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ECB-(RE)BASE: Heterogeneity in expectation formation and macroeconomic dynamics

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Abstract

This paper introduces ECB-(RE)BASE as the model-consistent, or rational expectation version of the ECB-BASE model. It brings new analytical capabilities to consider varying degrees of heterogeneity in expectation formation across the agents of the model. While the original version of ECB-BASE features VAR-based expectations, we examine two alternative versions either with full model-consistent expectations or with hybrid expectations. The paper provides a didactic exposition of the changes in the model properties brought by the various expectation settings. Furthermore, we conduct illustrative scenarios around the macroeconomic shocks experienced over the recent years. The simulations notably suggest that moving from VAR-based to model-consistent expectations would limit the pandemic-induced macroeconomic volatility but would exacerbate the price pressures during the inflation surge period. Overall, this model development extends the range of possibilities for risk and policy analysis which can enhance the contribution of ECB-(RE)BASE to monetary policy preparation.

Keywords: *Semi-structural model, model-consistent expectations, euro area, monetary policy*
JEL classification: C3, C5, E1, E2, E5

Non-technical summary

This is part of a series of papers that document key features around the ECB-BASE project as the main euro area semi-structural macroeconomic model developed for forecasting and policy analysis at the ECB. We introduce ECB-(RE)BASE as the model-consistent, rational expectation version of the main model. Semi-structural models are well suited for economic forecasting due to their rigorous foundation in empirical relationships. The role of expectations is very important in these models. Expectation formation that are based on backward- and contemporaneous information (VAR-based expectations) lead to better forecasting performance, making semi-structural models a popular tool at central banks. Yet, there is value in exploring also other expectation formation approaches such as rational expectations which is the prevailing paradigm behind much of the academic structural modelling literature and which allows to analyze permanent policy shifts and anticipation effects. In this sense, ECB-(RE)BASE can provide an important analytical capability during inputs to monetary policy preparations. Furthermore, the design and solution methods employed for ECB-(RE)BASE enables a 'partialisation' of individual economic sectors (model blocks) and therefore permits the simultaneous usage of different types of expectations. This is then called 'hybrid expectations'.

ECB-(RE)BASE has the same structure as ECB-BASE with a rich description of economic interactions making the model fit for policy and scenario analysis. The model is open economy, has a supply-side description, a detailed expenditure component breakdown, builds on a New Keynesian price-wage-output gap core implying price and wage rigidities, has a reduced-form financing cost description, and allows for monetary and fiscal policy channels.

We describe the role of expectations in this model and document the differences that underlie the model-consistent expectation version as opposed to the VAR-based expectation version. Central to the framework is the Polynomial Adjustment Costs (PAC) approach that determines the gradual transition of economic variables to their theory-implied targets that prevail in the long-run. Importantly, The adjustment dynamics depend on expectations about the target growth rates. Beyond that, expectations are also important in determining the financing conditions of firms and households, the asset valuations, and the exchange rate. Price and wage setting is based on Phillips curve relationships with a role for expectations. Finally, aggregate consumption decisions are determined via households' perception about their full life-time income streams.

We document the economic dynamics under different expectation settings for the main shocks of the model. In general, there is no obvious one-directional change when switching from backward-looking expectations to forward-looking expectations in the same model. We find that forward expectations imply dampening but also front-loading dynamics compared to backward settings. For example, full model-consistent expectations tends to result in a cyclical smoothing of consumption, because households anticipate the future income stream without error. But macroeconomic features can also be amplified, in particular in the price and wage setting where forward expectations imply a different sensitivity to economic slack.

An example is the propagation of an unexpected monetary policy shock, for which we do not find amplification effects in the model-consistent expectation setting but rather find dampening forces to dominate. Indeed, when comparing to the benchmark VAR expectations, it is important to recall that VARs may be thought off as a simplified, yet 'sufficient statistics' representation of the full model. In addition, different to other models in the literature, ECB-(RE)BASE does not feature an explicit and overly powerful real-interest rate channel and therefore does not suffer from a forward guidance puzzle.

Finally, we show that considering forward expectations allows for anticipation of shocks that only materialize in the future (news shocks). This is particularly important as it enables us to investigate alternative transition dynamics after policy announcements and creates a new analytical capability of the model.

Lastly, we illustrate the repercussions of different expectation settings for the macroeconomic dynamics by putting the model into practice. We show that a more forward-looking interpretation of the COVID-19 pandemic shocks leads to less severe production and consumption deterioration because individuals 'look through' the income implications of the lock-downs, which are understood to be temporary. Inter-playing with supply restrictions during that phase, model-consistent expectations would see more upward inflation pressures than under backward expectations. We also evaluate the recent phase of strongly increasing energy and consumer prices. More forward expectations would see a faster price transmission and a more severe loss in real income and hence a stronger decline in consumption. Compared to backward-looking expectations, forward settings lead to a more severe nominal-side response to the same markup shocks and therefore would also imply a stronger response of endogenous monetary policy.

