreign block, affect exports and imports. Financing conditions, as well as asset prices, influence borrowing and transmit into the consumption and investment decisions.

In the wage-price block, reduced-form pricing curves assign an important role to forward-looking expectations.[3] Important to notice is that this auxiliary model is estimated under rational expectations as a stand-alone system. It is therefore straightforward to revert to this specification when transitioning from a VAR to an MCE setup.[4] Given the prominence of the financial block in the model, in (RE)BASE, we respecify the model's asset pricing problem and align it to the formulations standard to the DSGE literature.[5] To do so, it is convenient to change the logic of how bond prices and financing rates are constructed. Furthermore, we also treat the exchange rate mechanism as a financial feature. Postulating the exchange rate as

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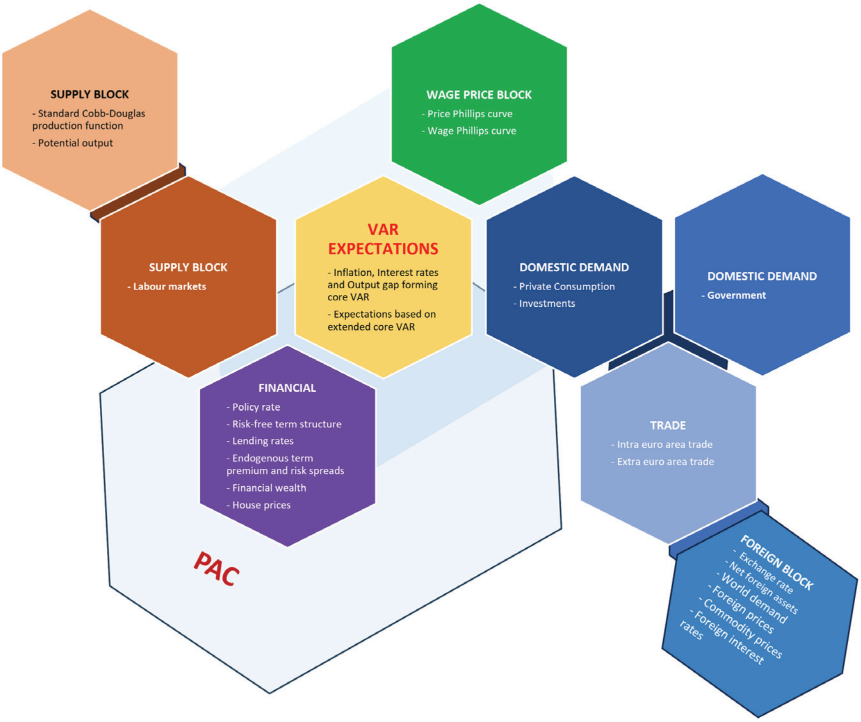
[3] The reduced-form goods price Phillips curve is of the form $\pi_t = \{(1-\delta_\pi)(1-\beta_\pi)(1-\varphi_\pi)\}^{-1}\{(1-\delta_\pi)(1-\beta_\pi)(1-\varphi_\pi)\overline{\pi}_t^e + \beta_\pi \mathbb{E}_t \pi_{t+1} + \delta_\pi \pi_{t-1} + \beta_{\hat{y}}^\pi mc_t + \varphi_\pi \pi_t^{oil}\} + \epsilon_t^\pi$. π_t is the core deflator inflation, mc_t are marginal costs, and π_t^{oil} is imported energy price inflation. The medium-term inflation expectations, $\overline{\pi}_t^e$, are imperfectly anchored and are updated based on past inflation realizations. They follow this rule throughout this paper.

[4] Given that (RE)BASE and BASE share an identical specification of the wage-setting structure, we do not restate it here.

[5] House prices are modeled as in ECB-BASE. They are not per se modeled as financial asset valuations like the bond prices are, but rather are determined according to simple empirical relationships based on contemporaneous information and on the medium-term inflation anchor. However, the transition dynamics of house prices to the target value follow the PAC framework.

Figure 1. Overview of the ECB-BASE Model and the Center-Stage of Expectations



Note: Each small hexagon represents a specific model "block." The blocks gravitate toward specific long-run anchors, which discipline the model through the expectation terms. In the case of VAR expectations, a core VAR serves to pin down the main relationships between inflation, the output gap, and the interest rate, which is then extended to account for other explanatory forces differing across model blocks, while at the same time ensuring a certain degree of system-wide consistency. The large light blue shaded hexagon indicates where these expectations enter. Furthermore, the main adjustment dynamics governed by polynomial adjustment costs (PAC) are also subjected to the expectations. The framed light blue hexagon touches the blocks where PAC play a role. To be precise, they govern the transition dynamics of private consumption, private business and residential investment, house prices, property income, and employment.

a forward-looking variable implies a significant departure from the empirical setup used in the original model.

An interesting specificity of the model is the prominence of multiple income sources (labor, transfer, and property income) as main determinants of consumption. While the underlying theory behind the relationships entering the VAR expectations and MCE version of the model is the same, the former requires significant algebraic manipulation of the equations in order to arrive at a trend-gap representation. On the other hand, the MCE version of the model eliminates the need for this trend-gap decomposition. Therefore, in order to facilitate the exposition of the changes in the model structure versus the original BASE, we do present the aforementioned changes in more detail in the following section.

We should also reiterate the significant role played by the expectations in the adjustment process of the model's main macroeconomic variables. The adjustment to the long-run trend values is a sluggish transition process arising as a consequence of the various adjustment costs featured in the model and governed, at least in part, by the expectations. Figure 1 illustrates the various blocks featuring expectations and their main formation mechanism. Two light blue shaded hexagonal areas overlapping each other connect the model blocks where either core VAR expectations and/or PAC-based formulations enter the model.

In the following, we describe the modifications in the model necessary to swap it into its MCE form. The order of exposition preempts the order in which we want to switch on certain features sequentially in the simulation exercises presented later.

2.1 Modified Financial Blocks

2.1.1 Bond Prices and the Long-Term Interest Rate

The following assets are modeled with forward-looking expectation formation: 10-year (long-term) bonds, corporate bonds, and equities/stocks. The short-term nominal bond price is not explicitly modeled. The policymaker steers the value of short-term bonds by setting a nominal interest rate according to the Taylor rule.

The long-term interest rate in ECB-(RE)BASE is a 10-year benchmark government bond yield. Computationally, it is convenient to use infinitely-lived consol-style bond pricing equations, which have a tractable recursive formulation. We follow the approach of Woodford (2001) such that the long-term bond is modeled as a coupon-paying consol.[6] Coupon payments are expected to occur in each period, starting from t+1, and the duration of the bond is chosen to reflect a 10-year horizon of payments.[7]

To price the long-term bond, investors discount expected future coupon payments and add a term premium, $\bar{tp}$, to the one-period-ahead pricing kernel. The bond price, Q_t^{10Y}, is given by the following recursive forward form:

$$Q_t^{10Y} = \frac{c}{(1+i_t)} + \rho \mathbb{E}_t \left[\frac{Q_{t+1}^{10Y}}{(1+i_t)(1+\bar{tp})} \right], \tag{4}$$

where i_t is the short-term nominal interest rate, c is the coupon payment, calibrated to normalize a steady-state bond price, $\overline{Q^{10Y}}$, to 1, and ρ is the decaying factor of coupon payments, calibrated to match a Macaulay duration of 40 quarters. $\bar{tp}$ is the term premium associated with holding a bond for a 10-year period.[8]

The long-term interest rate, i_t^{10Y}, is then defined as the compounded yield to maturity on the consol,

$$i_t^{10Y} = c/Q_t^{10Y} + \rho - 1. \tag{5}$$

Note that the rate of return on bond holding r_t^{10Y} is given by

$$r_t^{10Y} = \frac{c + \rho Q_t^{10Y}}{Q_{t-1}^{10Y}} - 1. \tag{6}$$

A similar modeling strategy is adopted for the value of corporate bonds and its rate of return, r_t^{CB}. It follows a specification as

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[6] In the original ECB-BASE model, in contrast, bond values are not explicitly modeled. Instead, the risk-free interest rate according to the expectation hypothesis is formed based on a VAR forecast. A term premium is then added to reflect the duration risk.

[7] The bond pays a coupon: c at t+1, ρc in t+2, $\rho^2 c$ in t+3, and so on.

[8] In general, the term premium can be responsive to the cycle in ECB-BASE: $tp_t = c^{tp} + \rho^{tp} tp_{t-1} + \lambda^{tp} \mathbb{E}_t[OG_{t+40}] + \epsilon_t^{tp}$. The expression $\mathbb{E}_t[OG_{t+40}]$ stands for the expected output gap position of the economy in 10 years and is replaced by a VAR forecast where the future cyclical position is projected based on current economic conditions. In order to avoid a convoluted expectation formation inside the determination of long-term interest rates, the (RE)BASE setting fixes the term premium to its baseline value, $\bar{tp} = c^{tp}/(1-\rho^{tp})$. To make comparison viable, we also fix the term premium in the backward-expectation cases for the remainder of the paper.

in Equation (4), except that, in addition to the term premium, a corporate bond spread above risk-free rates is then added to the discounting.

2.1.2 Equity Prices

The description of equity prices follows the Dividend Discount Model. The equity price, P_t^{EQ}, is then equal to the present value of expected future dividend cash flows that are discounted with an appropriate risk factor:[9]

$$P_t^{EQ} = \mathbb{E}_t \sum_{k=0}^{\infty} \frac{c_S D_{t+k}}{(1 + i_t^{COE})^k}, \tag{7}$$

where D_t are dividend payments and c_S is a normalizing constant. Cost of equity, i_t^{COE}, is constructed as $i_t^{COE} = i_t + s_t^{COE}$, with the equity premium, s_t^{COE}, determined as in the original ECB-BASE.