1 Introduction

This paper introduces ECB-(RE)BASE as the model-consistent, or rational, expectation (MCE or RE) version of the ECB-BASE model, the semi-structural macroeconomic model for the euro area developed at the ECB. ECB-BASE was introduced by Angelini et al. (2019) and is used to inform monetary policy preparation by contributing to the economic projections, the associated risk and scenario analysis, as well as quantitative policy evaluation. The semi-structural models around ECB-BASE/MC and ECB-(RE)BASE form the core of a macro-econometric portfolio for these purposes with different strengths and focuses. They strike a balance between theoretical structure and sound empirical underpinning. Expectation formation plays a major role for the macroeconomic propagation in this class of models. The introduction of ECB-(RE)BASE closes a gap in that it enables policy analysis in the semi-structural model world under forward-looking expectations and associated anticipation effects, for which otherwise mainly the DSGE class of models is known for (see Ciccarelli et al. (2024)).

Angelini et al. (2019) estimated and presented key features of ECB-BASE where agents expectations about the future are formed through econometric predictions using contemporaneous and past information. This paper, in turn, analyses how the introduction of model-consistent, or rational, expectations in BASE would alter the macroeconomic properties of the model. It then assesses the role of alternative expectations settings by evaluating the macroeconomic dynamics during the pandemic and inflation surge periods through the lens of this model.

Overall, the ECB-(RE)BASE project brings new analytical capabilities to consider varying degrees of heterogeneity in expectation formation across the agents of the model. While the original BASE specification and the fully model-consistent expectations of (RE)BASE are providing useful benchmarks, hybrid settings might prove relevant as well. This model development opens up for a new range of risk and policy analysis which can enhance the contribution of (RE)BASE to monetary policy preparation. At this stage however, we focus the paper on a didactic exposition of changes brought by the various expectations settings, taking the deep parameters of the model as in the original estimated BASE version. We leave for further research the associated empirical validation of (RE)BASE under alternative expectations modalities.

ECB-(RE)BASE is part of the semi-structural model family at the ECB that is centered around the euro area blueprint model ECB-BASE and ECB-MC as the multi-country version thereof. ECB-BASE/MC boosts a user-friendly infrastructure where the models can be run under different modalities and proves to be conceptually flexible to incorporate new features. This flexibility is exemplified in the model spin-off ECB-BASIR (see Angelini et al. (2023)) which incorporated a pandemic-macro module and allowed to analyze policies during the COVID-19 pandemic. Against this context, the ECB-(RE)BASE project as well benefited from the contributions of a larger team that constantly advances the semi-structural modeling framework at the ECB. This paper now focuses on the expectation formation aspect and therefore discusses only the relevant parts that are necessary to understand the macroeconomic propagation and we document relevant changes necessary for solving the model, but the reader is referred to Angelini et al. (2019) for a full description of the large-scale model.

ECB-BASE as a semi-structural model is estimated equation-by-equation while expectations are formed on the basis of forecasts from Vector-Autoregressions (VAR). The VAR structure implies that economic agents update their believes about the future on the basis of current and past states. The VAR is a reduced-form view on the full economic environment and can therefore be considered a version of limited (or restricted) information as agents make 'mistakes' in comparison to what the model economy's relationships imply for the future Massaro (2013). Expectations are not adaptive, which would require continuously re-estimating the VAR model based on the observed forecast errors. In the literature, adaptive learning has been shown to provide a better fit to the data and is therefore considered suitable for forecasting purposes (Slobodyan and Wouters (2012), Warne (2023)). This line of research is left for the future. The model's wage-inflation-production-output core module, in turn, is estimated as a system under rational expectations. This module in itself is an estimated small open-economy New Keynesian DSGE model of the euro area, with prices and wages modeled with Phillips curves and aggregate demand modeled with a dynamic IS curve. Inherently, ECB-BASE is therefore a model economy with a combination of expectation modalities. Indeed, the conceptual flexibility of semi-structural models allows for multiple expectation formations to prevail at the same time: under hybrid expectations, part of the model economy can be backward-looking while another part of the economy can form model-consistent forward expectations. This is an important advantage as it allows to analyze the consequences of different economic sectors being backward or forward-looking.

This paper relates to the literature on different expectation formation and here in particular on the setting in semi-structural models. The main reference is the FRB/US model (Brayton and Tinsley (1996), Brayton et al. (1997)) which served as inspiration in the development of ECB-BASE and explicitly distinguished between VAR expectations and rational expectations. FED staff occasionally compared the impulse responses the model produces under different expectation settings. Brayton et al. (2014) shows that VAR-based expectations can imply high inertia that differs from the inertia implied by the Taylor rule. In this case, the MCE imply a softer price response to a monetary policy rate shock than under VAR expectations.

FRB/US simulations with an emphasis on the role of expectations have been used for monetary policy analysis in particular (e.g. Reifschneider and Williams (2000), Chung et al. (2012) among others). Kiley and Roberts (2017) assessed the frequency and potential costs of Lower Bound incidences. They show that clear commitment strategies by the central bank to keep the interest rate lower until the inflation objective is reached in the future are very effective under MCE in the FRB/US model. Bernanke et al. (2019) show that MCE can achieve a lower output volatility than hybrid expectations when there is a possibility of hitting the Lower Bound, because the public's expectations on the future inflation anchor help lift the economy out of the constraint. Tetlow (2022) uses the FRB/US to assess the cost of disinflation. Consistent with the argument above, he shows that a persistent reduction in inflation can be achieved under MCE via a credible announcement of shifting the inflation anchor without causing a decline in demand. VAR expectations on the other side necessitate a stronger Taylor rule adjustment and therefore cause a more painful decline in demand to achieve the same end.

The contributions of our paper are the following. First, we document the technical approach of model-consistent expectations in ECB-(RE)BASE. Second, we show the implications of changing expectations from a backward formation to a forward-looking expectations approach for the main shocks. Third, we show-case the role of anticipation effects in the model-consistent expectations environment. Fourth, we apply the model to a scenario analysis around the macroeconomic shocks experienced over the recent years. We find that macroeconomic transmission can be dampened or amplified in the model-consistent expectations setting. Dampening tends to stem from ”looking-through” the implications of cyclical shocks for the expected lifetime income. Amplification tends to stem from front-loading of price and wage adjustments. Therefore, in these scenarios, forwarding-looking expectations contain the pandemic-induced macroeconomic volatility but exacerbate the price pressures during the inflation surge period.

The paper is structured as follows. Section 2 describes the role of expectations in ECB-(RE)BASE and describes the relevant parts of the model. Section 3 discusses the impulse responses for main shock families comparing across expectation modalities. Section 4 views a pandemic and inflation shock through the lens of this model's expectation settings. Finally, section 5 concludes.

2 ECB-(RE)BASE

This section spells out the modifications to the original ECB-BASE model in order to transform it to a forward expectation ECB-(RE)BASE model. We highlight the model blocks where expectations can be switched from backward VAR-based to MCE. Finally, the section explains the computational solution strategy.

2.1 Modified financial block equations for ECB-(RE)BASE

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 as well as equities/stocks. The policy maker is assumed to steer the values of short-term maturity bonds by setting a nominal interest rate according to the Taylor rule, as in ECB-BASE.

The long-term interest rate in ECB-(RE)BASE is a 10-year benchmark government bond yield. For the sake of computational efficiency, we aim to model the term premium on a bond with a duration of 10 years. Computationally, it is convenient to use infinitely lived console-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 console. 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.[1]

Given that the model is solved under perfect foresight, the term-premium in the bond pricing equations is introduced in a reduced-form way. To price the long-term bond, agents discount expected future coupon payments, adding a premium tp_{t+1} to the one-period-ahead pricing kernel. The bond price Q^{10Y} is given by the following recursive forward form:

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

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 Macauly duration of 40 quarters.

The long-term interest rate i^{10Y} is then defined as the compounded yield to maturity on the console:

$$i_t^{10Y} = c/Q_t^{10Y} + \rho - 1 \tag{2}$$

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

$$r_t^{10Y} = \frac{c + \rho Q_t^{10Y}}{Q_{t-1}^{10Y}} - 1 \tag{3}$$

Next, we derive the term premium tp_t^{10Y} as the difference between the 10-year bond yield and a risk neutral equivalent, i_t^{E10Y}:

$$tp_t^{10Y} = i_t^{10Y} - i_t^{E10Y} \tag{4}$$

To construct the risk neutral rate, we consider a hypothetical bond priced Q^{E10Y}, with the same console features as the bond priced Q^{10Y}, but for which the one-period-ahead pricing kernel is $1/(1+i_t)$. The bond pricing equation then becomes:

$$Q_t^{E10Y} = \frac{c}{(1+i_t)} + \rho \mathbb{E}_t \left[\frac{Q_{t+1}^{E10Y}}{(1+i_t)} \right] \tag{5}$$

The corresponding compounded yield-to-maturity on this console is then defined as:

$$i_t^{E10Y} = c/Q_t^{E10Y} + \rho - 1 \tag{6}$$

As in the original version of ECB-BASE, the term premium tp_t^{10Y} embeds an estimated counter-cyclical factor, notably related to VAR-expectations on the output gap. This endogenous term is kept across all expectations settings (except if stated otherwise).

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

A similar modeling strategy is adopted for corporate bonds.

2.1.2 Equity prices

The modeling of equity prices rests on the Dividend Discount Model. The equity price P^{EQ} is then equal the present value of expected future dividend cash flows that are discounted with an appropriate risk factor.[2]

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

where D are dividend payments and c_S is a normalizing constant. Cost of equity i^{COE} is constructed as $i_t^{COE} = i_t + s_t^{COE}$, with the equity premium s^{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 D to share-holders 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 encompass rational expectations on future dividend growth. c_S is calibrated to target a baseline dividend yield of 2.85%, consistent with the historical average of the MSCI Dividend Yield indicator.

Finally, net financial assets FW held by households 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.[3] The no-arbitrage condition is

[2] 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 g^{LT} phase that lasts forever. Future growth of dividends is projected based on either exogenous information or they can follow rules that rely on information from the past. Keeping otherwise the notation of the main text, the backward-looking equity price can be written as $P_t^{EQ} = \frac{c_S D_t}{i_t^{COE} - g_t^{LT}} \left(1 + g_t^{LT} + H(g_t^{ST} - g_t^{LT})\right)$.

[3] In the original model, the nominal exchange rate is government by an empirical relationship that tracks the price and long-term rate differential between the euro area and foreign market.

that the rate of return on domestic short-term 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:

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

where s 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 and i^F are the short-term nominal interest rates in the domestic and foreign markets respectively. In all applications that follow, foreign markets are assumed to be exogenous and therefore do not transmit feedback via exchange rate effects to the euro area economy. Any exchange rate response is triggered by domestic interest rate changes.