Writing the equity price equation forward, it is cast into a form similar to the bond price equations shown above:

$$P_t^{EQ} = \frac{c_S D_t}{(1 + i_t^{COE})} + \mathbb{E}_t \left[\frac{P_{t+1}^{EQ}}{(1 + i_t^{COE})} \right]. \tag{8}$$

Dividend payouts to shareholders, D_t, can be approximated by dividend income received by the household sector, which is endogenously determined in the model's property income block. The MCE setting therefore features a forward-looking formation of equity prices that encompasses rational expectations on future dividend growth. c_S is calibrated to target a baseline dividend yield of 2.85 percent, consistent with the historical average of the MSCI Dividend Yield indicator.

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[9] In the original ECB-BASE, this equation is cast into a backward-looking version of the Dividend Discount Model. As in Fuller and Hsia (1984), it assumes two stages of dividend growth. There is an extraordinary growth phase (characterized by g^{ST}) that lasts for $2H$ years and a stable growth rate phase (g^{LT}) that lasts forever. Future growth of dividends is either projected based on exogenous information or can follow rules that rely on information from the past. Keeping the notation of the main text in all other cases, the backward-looking equity price can be written as $P_t^{EQ} = \frac{c_S D_t}{i_t^{COE} - g_t^{LT}} \left(1 + g_t^{LT} + H(g_t^{ST} - g_t^{LT})\right)$.

Finally, net financial assets held by households, FW_t, are affected by changes in stock prices and gain from returns earned on long-term and corporate bonds:

$$\frac{FW_t}{FW_{t-1}} = \omega_0 + \omega_{10Y}(1 + r_t^{10Y}) + \omega_{CB}(1 + r_t^{CB}) + \omega_{EQ}(P_t^{EQ}/P_{t-1}^{EQ}), \tag{9}$$

where ω_0, ω_{10Y}, ω_{CB}, and ω_{EQ} are calibrated shares of assets not subject to revaluation, government debt securities, corporate debt securities, and equities in total financial assets.

2.1.3 Exchange Rate

The nominal exchange rate is determined via an uncovered interest rate parity (UIP) condition that clears the interest rate differential with trading partners. The no-arbitrage condition is that the rate of return on domestic bonds in the domestic currency must equal the rate of return on foreign bonds whose payoff is converted into the domestic currency via the future spot exchange rate:

$$i_t^{10Y} = i_t^{10Y,F} + \mathbb{E}_t\left(s_{t+1} - s_t\right), \tag{10}$$

where s_t is the log of the nominal exchange rate of the domestic currency over a basket of trade-weighted currencies, i.e., the nominal effective exchange rate. i_t^{10Y} and $i_t^{10Y,F}$ are the long-term nominal interest rates in the domestic and foreign markets (the U.S.), respectively.

In the original model, the nominal exchange rate is governed by an empirical relationship that tracks the price and real interest rate differentials between the euro area and the foreign market. In order to depart from purchasing power parity, and therefore from a flexible price case, an explicit functional form for the change of the real exchange rate is assumed[10] and constitutes the basis for the estimation. As a result, an (estimated) scaling of interest

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[10] In BASE, the real exchange rate, defined as $q_t = s_t + p_t^F - p_t$, is assumed to follow $\mathbb{E}_t\left(q_{t+1} - \bar{q}_{t+1}\right) = \theta(q_t - \bar{q}_t)$.

rate changes affects the determination of the exchange rate level in ECB-BASE.[11]

To mimic this setup for the MCE version, we modify the UIP condition such that the expected change of the nominal exchange rate is a scaling of the interest rate differential:

$$\mathbb{E}_t \Delta s_{t+1} = \theta_{uip} \left(i_t^{10Y} - i_t^{10Y,F} \right), \tag{11}$$

where the scaling parameter, θ_{uip}, has been calibrated to match the medium-term dynamics of the exchange rate response to a monetary policy shock of the economy described by the original estimated model version.

In all applications that follow, foreign markets are assumed to be exogenous and therefore do not transmit feedback to the euro-area economy. Any exchange rate response is triggered by domestic interest rate changes. This makes it possible to condition the euro-area economy on an unchanged global environment, thus avoiding modeling complexities which would be beyond the scope of this paper.

2.2 Modified Income

The long-term consumption growth rate, consistent with economic theory, is derived from utility maximization where households consider their lifetime income stream and the value of financial assets (housing wealth and financial wealth). The reader is referred to Angelini et al. (2019) for the full derivation.

The permanent income construct is used to pin down target consumption, $\log C_t^*$. The empirical specification of the target consumption equation, which has been estimated in the original model, is

$$\begin{aligned} \log C_t^* = \eta_0 + \eta_T \log {EY_t}^T + \eta_P \log {EY_t}^P + \eta_D \log W_t^D \\ + (1 - \eta_T - \eta_P - \eta_D) \log EY_t^L, \end{aligned} \tag{12}$$

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[11] In BASE, the empirical relationship pins down the current period level of the nominal exchange rate directly (not in expectations). The parameter restrictions employed in the estimation imply $s_t = p_t - p_t^F + 1/(1 - \theta) \left(i_t^{10Y} - \bar{\pi}_t^e - (i_t^{10Y,F} - \bar{\pi}_t^{e,F}) \right) + \bar{q}_t$.

where ${EY_t}^i$ denotes the permanent income type $i \in \{T = transfer, P = property, L = labor\}$, ${W_t}^D$ denotes observed financial and housing wealth, and η_i stands for propensities to consume out of income type i.[12]

Permanent income is formally derived from the expected present discounted value of future incomes, denoted as J_t:

$$J_t^i = \mathbb{E}_t \sum_{k=0}^{\infty} (1 + r + \phi_0)^{-k} Y_{t+k}^i. \tag{13}$$

Expected permanent income, EY_t, is defined as

$$EY_t^i = (1 - \breve{\beta}) J_t^i, \tag{14}$$

with $\breve{\beta}$ representing the discount factor and equal to $(1+g)/(1+\bar{r}-\bar{\pi}+\phi_0)$. $\bar{r}-\bar{\pi}$ is the baseline real interest rate, ϕ_0 is a risk-adjustment factor, and g is the growth rate of potential output.

The expected permanent income of type i can be rewritten in recursive form:[13]

$$EY_t^i = (1 - \breve{\beta}) Y_t^i + \breve{\beta} \mathbb{E}_t (EY_{t+1}^i), \tag{15}$$

where the one-period-ahead expectation of permanent income, $\mathbb{E}_t(EY_{t+1}^i)$, is evaluated as a rational expectation forward term.

2.3 Reformulating the Adjustment Costs

An essential feature of the ECB-BASE model is the significant role played by expectations in the adjustment process and therefore the

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[12] We assume that $\eta_T + \eta_P + \eta_D + \eta_L = 1$. Furthermore, although aggregate property wealth can be directly obtained from the data, there are numerous issues related to its measurement. Because of that, we decided to follow FRB/US and postulate that the true property wealth is a weighted average of observed financial and housing wealth and the present value of property income. This results in financial and housing wealth entering the equation as observed and not as the present discounted value of its future streams.

[13] This is different from the original ECB-BASE model where, in order to apply VAR expectations, permanent income is deconstructed into trend and gap terms. The long-run trends are set according to the baseline targets they are supposed to converge to. The gaps to these trends depend on VAR forecasts about the cyclical position of the economy.

stickiness of main macroeconomic variables. The sluggish adjustment of variables to a theory-implied target are modeled through the polynomial adjustment costs (PAC) approach.[14] The benefit of this is that the long-term anchors of the model are consistent with economic theory, but the transition to the target is consistent with empirical relationships. The variables shift toward the long-run targets in an error-correction-type setup. It further captures inertia via a lag structure as well as providing a role for expectations through a forward term.

Because in ECB-BASE, main macroeconomic interactions feature the PAC property, expectations appear in many parts of the model (recall Figure 1 for an overview). For instance, theory suggests that consumption depends (log-)linearly on permanent incomes ($\log C_t^\star$ in the previous section is the theory-implied consumption target). However, when the model is applied to the data, there is a discrepancy between the observed and the theoretical level and growth rate of consumption. The intertemporal (forward-looking) optimization that determines the transition is modeled via the PAC approach.[15]

Now, let y_t be a generic variable of interest and $y_t^\star$ be its theoretical counterpart, typically derived from an optimization problem. Assume that the optimizing agents also seek to minimize a cost function of transition, denoted by Θ_t, with respect to the variable of interest, y_t, while taking the target, $y_t^\star$, as given.[16] This cost function is designed to penalize not only deviations between the actual value of the variable, y_t, and the target value, $y_t^\star$, but also changes in the variable itself:

$$\Theta_t = \mathbb{E}_{t-1} \sum_{i=0}^{\infty} \beta^i \left[(y_{t+i} - y_{t+i}^\star)^2 + \sum_{k=1}^{m} b_k \left((1-L)^k y_{t+i} \right)^2 \right]. \quad (16)$$

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[14] For a reference and a more detailed presentation, please see Tinsley (2002).

[15] In the case of consumption, the PAC lag structure is akin to internal habit formation in other models. The advantage of the PAC approach, however, is that it is generic and therefore offers flexibility in modeling any macroeconomic variable via this approach.

[16] The optimization problem resembles that of an HP filter, yet the instrument employed is distinct.

This cost encompasses the anticipated present value of squared deviations of the decision variable y_t from its target path $y_t^{\star}$, in addition to adjustment costs associated with the growth rate and higher-order derivatives of the decision variable. Expectations are formed based on the information available up until the end of period $t-1$.[17] The decision rule derived from the minimization of Θ_t is as follows:

$$\Delta y_t = a_0(y_{t-1}^{*} - y_{t-1}) + \sum_{k=1}^{m-1} a_k \Delta y_{t-k} + \mathbb{E}_{t-1} \sum_{j=0}^{\infty} d_j \Delta y_{t+j}^{*}, \quad (17)$$

where the coefficients entering the above decision rule are nonlinear functions of the adjustment cost parameters, b_k, and the discount factor, β. The change in the decision variable depends on deviations from the nonstationary optimal target value, its own lagged values, and the expected infinite discounted sum of future target values. The PAC approach not only introduces persistence to the variable of interest but also creates a dependency on the future values of the target. In contrast to the quadratic cost adjustment optimization problem obtained by setting the number of lags to $m = 1$, as used in Kennan (1979) and Rotemberg (1982), the PAC generalization of the adjustment cost function permits the inclusion of higher-order (frictions) derivatives by setting $m \geq 2$. This will result in a decision rule incorporating an arbitrary number of lags on the endogenous variable and lead changes in the target variable. Note that it is the lagged changes that potentially improve the short-term dynamic properties of the model and its empirical fit.

For ease of exposition, now define auxiliary variable Z_t, which captures the present value forward term in the PAC approach:

$$Z_t = \mathbb{E}_{t-1} \sum_{j=0}^{\infty} d_j \Delta y_{t+i}^{*}. \quad (18)$$

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[17] Notice that when considering the PAC framework, the expectations are formed by using the information available at time $t-1$ and not at t as is was the case in the previous sections. Although it might seem that the issue of including lagged versus current information when forming expectations in the PAC-based model blocks might be somewhat inconsistent, there is no clear-cut argument promoting either. By the fact that all right-hand side variables of Equation (16), and subsequently of Equation (17), are formed based on the same filtration, inconsistency is not present (Laubach and Reifschneider 2003).

Under MCE, the expected path of the target variable can be directly inferred from the system-wide solution of the model.[18] This is contrary to the VAR case. While the VAR, in principle, may be considered a sufficient statistic representation of the full model, expectations are still formed with a restricted information set. In certain applications, such as the analysis of permanent policy change effects, this may result in persistent expectation errors under the VAR setup (see, for example, Brayton, Davis, and Tulip 2000).

Now, the solution under MCE requires rewriting the infinite sum in Equation (18) into a recursive finite-lead representation in terms of Z_t and $\Delta y_t^\star$, a discount factor, β, and the polynomial coefficients, α_i, which are recoverable from the estimated coefficients, a_i.[19] After some algebraic manipulations, one can derive the MCE representation of the PAC expectation term:

$$Z_t = -\sum_{i=1}^{m} \alpha_i \beta^i Z_{t+i} + a_0 \left(\Delta y_t^* - \sum_{k=1}^{m-1} \sum_{j=k}^{m-1} \alpha_{j+1} \beta^{j+1} \Delta y_{t+k}^\star \right). \quad (19)$$

Note that this setup allows us to retain the estimated parameters, α, which have been estimated under the VAR expectation assumption. It also allows for convenient switching between VAR expectations and MCE depending on how Z_t is determined. Since the adjustment costs feature in many model blocks, the researcher may conveniently decide between hybrid expectation setups, where some sector adjustments can follow VAR-based expectations and others MCE.

2.4 Dynare's Computational Environment for ECB-(RE)BASE

All the model's simulations and estimates are carried out using Dynare's new features. Dynare provides commands to define the

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[18] Under VAR-based expectations in the original model, Z_t is expressed as $Z_t = \sum_{j=0}^{\infty} d_j \iota H^{i+1} x_{t-1} = h' x_{t-1}$, where coefficient vector h' is a nonlinear function of VAR matrix H, discount factor β and a_k coefficients. x are the VAR variables which are a subset of the full model variable set. ι is a selection vector that picks variables in x that are considered to be relevant for the imperfect information set under which the VAR forecast is formed.

[19] With $\alpha_{m-1} = a_{m-1}$, $\alpha_i = -\Delta a_i$ for $i = 2, \ldots, m-2$ and $\alpha_1 = a_0 - a_1 - 1$.

backward auxiliary model used to form expectations, `var_model` and `trend_component_model`,[20] by targeting a set of equations in the `model` block. Any expected variable in the model can be computed using the auxiliary model, provided that the variable to be expected is part of the auxiliary model and that the expectation operator is applied directly to the variable.[21] This is done by defining an expectation model with the `var_expectation_model` command. It refers to a previously defined auxiliary model and allows setting of the anticipated variable and the expectation horizon. Then, in the `model` block we can use the `var_expectation` keyword, which must be linked to an expectation model, as a replacement for a forward variable. We use this approach for all expectations, including those not related to PAC equations.

Dynare also provides commands related to the target and the anticipations in the PAC equation. In the simplest situation, where the target of the PAC equation is a single nonstationary variable, y^* in Equation (17), Dynare automatically identifies the target by parsing the error-correction term. This is the case for all the ECB-(RE)BASE PAC equations, but composite targets are also allowed:[22] the target is then a linear combination of nonstationary and stationary variables. The command `pac_model` defines the model for a PAC equation. For VAR-based expectations, the PAC model must be linked to a previously defined auxiliary model. If this reference is not given, Dynare understands that the expectations must be model-consistent (MCE), as in Equation (19). This command is also used to set the discount factor and, if necessary, defines the correction for growth neutrality. Once the PAC model has been defined, we can substitute the operator `pac_expectation` for Z_t in the notation above. Dynare replaces it with an auxiliary variable, whose definition can be either Equation (19) or the VAR forecast, depending on whether there is a link to an auxiliary model in the PAC model, and computes the necessary parameters (parameters α_k or vector h).

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[20] See the reference manual, Adjemian, Juillard et al. (2024), for a full description of these commands and those introduced below. Note that, except for the PAC equation, all the estimation routines are undocumented.

[21] The latter condition differs from what is assumed by default in Dynare, where the conditional expectation applies to the entire (nonlinear) equation.

[22] See the commands `pac_target_info` and `pac_target_nonstationary` in Adjemian, Juillard et al. (2024).

The PAC equations are estimated under VAR-based forecasts. The estimation of the autoregressive parameters, a_k $(k = 0, \ldots, m)$, is not obvious since the vector h in the VAR depends nonlinearly on the autoregressive parameters. In the literature, this equation is typically estimated through iterated ordinary least squares (as in FRB/US). However, Dynare also permits estimation of this equation using nonlinear least squares (NLS), which is the favored approach here.

The simulation of the model uses simulation routines specialized either for backward models if all the expectations are VAR-based, or relying on the perfect foresight solvers or extended path simulation routine if some expectations are model-consistent. Note that Dynare can reduce computation time by exploiting the property that each equation of the semi-structural model is written as an endogenous variable equal to an expression.

3. Monetary Policy Transmission across Alternative Expectations

This section explores how transmission dynamics change by incorporating model-consistent expectations in the model economy. We focus on investigating the propagation of monetary policy shocks, as they are a major driver of economic variation and are of key interest for the central bank's model-based analysis.

All simulations are conducted relative to a baseline. Initially, we establish the model's balanced-growth path (BGP) by executing a sufficiently long simulation of the respective version of the model, ensuring that the system settles at constant growth rates. Consequently, the growth rates of stationary variables become zero, while those of nonstationary variables align with their theoretical long-run growth rates. The initial simulation periods, where the system has not yet stabilized, are discarded. Thereafter, any further simulations can be performed around this stable BGP.

3.1 Alternative Expectations Settings

In the following analysis, we implement a shock of identical magnitude in the model economy while sequentially switching the expectation settings of various sectors to the MCE version. Table 1 provides

Table 1. The Role of Expectations in the Model's Blocks

	VAR Expectations	**Financial MCE**	**Financial + PCs MCE**	**Financial + PCs + Income MCE**	**Full MCE**
Exchange Rate/UIP		✓	✓	✓	✓
Equity Prices		✓	✓	✓	✓
Bond Prices/Interest Rates		✓	✓	✓	✓
Wage Setting			✓	✓	✓
Price Setting*			✓	✓	✓
Permanent Income				✓	✓
Household Consumption PAC					✓
Business Investment PAC					✓
Residential Investment PAC					✓
Employment PAC					✓
House Prices PAC					✓
Property Income PAC					✓

* The medium-term inflation target of the central bank remains imperfectly anchored throughout this paper. It is calibrated to be of low sensitivity with respect to current price inflation and therefore not influence simulations noticeably.

Note: The first column refers to model blocks where expectations play a role in the BASE model. The columns describe the expectation modalities considered when switching expectations. A check mark means that the VAR expectations/the backward rule of the equation in the BASE model is switched to its MCE version of (RE)BASE. PCs = Phillips curves.

an overview of the modalities we consider. Between the pure VAR expectations setting and the "Full MCE" setting, there exists a spectrum of hybrid expectation settings. In the context of examining the effects of monetary policy, these hybrids may prove useful, as they reflect the degree to which certain sectors understand policy signals. For instance, Bernanke, Kiley, and Roberts (2019) use expectation settings where the private sector is backward-looking, serving as a stand-in for imperfect credibility of policy shifts. Conversely, simulations under the Full MCE setting, i.e., rational expectations, are related to full credibility.

First, we consider the scenario where only the financial sector is forward-looking. As argued by Bernanke, Kiley, and Roberts (2019), financial markets may be perceived as having greater incentives, expertise, and resources to comprehend and evaluate the implications of monetary policy. This setting is particularly relevant when policy shifts are considered temporary, requiring significant effort to discern their consequences, while households and nonfinancial firms may choose to fully invest resources only in the case of more permanent changes.