2.2 MCE in WAPRO and consumption-income nexus

2.2.1 WAPRO

Just as in the ECB-BASE model, the core price properties of ECB-(RE)BASE are governed by the Wage-Price-Output gap (WAPRO) block, which in turn is based on an auxiliary reduced form New Keynesian model that has been estimated under rational expectations (see appendix B.4 in Angelini et al. (2019)). It is therefore straightforward to consider model-consistent expectations in the price and wage formation processes.

At the heart of WAPRO are the price and wage Phillips curves. Compared to the original ECB-BASE, the goods price curve has been augmented with a role for the energy price deflator. For later applications of the model, we use the oil price shock as the main inflation push shock. This modification is intended to capture, indirectly and in a reduced-form, the importance of energy imports in the production and therefore the pricing of output goods. The augmented goods price curve is

$$\begin{aligned}
\pi_t = \frac{1}{1 + \beta_\pi\delta_\pi + \beta_\pi\varphi_\pi + \delta_\pi\varphi_\pi - \beta_\pi\delta_\pi\varphi_\pi} & \{(1-\delta_\pi)(1-\beta_\pi)(1-\varphi_\pi)\overline{\pi}_t \\
& + \beta_\pi \mathbb{E}_t \pi_{t+1} + \delta_\pi \pi_{t-1} \\
& + \beta_{\hat{y}}^{\pi}(\hat{w}_t + (\frac{\alpha}{1-\alpha})\hat{y}_t) \\
& + \varphi_\pi \frac{1}{p}\sum_{k=0}^{p} \pi_{t-k}^{MED}\} + \epsilon_t^\pi
\end{aligned}$$

where π is goods price inflation (GDP deflator growth), $\overline{\pi}$ is the long-term inflation target, π^{MED} is growth of the energy import deflator. The wage gap $\hat{w}$ and the output gap $\hat{y}$ evolve as in ECB-BASE. All Phillips curve parameters are kept as in the original estimation. The coefficient φ_π and the lag structure with lag number p have been calibrated (in the backward model) to trace an energy shock pass-through to euro area inflation as observed in the recent energy crisis. The

Phillips curve further features medium-term inflation expectations which are gradually updated on the basis of past inflation information, but pin-down the long-term anchor of the inflation process to the steady-state inflation target. The medium-term inflation expectations remain imperfectly anchored throughout all expectation modalities in the remainder of the paper:

$$\overline{\pi}_t = \rho\overline{\pi}_{t-1} + (1-\rho)[\omega\pi_{t-1} + (1-\omega)\overline{\pi}] + \epsilon_t^{\pi^e} \tag{11}$$

where $\overline{\pi}$ is the central bank inflation target. The parameter ρ has been re-calibrated to match a low pass-through of past inflation into the medium-term expectations as has been observed before the recent energy crisis.

The wage Phillips curve is not reformulated for this paper and therefore is not restated here. Similar to the goods price case, the one-period-ahead expectation of nominal wage inflation $\mathbb{E}_t W_{t+1}$ enters the equation.

MCE: Under model-consistent expectations, the one-period-ahead expectation of inflation $\mathbb{E}_t\pi_{t+1}$, and wages $\mathbb{E}_t W_{t+1}$, are evaluated as a rational expectation forward term.

VAR-based expectations: In the backward-mode of ECB-BASE, $\mathbb{E}_t\pi_{t+1}$ and $\mathbb{E}_t W_{t+1}$ are replaced with forecasts from a VAR containing the respective variables. Let z_t be a $n \times 1$ vector of variables useful for predicting inflation or wages. We define an auxiliary model, that will only be used to build the forecasts, for this vector:

$$\Delta z_t = \Lambda_0(z_{t-1} - z^*_{t-1}) + \sum_{k=1}^{K} \Lambda_k \Delta z_{t-k} + \varepsilon_t \tag{12}$$

where $z^\star_t = z^\star_{t-1} + \eta_t$ is the long run target of z_t. This model can be equivalently written as a VAR(K+1) model in levels:

$$\check{z}_t = \sum_{i=1}^{K+1} B_i \check{z}_{t-i} + \zeta_t$$

where $\check{z}_t = (z'_t, z^{\star\prime}_t)'$, $\zeta_t = (\varepsilon'_t, \eta'_t)'$,

$$B_1 = \begin{pmatrix} I_n + \Lambda_0 + \Lambda_1 & -\Lambda_0 \\ O_n & I_n \end{pmatrix}$$

$$B_i = \begin{pmatrix} \Lambda_i - \Lambda_{i-1} & O_n \\ O_n & O_n \end{pmatrix}$$

for $i = 2, \ldots, K$, and

$$B_{K+1} = \begin{pmatrix} -\Lambda_K & O_n \\ O_n & O_n \end{pmatrix}$$

Once the level model has been constructed, it can be transformed into a VAR(1) model:

$$x_t = Hx_{t-1} + \epsilon_t$$

where $x_t = (\breve{z}'_t, \ldots, \breve{z}'_{t-K})'$ and $\epsilon_t = (\zeta'_t, 0, \ldots, 0)'$ are $(K+1)n \times 1$ vectors, and H is a $(K+1)n \times (K+1)n$ matrix (the so called companion matrix). The one step ahead (VAR based) forecasts are obtained from this representation. Suppose we need to forecast inflation. Let ι be a selection (row) vector such that $\pi_t = \iota x_t$ (obviously, inflation has to be a variable in the VAR model). Then for a VAR based forecast we will replace $\mathbb{E}_t[\pi_{t+1}]$ in the Phillips curve with $\iota H x_t$, where the variables x_t are determined system-wide (not from the VAR which is solely used to define the companion matrix H).