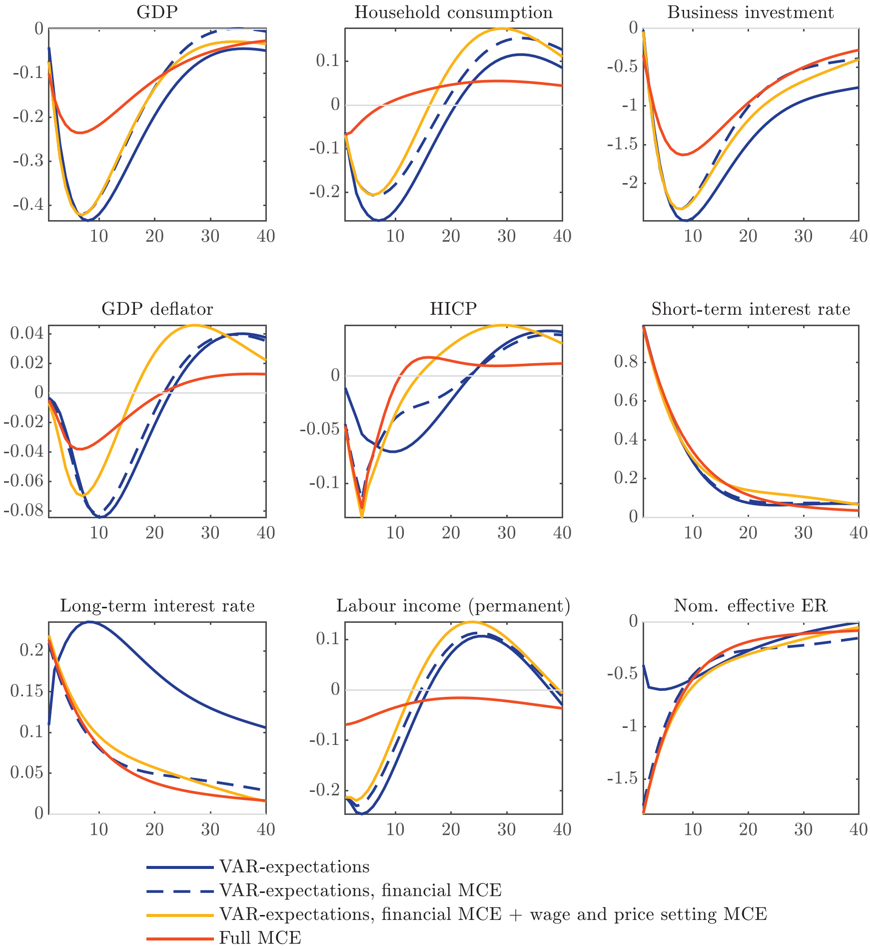
Then, we consider the supply side, and therefore the nominal sphere, as forward-looking. This can be motivated by goods-producing firms possessing comparatively more means and incentives to understand policy changes than households. In this sequence, households and therefore consumers are least likely to be forward-looking. Switching income evaluations to MCE can be thought of as extending rational expectations to this sector as well. Finally, all transmission dynamics (PAC) are adjusted to be forward-looking in the Full MCE setting.

Sectors adhering to VAR expectations form future expectations based on past regularities. This may serve as a reasonable approximation of the true model during normal times, but the Full MCE is likely to yield significantly different insights when analyzing shifts during specific crises or nonlinearities, such as the Lower Bound period on interest rates (Reifschneider and Roberts 2006).

3.2 Simulations of Policy Shocks

Figure 2 presents impulse response functions for a standard monetary policy shock, sequentially swapping expectations from the

Figure 2. Monetary Policy Shock (100 Basis Points)—Switching Expectations in Sectors



Note: Responses to an unanticipated increase in the short-term nominal interest rate by 100 basis points. All simulations are conditioned on the term premium and financing spreads being fixed to their baseline values. The horizontal axis shows time in quarters. The vertical axis depicts short- and long-term interest rates as annualized percentage point deviation from the baseline value. GDP deflator inflation and HICP inflation are shown in percentage point deviation from the baseline year-on-year growth rate. All other variables are in percent deviation from their baseline levels.

VAR-based version to the Full MCE version (see the channels that are switched on in the overview in Table 1). The economy responds to an unanticipated shock to the monetary policy rule of the model, such that the short-term interest rate increases by 100 basis points upon impact.

The ECB-BASE VAR expectation response is depicted by the solid blue line. It is important to note that the increase in the monetary policy rate has expectational features in this backward-looking setting also. The short-term interest rate is incorporated into the core VAR of ECB-BASE, thereby influencing all VAR-based expectations. Higher short-term interest rates permeate through the yield curve since the risk-free long-term rate depends on expected future short-term rates. Alongside an endogenous rise in spreads, this shift in interest rates elevates borrowing costs for households and firms, consequently dampening consumption expenditures as well as business and residential investment. The reduction in aggregate demand exerts downward pressure on nominal wages and prices via the Phillips curve mechanism. Additionally, monetary policy tightening leads to an appreciation of the exchange rate, and the resultant loss in export market shares further exacerbates the contractionary effect on economic activity.

Next, we switch the financial block of the model to MCE (represented by the dashed blue line). This results in a more abrupt repricing in the yield curve, which gradually unwinds, contrary to the hump-shaped response suggested by VAR-based expectations. This directly translates into a more moderate reaction in financing costs, which is a central propagation channel and results in a lesser decline in investment and consumption expenditures. Moreover, the revaluation of nominal assets is less negative, thereby exerting less downward pressure on consumption decisions compared to the VAR-based expectations case. In line with the dampened demand cycle, the GDP deflator also exhibits a more subdued response. The determination of the exchange rate changes with financial MCE causes the euro to appreciate in a more front-loaded fashion, which directly impacts HICP inflation. This is due to an exchange rate repricing channel affecting imported energy, which will be discussed in more detail later. But overall, switching the financial sector to a forward-looking setting has limited implications on the real side. This is because a milder pass-through to financing rates under the financial MCE specification is offset by a stronger euro appreciation, triggering a worsening of the trade position.

We proceed by switching the price and wage Phillips curves to the MCE mode (illustrated by the yellow line). This model version is to be understood as an economy where firms are strongly forward-looking, in addition to the financial sector, but households are not. The domestic price response is somewhat front-loaded compared to the VAR expectation case, albeit not amplified. Since the wage setting also becomes more front-loaded, income and, consequently, consumption dynamics experience some changes. Other real expenditures, however, do not exhibit substantial changes.

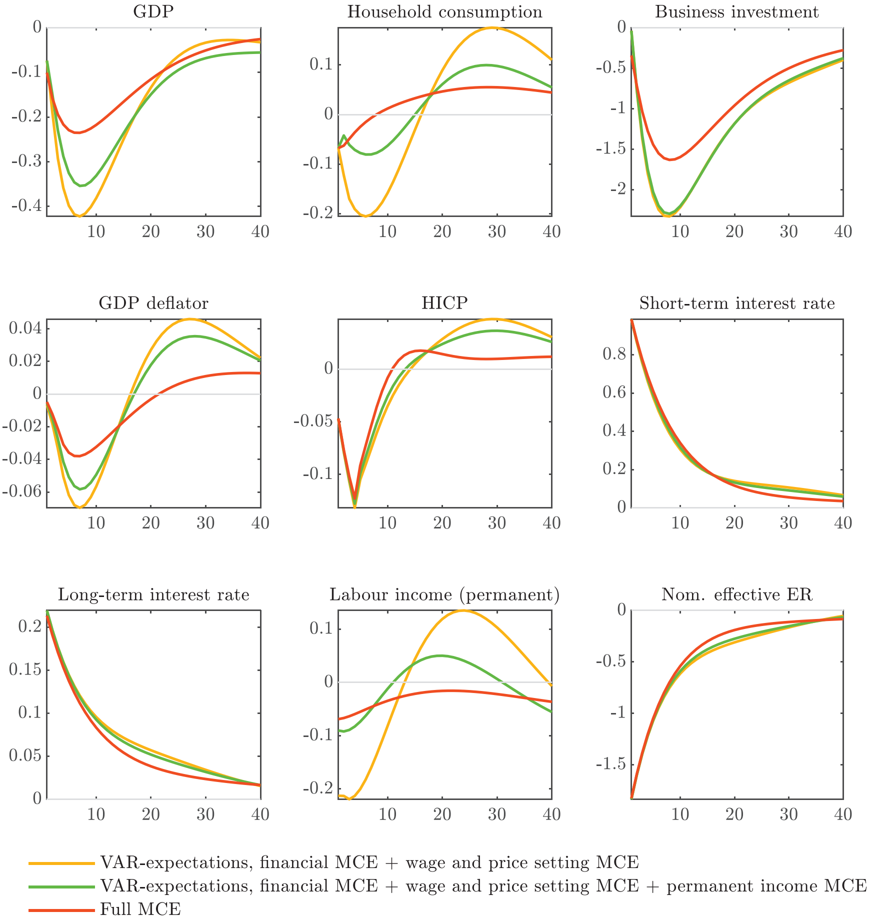
Finally, we switch the entire model into Full MCE mode (depicted by the red line). The transmission of the monetary policy shock becomes smoother than in the previous settings. A significant factor is the permanent income perception, which strongly influences consumption decisions. The household sector now anticipates the full future repercussions of the cycle. As a result, consumers tend to "look through" the demand deterioration and its implications for their lifetime income. Consumption, and thus economic activity and other expenditures, are smoothed out compared to the more backward-looking expectation settings. Moreover, with all adjustment dynamics now operating in forward mode, transitions become more gradual, leading to considerable smoothing of both expenditure and output.