2.2.2 Consumption and permanent incomes

Private households are important forward-looking actors in the model economy. The long-term consumption target 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 a more detailed derivation.

The permanent income construct is used in ECB-(RE)BASE to derive target consumption. The empirical specification of the target consumption equation that has been estimated in the original model is:

$$\log C^*_t = \eta_0 + \eta_T \log {EY_t}^T + \eta_P \log {EY_t}^P + \eta_D \log {W_t}^D + (1 - \eta_T - \eta_P - \eta_D) \log EY^L_t \tag{13}$$

where ${EY_t}^i$ denotes the permanent income type $i \in \{T = transfer, P = propery, L = labour\}$, ${W_t}^D$ denotes observed financial and housing wealth and η_i stands for propensities to consume out of income type i.[4] More formally, the expected present discounted value of future incomes can be written as

$$\widehat{W}_t^{\,j} = \mathbb{E}_t \sum_{k=0}^{\infty} (1 + r + \phi_0)^{-k} Y^j_{t+k} \tag{14}$$

where j beside T, P, L also represents total aggregate income. Expected permanent income EY can then be defined as

$$EY^j_t = (1 - \breve{\beta})\widehat{W}_t^{\,j} \tag{15}$$

with $\breve{\beta}$ representing the discount factor and equals to $(1+g)/(1+r+\phi_0)$, r is the real interest rate, ϕ_0 is a risk-adjustment factor, and g is the growth rate of potential output $\bar{X}_t$. As can be seen from (15) we need to determine the expected values of the future income types as well as

[4] It is important to point out two things. First we assume that $\eta_T + \eta_P + \eta_D + \eta_L = 1$. Second, 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 presented discounted value of its future streams.

of the aggregate income.

MCE: Under model-consistent expectations, the expected permanent income of type j can be re-written in recursive form:

$$EY_t^j = (1 - \breve{\beta})Y_t^j + \breve{\beta}\mathbb{E}_t(EY_{t+1}^j) \tag{16}$$

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

VAR-based expectations: In the backward mode of ECB-BASE, the infinite sums of present value incomes are formed using (extended) VARs as described in the previous section. To illustrate the basic mechanism behind the use of VARs let us define the income-to-GDP ratio $\theta_t = Y_t/X_t$, which allows us to decompose total income Y_{t+k} into a function of the gap and trend components of θ_t and output as follows:

$$Y_{t+k} = \overline{\theta}_{t+k}\overline{X}_{t+k}(1+g)^k(1+\widetilde{\theta}_{t+k})(1+\widetilde{X}_{t+k}) \tag{17}$$

where $\bar{\theta}_t$ is the trend income-to-GDP ratio and $\tilde{\theta}_t = \theta_t/\bar{\theta}_t - 1$ is its deviation from trend, $\tilde{X}_t$ denotes the output gap. After some algebraic manipulations, we can write a log-linear expression for the present value of total income $\widehat{W}_t$ as

$$\log \widehat{W}_t \approx \log\left(\frac{\overline{\theta}_t\overline{X}_t}{1-\breve{\beta}}\right) + (1-\breve{\beta})\mathbb{E}_t\sum_{k=0}^{\infty}\breve{\beta}^k(\widetilde{\theta}_{t+k} + \widetilde{X}_{t+k}) \tag{18}$$

which implies that

$$EY_t = (1-\breve{\beta})\widehat{W}_t = \overline{\theta}_t\overline{X}_t \exp\Big((1-\breve{\beta})\mathbb{E}_t\sum_{k=0}^{\infty}\breve{\beta}^k(\widetilde{\theta}_{t+k}+\widetilde{X}_{t+k})\Big) \tag{19}$$

The decomposition for each income type i can be derived by controlling for the respective share of type i income in total income, which is denoted by θ_t^i. The expected permanent income for each type i is

$$EY_t^i = (1-\breve{\beta})\widehat{W}_t = \overline{\theta}_t\overline{\theta}_t^i\overline{X}_t \exp\Big((1-\breve{\beta})\mathbb{E}_t\sum_{k=0}^{\infty}\breve{\beta}^k(\widetilde{\theta}_{t+k}+\widetilde{\theta}_{t+k}^i+\widetilde{X}_{t+k})\Big) \tag{20}$$

Based on (19) and (20) it is easy to identify the object that have to be included in the VARs in order to be able to calculate permanent incomes. In the previous example, it boils down to the need to forecast both $\widetilde{\theta}_{t+k}$, $\widetilde{\theta}_{t+k}^i$ and $\widetilde{X}_{t+k}$ $\forall i = k, \ldots.., \infty$. Combining the above with the VAR exposition from the previous subsection we can rewrite (20) as

$$\log EY_t^i = \log(1-\breve{\beta})\widehat{W}_t^i = \log\left(\overline{\theta}_t\overline{\theta}_t^i\overline{X}_t\right) + (1-\breve{\beta})(\iota_{\widetilde{\theta}} + \iota_{\widetilde{\theta}^i} + \iota_{\widetilde{X}^i})(I - \breve{\beta}H)^{-1}x_t \tag{21}$$

with $\overline{\theta}_t^i$ and $\iota_{\widetilde{\theta}^i}$ being absent from the equation in the case of aggregate total income.