3.2.1 Permanent Income Smoothing

In the (RE)BASE model, model-consistent expectations do not amplify the effect of unexpected standard monetary policy shocks on output. Our next step is to disentangle the influence of income smoothing from the effect of smoother transition dynamics that are due to switching PAC expectations. This analysis is particularly useful as it highlights a unique feature of our model: unlike typical DSGE model specifications, consumption behavior is not driven by an Euler equation where the real interest rate directly steers consumption-saving decisions. Instead, our model focuses on empirical relationships concerning the propensity to consume from various sources of income and wealth.

To explore the significance of the permanent income channel on its own, Figure 3 illustrates another model version adding to the

Figure 3. Monetary Policy Shock (100 Basis Points)—The Role of Income Smoothing



Note: Responses to an unanticipated increase in the short-term nominal interest rate by 100 basis points. All simulations are conditioned on the term premium and financing spreads being fixed to their baseline values. The horizontal axis shows time in quarters. The vertical axis depicts short- and long-term interest rates as annualized percentage point deviation from the baseline value. GDP deflator inflation and HICP inflation are shown in percentage point deviation from the baseline year-on-year growth rate. All other variables are in percent deviation from their baseline levels.

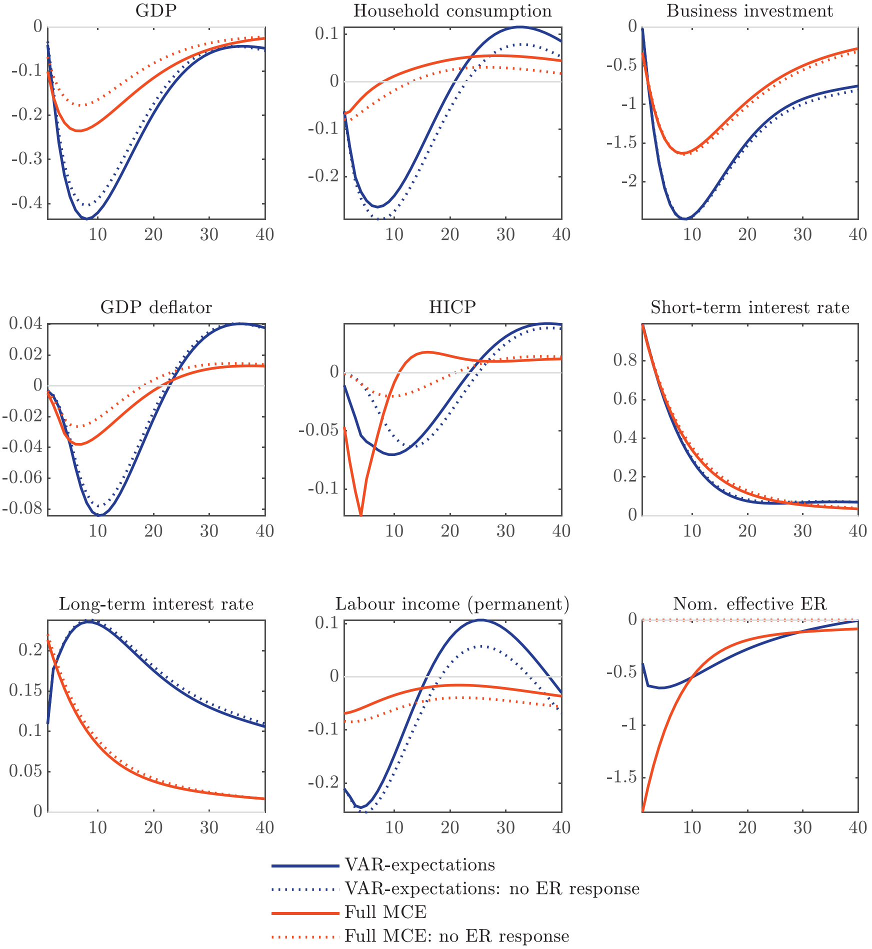
previous exercise. We begin with the hybrid setting where the supply side has been switched to MCE. Then, represented by the green line, the permanent income perception only is changed to MCE. This is done without yet considering MCE in the PAC setting. The permanent income MCE accounts for more than half of the cyclical change in consumption when comparing the hybrid modality to the Full MCE modality. However, investment is not affected to the same extent. Since consumption is smoothed, the decreases in output and prices are lower—proportional to the share of consumption. The remaining difference compared to the Full MCE is attributed to transitioning the PAC specifications to a model-consistent expectation mode.

3.2.2 The Role of the Exchange Rate

The analysis thus far has been conducted by considering a response of the exchange rate to the interest rate differential between domestic and foreign (U.S.) interest rates. The exchange rate channel is a crucial aspect of monetary policy transmission and merits separate investigation. The deflators for import and export prices are modeled based on domestic and external cost pressures, along with considering the role of price competition in international trade. Consequently, the exchange rate directly influences the prices at which euro-area exports compete in third markets. Additionally, the model explicitly accounts for the price of oil and gas energy. The euro area is heavily reliant on energy imports, which are predominantly priced in U.S. dollars. Therefore, the EUR/USD exchange rate impacts GDP deflator inflation by affecting the price of the inputs to production. The model also entails a link of HICP energy inflation to these international market prices when converted to domestic prices. Therefore, the model specifically accounts for the prominent role of household expenditures on petrol and heating.

Figure 4 begins with the VAR expectation case, where the financial sector is in MCE mode as a backward-looking benchmark version. It is plotted against the Full MCE case. There is no feedback of the global environment to changes in the euro area. An expansionary monetary policy in the euro area subsequently triggers an appreciation of the euro as domestic interest rates rise and opens the differential with unchanged foreign markets. The exchange rate

Figure 4. Monetary Policy Shock (100 Basis Points)— The Role of the Exchange Rate Channel



Note: Responses to an unanticipated increase in the short-term nominal interest rate by 100 basis points. All simulations are conditioned on the term premium and financing spreads being fixed to their baseline values. The horizontal axis shows time in quarters. The vertical axis depicts short- and long-term interest rates as annualized percentage point deviation from the baseline value. GDP deflator inflation and HICP inflation are shown in percentage point deviation from the baseline year-on-year growth rate. All other variables are in percent deviation from their baseline levels.

response in the backward-looking version is notably more gradual, while the Full MCE case displays a more immediate loading with a stronger mean reversion. This is a known feature in the literature, where the DSGE approach to specifying a UIP condition on expected exchange rate changes typically does not lead to enough persistence to generate a hump-shaped response (Adolfson et al. 2008).

Illustrated by lightly dotted lines, the figure demonstrates alternative economic responses under an unchanged exchange rate. This switches off the loss of export market shares and the deterioration in net trade. Output therefore declines by less. It also switches off the endogenous repricing of energy imports quoted in domestic currency. In the endogenous model, an appreciation results in a real income gain because energy prices become cheaper. This channel mitigates the negative impact of production loss due to lower exports but does not fully compensate for it.

The significance of the exchange rate channel for output dynamics is slightly stronger under Full MCE. Given that HICP energy inflation is a significant contributor to total HICP inflation, the exchange rate influences consumer prices more directly, as opposed to the more gradual pass-through to producers' factory gate prices. Without the exchange rate channel, the differences in HICP dynamics across expectations are more akin to the dynamics of GDP deflator inflation. Overall, this channel somewhat obscures the heterogeneity of the importance of expectation settings for price developments.

3.2.3 Anticipation of News Shocks

A main capability of our forward-looking expectation model is its ability to analyze anticipated news shocks. It has been shown that these news shocks, in addition to surprise shocks, play a quantitatively significant role in business cycle fluctuations (Schmitt-Grohé and Uribe 2012). It has been demonstrated that theoretical models can be effectively augmented with news shocks to generate impulse responses that exhibit comovements consistent with empirical data (Barsky and Sims 2011).

In (RE)BASE, a news shock on the monetary policy rate is implemented as follows. The nominal short-term interest rate reacts as

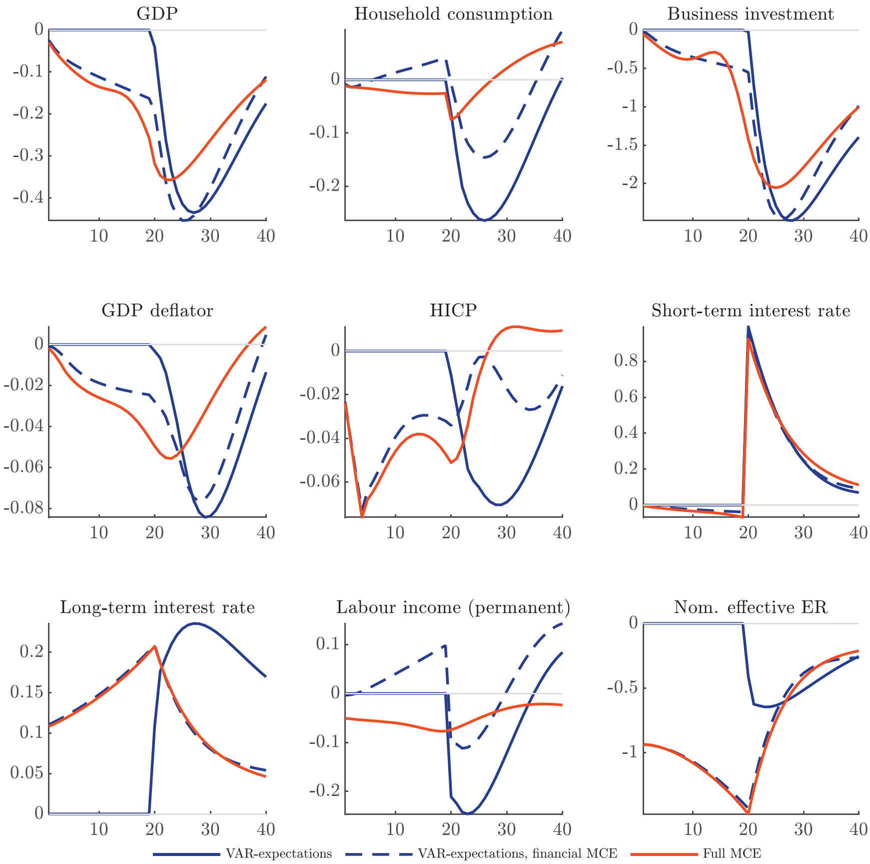
$$i_t = \beta_1 i_{t-1} + (1-\beta_1)[\bar{i} + \beta_2 \hat{\pi}_t] + \beta_3 \Delta\pi_t + \beta_4 \Delta y_t + \epsilon^i_{0,t} + \epsilon^i_{1,t-1} + \ldots \quad (20)$$

The first part of the equation is the model's Taylor rule, reflecting the interest rate's response to the inflation gap, $\hat{\pi}_t$, the change in the inflation rate, $\Delta\pi_t$, and output growth, Δy_t. As the simulations are conducted under perfect foresight, the model economy resolves under a known path of shocks, $\epsilon^i_{k,t-k}$. It is important to note that this process is independent of how the private sector forms expectations. Technically, anticipated news shocks can be simulated across all different expectation settings. An economy relying on backward-looking information would not yet respond to a news shock related to the future. Under rational expectations in (RE)BASE, however, this information influences the mechanics as soon as the shock path becomes known, referred to as the date of announcement.

In the spectrum of credibility discussed above, this can be seen as two polar cases. If the model's expectations are fully VAR-based, then a future policy change cannot be credibly communicated, surprising the economy if it materializes. Conversely, Full MCE implies full anticipation under perfect foresight, connoting full credibility of central bank communication.

Figure 5 illustrates the model economy's responses to an announced increase in the short-term interest rate, 20 periods ahead. Under VAR expectations, the contractionary shock is a complete surprise in period 20. The model's response function is equivalent to shifting an unanticipated shock to period 20. Rational expectations active in the financial block then serve as another benchmark case. It reflects a scenario where only the financial sector understands the monetary policy shift while other sectors do not, emulating an imperfect credibility setup. The long-term interest rate reprices upon announcement at $t = 1$, leading to an immediate increase in firms' and households' borrowing costs. Investment and consumption, and thus GDP, begin to decrease even before the actual hike in the monetary policy rate. Similarly, the value of nominal financial assets also declines immediately, further weighing on consumption. Importantly, the exchange rate also reprices at the time of announcement, adding another layer of anticipation. The appreciation fuels the decrease in output through declining exports, though it also leads to a rapid decline in HICP energy prices, amplifying the response of total HICP.

Figure 5. Monetary Policy Shock (100 Basis Points)—Anticipated News Shock



Note: Responses to an announced increase in the short-term nominal interest rate by 100 basis points, 20 periods in the future, across expectation settings. All simulations are conditioned on the term premium and financing spreads being fixed to their baseline values. The horizontal axis shows time in quarters. The vertical axis depicts short- and long-term interest rates as annualized percentage point deviation from the baseline value. GDP deflator inflation and HICP inflation are shown in percentage point deviation from the baseline year-on-year growth rate. All other variables are in percent deviation from their baseline levels.

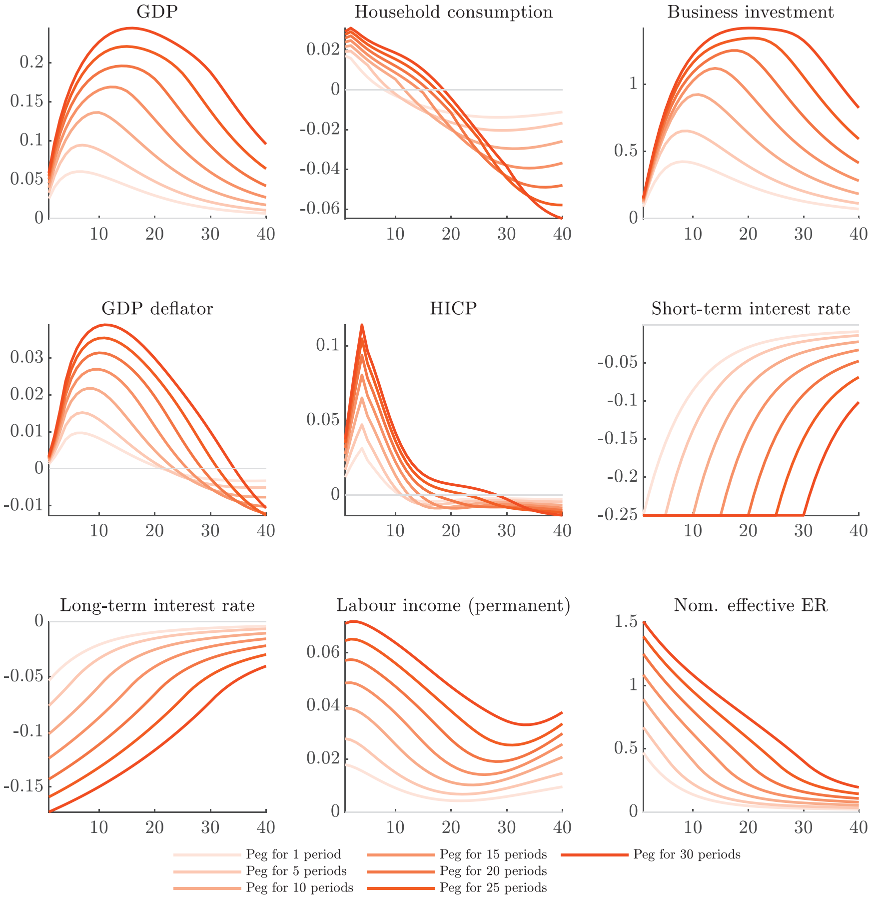
In the Full MCE model, considering a fully credible policy announcement leads to price and wage dynamics that are somewhat front-loaded compared to the benchmark case. Notably, households' evaluation of permanent income becomes much smoother, with a significant decrease already during the anticipation phase. This results in consumption smoothing over the full cycle, with a stronger decrease up front but more positive dynamics after the short-term interest rate increase actually becomes apparent at $t = 20$.

3.2.4 Forward Guidance

In the previous exercise, the Taylor rule is active throughout, albeit only moderately leaning against the cyclical downturn during the anticipation phase. The steady interest rate policy, however, does not create a forward guidance puzzle in ECB-(RE)BASE. Many New Keynesian models face the phenomenon of generating explosive economic dynamics at a fixed interest rate for prolonged periods, an issue that has been of focal attention during times when the interest rate was at the Zero Lower Bound (see, for example, Cochrane 2017). Recently, Maliar and Taylor (2024) demonstrated that the puzzle arises at literally fixed rates as well as for policy rate rules that are insufficiently responsive to contain future shocks.

To systematically investigate the role of forward guidance in our model, we simulate exercises similar to those in Christoffel et al. (2022). The authors show that without mitigating the puzzle, a continuous peg of the interest rate for 10 periods creates explosive economic behavior in the New Area-Wide model, a medium-scale DSGE model of the euro area. Figure 6 presents exercises conducted with (RE)BASE, where the central bank pegs the interest rate to a value 25 basis points below the baseline value for different durations. The economic dynamics shift proportionally to the length of the peg and do not become explosive. A major difference from other New Keynesian models is the absence of intertemporal reallocation forces on consumption implied by an Euler equation. Christoffel et al. (2022) tame the forward guidance puzzle in the DSGE by introducing additional discounting and conditioning expectations on survey data. Both factors limit the importance of future stimulus implied by holding the policy rate fixed for an additional quarter. The parametrization of ECB-(RE)BASE, as a strongly data-conditioned forecast model, already displays relative dynamic stability without further interventions.

Figure 6. Forward Guidance—Peg of the Policy Rate (–25 Basis Points) for Multiple Periods



Note: Responses to an anticipated and credible peg of the short-term nominal interest rate by 25 basis points below the baseline value for multiple periods. Expectations modality: Full MCE. All simulations are conditioned on the term premium and financing spreads being fixed to their baseline values. The horizontal axis shows time in quarters. The vertical axis depicts short- and long-term interest rates as annualized percentage point deviation from the baseline value. GDP deflator inflation and HICP inflation are shown in percentage point deviation from the baseline year-on-year growth rate. All other variables are in percent deviation from their baseline levels.