2.3 Expectations in PAC equations

An essential feature of the ECB-BASE model is the significant role played by expectations in the adjustment process of main macroeconomic variables. In this class of models, the sluggish adjustment of variables to a theory-implied target are modeled through the Polynomial Adjustment Costs (PAC) approach[5]. The benefit of it is that the long-term anchors of the model are consistent with economic theory, but the transition to the target includes inertia effects via a lag structure as well as a role for expectations through forward terms.

Because in ECB-BASE, main macroeconomic interactions feature the PAC property, expectations appear in many parts of the model (see Table 1 for an overview). For instance, theory suggests that consumption depends (log-)linearly on permanent incomes ($\log C^{\star}$ in the previous section is the theory-implied consumption target). However, when the model is applied to the data, there is a discrepancy between observed and theoretical consumption levels and its dynamics. The inter-temporal (forward-looking) optimization by agents that determines the transition is modeled via the PAC approach[6].

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 agents seek to minimize a cost function, denoted by Θ_t, with respect to the variable of interest y_t, while taking the target $y_t^{\star}$ as given[7]. This cost function is designed to penalize both deviations between the actual value of the variable, y_t, and the target value, $y_t^{\star}$, as well as changes in the variable itself:

$$\Theta_t = \mathbb{E}_{t-1} \sum_{i=0}^{\infty} \beta^i \left[(y_{t+i} - y_{t+i}^{\star})^2 + \sum_{k=1}^{m} b_k \left((1-L)^k y_{t+i} \right)^2 \right] \tag{22}$$

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 $t-1$.[8] The decision rule derived from the

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

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

[7]The optimization problem bears resemblance to that of an HP filter, yet the instrument employed is distinct.

[8]Notice that when considering 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 vs current information when forming expectations in the PAC based model blocks might be somewhat inconsistent, there is no clear cut arguments promoting either. By the fact that all right hand side variables of (22) and subsequently of (23) are formed based on the same filtration, inconsistency is not present (Laubach and Reifschneider (2003).

minimization of Θ_t is as follows:

$$\Delta y_t = a_0(y^*_{t-1} - y_{t-1}) + \sum_{k=1}^{m-1} a_k \Delta y_{t-k} + \mathbb{E}_{t-1} \sum_{j=0}^{\infty} d_j \Delta y^*_{t+j} \tag{23}$$

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 non-stationary 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.

VAR-based expectations:

The expected target variable appearing in the last term of (23) can be constructed by postulating a non-structural VAR, as described in sections 2.2.1 and 2.2.2. Suppose that ι is a selection row vector such that $y^\star_t = \iota x_t$. Then the VAR based expectation of $\Delta y^\star_{t+i}$ is:

$$\mathbb{E}_{t-1} \Delta y^*_{t+i} = \iota H^{i+1} x_{t-1}, \tag{24}$$

Defining:

$$Z_t = \mathbb{E}_{t-1} \sum_{j=0}^{\infty} d_j \Delta y^*_{t+i} \tag{25}$$

and substituting (24) into (25), we can express the expectations of the infinite sum as

$$Z_t = \sum_{j=0}^{\infty} d_j \iota H^{i+1} x_{t-1} = h' x_{t-1} \tag{26}$$

where coefficient vector h' is a non-linear function of VAR matrix H, discount factor β and a_k coefficients.

The sole purpose of the VAR model is to determine the linear combination h' of the restricted endogenous variable set z_{t-1}. Given the constructed term Z_t, the PAC equation can be estimated. Note that this is done separately by model block, in an equation-by-equation manner. No information-feedback from other model blocks enters the expectations formed by individuals at this stage.

When simulating the full model in general equilibrium, the target variables are determined system-wide. 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. Therefore, using the full model, any simulated values of targets, or other endogenous variables in z_{t-1}, do not need to correspond exactly to those implied by forecasts from the VAR (i.e. the term Z_t). In certain applications, such as the analysis of permanent policy change effects, this may result in persistent expectation errors (see, for example, Brayton et al. (2000)).

MCE:

When simulating under MCE, the expected path of the target variable can be directly inferred from the system-wide solution of the model. The forecasts of the target variable then come from rational expectations instead of being a linear combination from lagged information as in the restricted VAR case. The MCE simulations are conducted keeping the PAC coefficients, which have been estimated under the VAR expectation assumption, unchanged.

Specifically, the solution approach requires to rewrite the infinite sum in (25) 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[9]. After some algebraic manipulations one can derive the MCE representation of the PAC expectation term:

$$Z_t = -\sum_{i=1}^{m} \alpha_i \beta^i Z_{t+i} + a_0 \left(\Delta y_t^* - \sum_{k=1}^{m-1} \sum_{j=k}^{m-1} \alpha_{j+1} \beta^{j+1} \Delta y_{t+k}^\star \right) \tag{27}$$

Note that in this PAC setup, the expectation formation mechanism is fully equation specific. This means that the model can be simulated solely under VAR expectations formation, under full MCE or in a so called 'hybrid' mode where some selected equations consider MCE setup while others are still running under VAR expectations.