4. Recent Supply Shocks through the Lens of Alternative Expectations

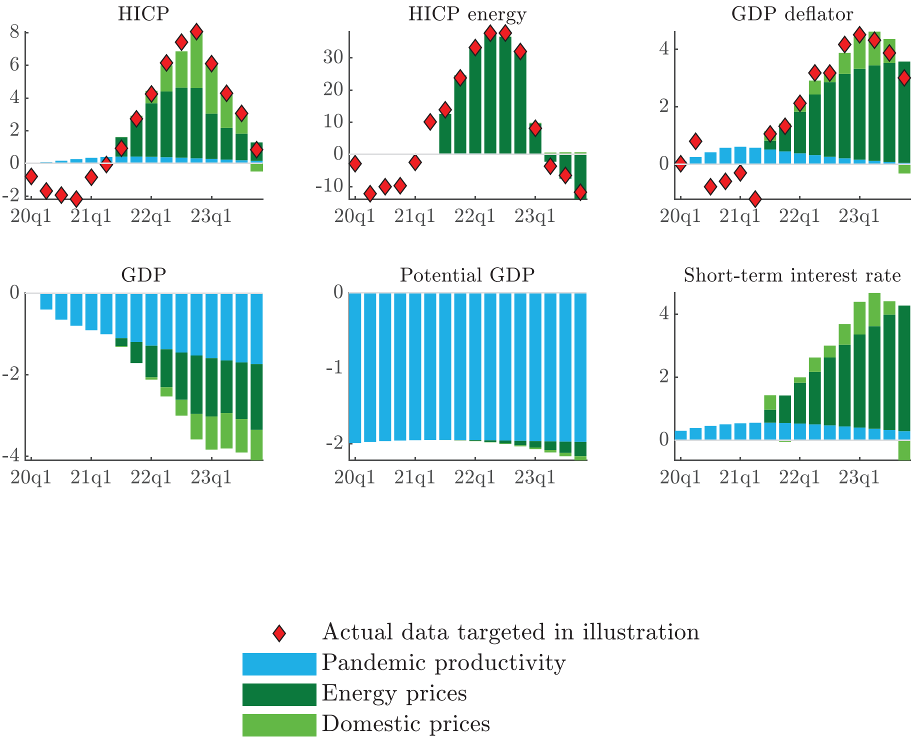
In this section, we apply the model to a real-world analysis. Recent supply shocks have exerted extraordinary inflation pressures on the euro-area economy. The resulting price movements were significant enough to provoke notable changes in the long-term inflation expectations of the private sector. This situation created a trade-off for central banks: the desire to "look through" these supply shocks to avoid exacerbating the cyclical downturn with interest rate hikes, versus the necessity to reanchor inflation expectations by demonstrating a firm commitment to combating above-target price pressures as they emerge. In terms of economic model interpretation, it has been shown that a full forward-looking setting implies an easier reanchoring of inflation expectations (Beaudry, Carter, and Lahiri 2023). Using (RE)BASE, we aim to explore how different expectations frameworks might lead to varying assessments of the trade-off between price stability and output that the central bank faces.

4.1 Scenario Design: Shock Calibrations

We construct a supply-shock scenario that is reminiscent of key characteristics of the recent inflation surge period. The scenario focuses solely on supply shocks. It is designed as follows: we activate three types of residuals to create a supply-shock scenario. Their contributions to the price increases and resulting macroeconomic dynamics through the model (considering VAR expectations) are documented in Figure 7.

First, we employ a stylized productivity shock that reduces potential GDP by approximately 2 percent from the onset of the COVID-19 pandemic. The shock aims to illustrate a contribution of the pandemic-induced supply-side pressures on prices. That may entail production and delivery bottlenecks as well as legacy effects from the lockdowns and containment policies on capacity. In order to calibrate this shock, we refer to the findings of Angelini et al. (2020), who introduced a pandemic module into ECB-BASE in order to study the interaction of the macroeconomy when individuals are exposed to, infected by, and recover from (SIR) the COVID-19 virus. According to this study, around 45 percent of the cumulative output loss during the pandemic is reflected into potential output. In our

Figure 7. Construction of a Supply-Shock Scenario—VAR Expectations



Note: The pandemic productivity shock is simulated as of 2020:Q1, while the other shocks are assumed to arise as of 2021:Q3. HICP, HICP energy, and GDP deflator inflation are shown in percentage point deviation from the year-on-year growth in the baseline. The data are shown as the deviation from a 2 percentage point baseline growth rate. The short-term interest rate is shown as the annualized percentage point deviation from the baseline value. All other variables are in percent deviation from their baseline level values.

exercise, we illustratively assume a 4 percent decrease in the level of output persisting even after the pandemic health crisis subsides.

Second, the scenario incorporates energy price shocks. These shocks are modeled by adjusting the path of imported oil prices to match the observed increase in HICP energy inflation in the euro area starting as of 2021:Q1.[23] This profile is matched until the end

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[23] See Table 2 for an overview of the data targeted in this scenario.

Table 2. Data Sources in the Construction of the Scenario

Observable	Raw Metric	SDW Codes	Further Treatment
HICP Inflation	Annual rate of change	ICP.M.U2.N.000000.4.ANR	Seasonally adjusted, quarterly average
HICP Energy Inflation	Annual rate of change	ICP.M.U2.N.NRGY00.4.ANR	Seasonally adjusted, quarterly average
GDP Deflator Inflation	Index	MNA.Q.Y.I9.W2.S1.S1.B.B1GQ. Z. Z. Z.IX.D.N	Annual rate of change

Source: SDW (ECB Statistical Data warehouse).

of our simulation horizon, 2023:Q4. The oil price mechanism in the model also entails a pass-through to the GDP deflator, capturing the effects of imported carbon energy sources used as inputs to production. Since our scenario targets HICP energy prices, we effectively capture a general imported energy price increase, which was largely due to elevated gas prices during this episode. The oil price shock mainly transmits as a loss of real income and, consequently, as a loss in purchasing power, leading to decreased consumption, production, and other expenditures. The central bank adjusts interest rate policies to stabilize the gap between GDP deflator growth and the target rate.

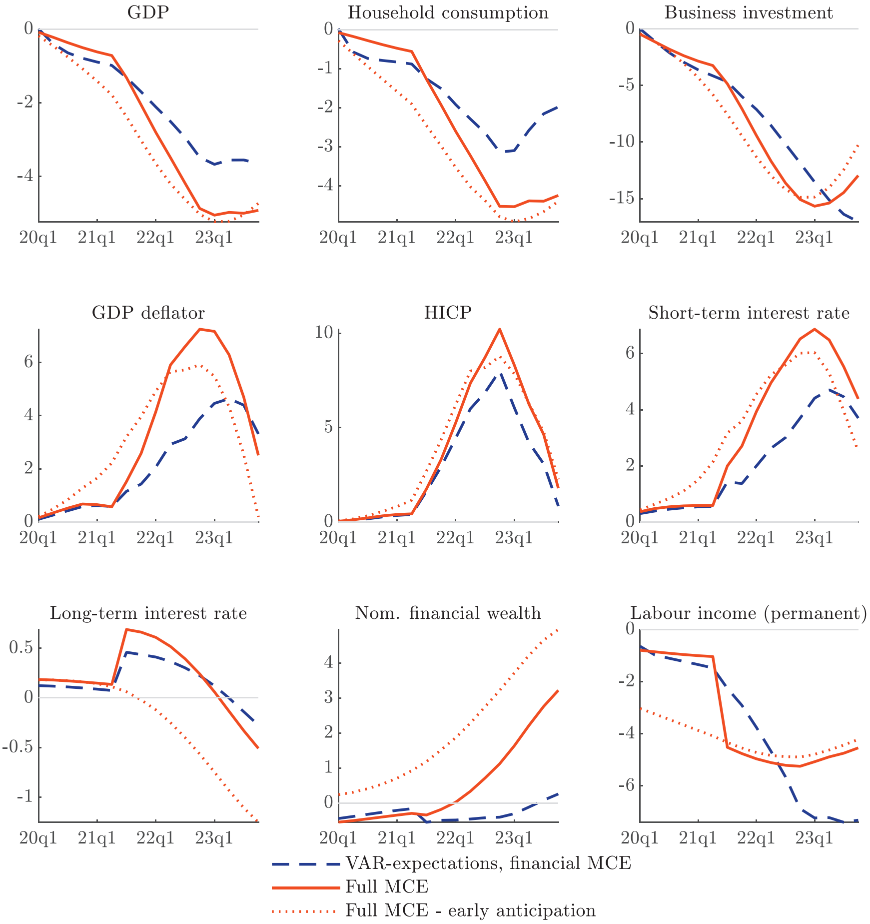
While the productivity shock contributes to the inflation surge scenario to a limited extent, adding the energy price shock would result in an increase in GDP deflator inflation comparable to what was observed in actual data. Overall, this initial combination would account for approximately half of the HICP inflation increase above the central bank target rate noted from 2021:Q3 to 2023:Q4. To complete the scenario, we introduce a shock that matches the remaining GDP deflator and HICP inflation deviations in the data through markup shocks. The markup shocks directly shift the GDP deflator (changing the residual of the main Phillips curve pricing equation) and the HICP excluding energy and food inflation. These shocks further contribute to price increases, triggering additional losses in real disposable income and leading to a further decline in consumption.

4.2 Supply Shocks across Expectation Settings

In this section, we keep the sequence of shocks fixed, but resimulate the model under backward expectation with the financial sector being forward-looking and under Full MCE. Figure 8 displays the main simulations as dashed blue and solid red lines. Each simulation displayed is created by the same combination of shock sequences constructed above. The interested reader is referred to the working paper, Adjemian, Bokan et al. (2024), for a systematic documentation of switching the expectations for each shock separately.

We begin with a backward-expectations setting, where only the financial sector is forward-looking and forms rational expectations. We assume an endogenous monetary policy where the nominal short-term interest rate starts to rise at the first signs of price

Figure 8. Macroeconomic Dynamics in the Supply-Shock Scenario across Expectation Modalities



Note: Responses to the same sequence of shocks, as constructed in Figure 7, across alternative expectation settings. In the first two simulations, the energy and domestic markup shocks are known to the economy as of 2021:Q3. In the simulations labeled “early anticipation,” the energy and domestic markup shocks are anticipated as of 2020:Q1 even if they materialize in 2021:Q3. All simulations are conditioned on the exchange rate, the term premium, and financing spreads being fixed to their baseline values. The graph depicts short- and long-term interest rates as the annualized percentage point deviation from the baseline value. GDP deflator inflation and HICP inflation are shown in percentage point deviation from the baseline year-on-year growth rate. All other variables are in percent deviation from their baseline levels.

increases from the pandemic leg of the scenario. The other shocks regarding energy and domestic price markups unexpectedly impact the economy as of 2021:Q3. The short-term interest rate then adjusts accordingly, and spills into the yield curve. Due to anticipation in the financial sector, the long-term interest rates reflect the expected repricing of the short-term rate path at the beginning of the markup shock sequence. The private sector gradually perceives the real income loss implied by the price increase, causing the consumption path to adjust correspondingly.

When simulating the inflation surge scenario under Full MCE, the markup shocks lead to a significantly larger price increase because the Phillips curve expectations front-load the nominal implications. With endogenous monetary policy, this would necessitate a quicker and more pronounced rise in interest rates. Furthermore, households anticipate and front-load the perceived real income loss. Overall, households sharply reduce their consumption under the Full MCE setting, resulting in a more pronounced decline in GDP compared to the backward expectations scenario.

Finally, the same inflation surge scenario can also be evaluated under stronger anticipation assumptions. In the simulations represented by the dotted lines in Figure 8, we input the same sequence of shocks as previously constructed into the model but now assume that the economy fully anticipates the effects as early as Q1:2020. This illustrates a highly forward-looking extreme case where the pricing pressures are anticipated immediately following the pandemic's opening phase. Under backward expectations, there is no significant economic difference between anticipation and no anticipation. However, under Full MCE, the price shock sequences result in a more gradual inflation increase, with price growth peaking below the initial scenario's peak for Full MCE. Households' decisions are then influenced more immediately, as they assess the post-pandemic inflation surge's implications for their real income early on. The central bank would also begin to tighten policy gradually, in foresight of price pressures building up in the economy.

In summary, these scenario exercises confirm that model-consistent expectations can significantly alter the cyclical properties viewed through the lens of the model, with critical implications for policy assessment. The cases presented are exemplary for some alternative economic repercussions that the central bank may distill when assessing the implications of supply shocks. To make recommendations for policy, timing, anticipation, and speed of adjustments to supply shocks all matter. Our experiments are also consistent with findings in the literature that, if the monetary authority had had full knowledge of the economic conditions prevailing from 2021 onward, optimal strategies might have called for anticipated hiking of interest rates in response to the increase in inflation (see Darracq Pariès, Kornprobst, and Priftis 2024).

5. Conclusion

ECB-(RE)BASE has been developed as part of the semi-structural model family around ECB-BASE/MC. It is a variant of the euro-area model ECB-BASE that can be simulated under a model-consistent expectation setting. Our implementation allows for the integration of different expectation settings in different parts of the model economy. A key technical challenge of ECB-(RE)BASE relates to the treatment of adjustment costs, which determine the sluggishness of macroeconomic transmissions.

We have shown that the expectation setting can significantly influence the transmission of monetary policy shocks through the model economy. The MCE setting leads to a dampening of monetary policy transmission to the real side of the economy because the modeling of gradual adjustment forces and the prominence of expected lifetime income dominate any implications of the financial sector being forward-looking. The MCE setting also leads to a front-loading of HICP responses due to the exchange rate effect on imported energy. Policy announcements lead to partial anticipation of economic dynamics if credibly understood by the private sector.

Additionally, we have illustrated the implications of expectation settings for macroeconomic volatility through an applied experiment. The markup and negative productivity shocks that have driven up inflation in recent years result in stronger nominal amplifications when assessed through a model with model-consistent expectations compared to a backward-looking setting. Anticipation of shocks increases the complexity of the inflation-output trade-off because the speed and persistence of transmission to the real and to the nominal side may differ substantially.

This information is crucial for the conduct of monetary policy. If the private sector is highly forward-looking, the same sequence of shocks may trigger more pronounced inflation cycles. Consequently, monetary policy needs to respond proactively to effectively limit price pressures while minimizing negative impacts on output.

References

Adjemian, S., N. Bokan, M. Darracq Pariès, G. Müller, and S. Zimic. 2024. "ECB-(RE)BASE: Heterogeneity in Expectation Formation and Macroeconomic Dynamics." Working Paper No. 2965, European Central Bank.

Adjemian, S., M. Juillard, F. Karamé, W. Mutschler, J. Pfeifer, M. Ratto, N. Rion, and S. Villemot. 2024. "Dynare: Reference Manual, Version 6." Dynare Working Papers No. 80, CEPREMAP.

Adolfson, M., S. Laséen, J. Lindé, and M. Villani. 2008. "Evaluating an Estimated New Keynesian Small Open Economy Model." *Journal of Economic Dynamics and Control* 32 (8): 2690–721.

Angelini, E., N. Bokan, K. Christoffel, M. Ciccarelli, and S. Zimic. 2019. "Introducing ECB BASE: The Blueprint of the New ECB Semi-Structural Model for the Euro Area." Working Paper No. 2315, European Central Bank.

Angelini, E., M. Damjanović, M. Darracq Pariès, and S. Zimic. 2020. "ECB-BASIR: A Primer on the Macroeconomic Implications of the COVID-19 Pandemic." Working Paper Series No. 2431, European Central Bank.

Barsky, R. B., and E. R. Sims. 2011. "News Shocks and Business Cycles." *Journal of Monetary Economics* 58 (3): 273–89.

Beaudry, P., T. J. Carter, and A. Lahiri. 2023. "The Central Bank's Dilemma: Look Through Supply Shocks or Control Inflation Expectations?" Technical Report, National Bureau of Economic Research.

Bernanke, B. S. 2024. "Forecasting for Monetary Policy Making and Communication: A Review." Technical Report, Bank of England.

Bernanke, B. S., M. T. Kiley, and J. M. Roberts. 2019. "Monetary Policy Strategies for a Low-Rate Environment." *AEA Papers and Proceedings* 109 (May): 421–26.

Brayton, F., M. Davis, and P. Tulip. 2000. "Polynomial Adjustment Costs in the FRB-US." Mimeo, Federal Reserve Bank.

Brayton, F., T. Laubach, and D. L. Reifschneider. 2014. "The FRB/US Model: A Tool for Macroeconomic Policy Analysis." FEDS Notes, Board of Governors of the Federal Reserve System, April 3.

Brayton, F., E. Mauskop, D. L. Reifschneider, and P. Tinsley. 1997. "The Role of Expectations in the FRB/US Macroeconomic Model." *Federal Reserve Bulletin* 83 (April): 227–45.

Brayton, F., and P. Tinsley. 1996. "A Guide to FRB/US: A Macroeconomic Model of the United States." Finance and Economics Discussion Series No. 96-42, Board of Governors of the Federal Reserve System.

Christoffel, K., F. Mazelis, C. Montes-Galdón, and T. Müller. 2022. "Disciplining Expectations and the Forward Guidance Puzzle." *Journal of Economic Dynamics and Control* 137 (C): 104336.

Chung, H., J.-P. Laforte, D. L. Reifschneider, and J. C. Williams. 2012. "Have We Underestimated the Likelihood and Severity of Zero Lower Bound Events?" *Journal of Money, Credit and Banking* 44 (s1): 47–82.

Cochrane, J. H. 2017. "The New-Keynesian Liquidity Trap." *Journal of Monetary Economics* 92: 47–63.

Darracq Pariès, M., A. Kornprobst, and R. Priftis. 2024. "Monetary Policy Strategies to Navigate Post-Pandemic Inflation: An Assessment Using the ECB's New Area-Wide Model." Working Paper No. 2935, European Central Bank.

Fuller, R., and C.-C. Hsia. 1984. "A Simplified Common Stock Valuation Model." *Financial Analysts Journal* 40 (5), September: 49–56.

Kennan, J. 1979. "The Estimation of Partial Adjustment Models with Rational Expectations." *Econometrica* 47 (6): 1441–55.

Kiley, M., and J. Roberts. 2017. "Monetary Policy in a Low Interest Rate World." *Brookings Papers on Economic Activity* 48 (Spring): 317–72.

Laubach, T., and D. L. Reifschneider. 2003. "Household Consumption and Investment in the FRB/US Model." Mimeo, Board of Governors of the Federal Reserve System.

Maliar, L., and J. B. Taylor. 2024. "Odyssean Forward Guidance in Normal Times." *Journal of Economic Dynamics and Control* 165 (August): 104877.

Reifschneider, D. L., and J. M. Roberts. 2006. "Expectations Formation and the Effectiveness of Strategies for Limiting the Consequences of the Zero Bound." *Journal of the Japanese and International Economies* 20 (3): 314–37.

Reifschneider, D. L., and J. C. Williams. 2000. "Three Lessons for Monetary Policy in a Low-Inflation Era." *Journal of Money, Credit and Banking* 32 (4): 936–66.

Rotemberg, J. J. 1982. "Monopolistic Price Adjustment and Aggregate Output." *Review of Economic Studies* 49 (4): 517–31.

Schmitt-Grohé, S., and M. Uribe. 2012. "What's News in Business Cycles." *Econometrica* 80 (6): 2733–64.

Slobodyan, S., and R. Wouters. 2012. "Learning in an Estimated Medium-Scale DSGE Model." *Journal of Economic Dynamics and Control* 36 (1): 26–46.

Tetlow, R. J. 2022. "How Large is the Output Cost of Disinflation?" Finance and Economics Discussion Series No. 2022-079, Board of Governors of the Federal Reserve System.

Tinsley, P. A. 2002. "Rational Error Correction." *Computational Economics* 19: 197–225.

Warne, A. 2023. "DSGE Model Forecasting: Rational Expectations vs. Adaptive Learning." Working Paper No. 2768, European Central Bank.

Woodford, M. 2001. "Fiscal Requirements for Price Stability." *Journal of Money, Credit and Banking* 33 (3): 669–728.