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 backward auxiliary model used to form expectations, `var_model` and `trend_component_model`[10], 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[11]. 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 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.

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

[10] See the reference manual, Adjemian 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.

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

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 non-stationary variable, y^* in equation (23), 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[12]: the target is then a linear combination of non-stationary and stationary variables. The command `pac_model` defines the model for a PAC equation. For VAR-based expectations, as in equation (26), 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 (27). 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 $\mathbb{E}_{t-1}\sum_{j=0}^{\infty} d_j \Delta y^*_{t+j}$ in equation (23). Dynare replaces it with an auxiliary variable, whose definition can be either (26) or (27), 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).

The PAC equations are estimated under VAR-based forecasts. The estimation of the autoregressive parameters a_k ($k = 0, \dots, m$) is not obvious, since the vector h in equation (26) 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 Macroeconomic propagation across alternative expectations settings

This section discusses impulse response functions of the main shocks of the model. We start from the backward expectations mode of ECB-BASE and introduce model-consistent expectations in some of the blocks of ECB-(RE)BASE. This enables to investigate step by step how transmission properties change. We first focus on monetary policy shocks and show that many insights about the role of alternation expectations formation mechanisms would also hold for other shocks.

All simulations are conducted around a baseline. We first create the model's balanced-growth path (BGP) by running a sufficiently long simulation of the purely backward version of the model, ensuring that in the last periods the system settled at constant growth rates. The growth rates of stationary variables are then zero and the growth rates of the of non-stationary variables match the theoretical long-run growth rates. Key features of the BGP are shown

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

in appendix Table 3. The initial simulation periods, where the system did not settle yet, are discarded. Thereafter, any simulations can be run on top of the stable BGP.

3.1 Alternative expectations settings

To recap the role of expectations in the model, Table 1 gives an overview over all model blocks. There are 4 main settings: *(1)* the ECB-BASE backward-looking model where expectations are formed based on VAR forecasts (*VAR-based*), *(2)* a benchmark model where expectations are still largely backward, except that MCE is used in the financial block and the UIP (*Backward with financial and/or UIP MCE*), *(3)* the hybrid expectations setting where additionally also the wage and price setters form forward-looking rational expectations (*Hybrid MCE*) and *(4)* the full forward expectations setting where all agents are assumed to form expectations in a model-consistent way (*Full MCE*). The second Setting provides a backward-reference version as explained in greater details in the following analysis of the monetary policy shock.

Table 1: The role of expectations across model blocks

	ECB-BASE backward-looking				Backward with fin. and UIP MCE	Hybrid MCE	Full MCE
	No exp.	Backward rule	VAR	PAC-VAR			
Permanent income			×				✓
Household consumption				×			✓
Business investment				×			✓
Residential investment				×			✓
Government	×						
Foreign ROW	×						
Trade	×						
Exchange rate / UIP	×				✓	✓	✓
Production	×						
Employment				×			✓
Wages			×			✓	✓
Core deflator			×			✓	✓
LT-inflation anchor		×					
HICP and other deflators	×						
Monetary policy rule	×						
Long-term interest rates			×		✓	✓	✓
Financial spreads			×				
Equity prices		×			✓	✓	✓
Property and dividend income				×			✓
House prices				×			✓
Wealth	×						
Net foreign assets	×						
Accounting closure	×						

The distinction in expectation modalities is inspired by the FRB/US. Bernanke et al. (2019) for example use the model under a mixed expectation setting. In analyzing monetary policy rules and different targeting, they use a mixed setting where asset-market participants form model-consistent expectations. They argue that an expectation setting where only financial markets (and the exchange rate) are forward-looking, but other agents are not, serves as a realistic benchmark case given higher incentives in understanding monetary policy and more possibilities in this segment of the economy.

Apart from the expectation dimension, we can consider modalities regarding the exogeneity of certain model blocks. Semi-structural models can be solved by conditioning the simulation to the baseline information in some model blocks (or for some single variables). In a comparison relative to the baseline, those variables would then not respond. For example, we exogenize the nominal exchange rate and financial spreads in selected simulations in order to disentangle the role of expectations across different macroeconomic propagation mechanisms.

Furthermore, model-consistent expectations open up modalities regarding anticipation. As soon as an announcement of an exogenous shock hits the model economy, the solution of perfect foresight implies a full knowledge of the transition path of the economy.

Along those dimensions, we consider the following modalities:

- Unanticipated shocks at time $t = 1$, fully endogenous model
- Unanticipated shocks at time $t = 1$, exogenous exchange rate and exogenous term, corporate, lending and cost of equity spreads
- Anticipated shocks at time $t = 1 + j$, exogenous exchange rate and exogenous term, corporate, lending and cost of equity spreads

3.2 Monetary policy interventions

3.2.1 Short-term interest rate shocks

Figure 2 shows impulse response functions for a standard monetary policy shock, swapping expectations from the VAR-based version to the *Backward with UIP and financial MCE* versions. The economy reacts to an unanticipated shock to the monetary policy rule of the model, such that the short-term interest rate increases by 100bps on impact.

The pure backward model transmission is reported in the plain lines of Figure 2. Note that, even in this case, the monetary policy rate increase has expectational propagation channels: the short-term interest rate enters in the core VAR of ECB-BASE and therefore affects all VAR-based expectations. Accordingly, higher short-term interest rates diffuse through the yield curve since the risk-free long-term rate is a function of expected future short-term rates. Compounded with an endogenous increase in spreads, the shift in interest rates leads to an increase in household and firms' borrowing costs which in turn weight on consumption expenditures as well as business and residential investment. The decline in aggregate demand triggers downward pressures on nominal wages and prices via the Phillips-curve mechanism. Monetary policy tightening also leads to an exchange rate appreciation and the resulting loss in export market shares further compounds the contractionary effect on economic activity.

The dotted lines in Figure 2 display the responses under a forward-looking exchange rate adjustment instead of the estimated exchange rate equation of the pure backward version. The magnitude of the nominal exchange rate appreciation and its dynamic profile is significantly affected, thereby leading to different trade response. The dashed lines in this figure also swap the financial block (notably the long-term interest rate determination) into the model-consistent expectation mode. There is then a more abrupt repricing in the yield curve which unwinds gradually, as opposed to the hump-shaped response of the VAR-based expectations. The NFC cost of financing and also the borrowing costs for households would then increase less compared with the VAR-based expectations, which is reflected in the slightly dampened response of expenditures and GDP. Similarly, the immediate repricing of equities is of a different profile. The revaluation of nominal assets is altogether less negative and therefore weighs less on consumption decisions when compared with the VAR-based expectations case.

Overall, changing the expectations formation for exchange rate determination and the financial sector has noticeable effects on the associated dependent variables but more limited implications for aggregate output and domestic price transmission.

In the reminder of the paper, we take the *Backward with financial and UIP MCE* model setting as the reference against which we compare *Hybrid* and *Full MCE*. One may actually argue that it is reasonable to assume financial sector professionals to be more informed and forward-looking than other agents in the economy.

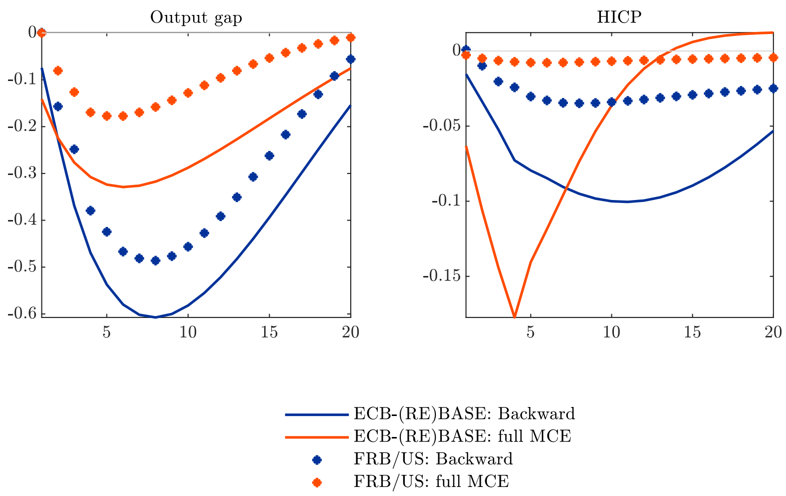
Figures 3 and 4 show responses to the monetary policy shock across expectations settings, first, for the fully endogenous model and, then, exogenizing the exchange rate and financial spreads. Moving to the hybrid expectation setting, wage and price setting becomes forward-looking. As a result, the adjustment of the GDP deflator is somewhat front-loaded. This front-loading does not come with an amplification. It turns out that the VAR-based expectations in the wage and price equations are broadly consistent with the propagation mechanism of unexpected shocks under model-consistent expectations. At the margin, the transmission with VAR-based expectations is somewhat stronger, and more hump-shaped. Otherwise, the real-side impacts are very similar, whether exchange rate is exogenous or not.

Turning to the comparison with the *Full MCE* expectations setting formation in permanent incomes and in PAC equations changes as well, the most striking differences arise from the way households perceive their life-time income, which proves crucial for the response of consumption expenditures. The agents' permanent income perceptions react much smoother than under VAR-based expectations. Households that are not liquidity constrained, look through the shorter term implications of the shock on their income streams. As a result, consumption behavior is smoothed out compared to the VAR-based expectations setting. Consequently, the negative effects of the monetary policy tightening on investment and economic activity is more muted. Note that the macroeconomic amplification triggered by the exchange rate appreciation and the endogeneity of financial spreads in Figure 3 partly masks the specificities of the *Full MCE* expectations setting. Abstracting from these two channels (in Figure 4) shows even more pronounced implications of "consumption smoothing" under *Full MCE*.

Overall, in the ECB-(RE)BASE model, model-consistent expectations do not amplify the impact of unexpected standard monetary policy shocks. More specifically, the permanent income smoothing under *Full MCE* generates the most significant difference: it implies a dampened consumption and output response compared to more backward expectations. This can be attributed to three broad factors. First and foremost, contrary to most DSGE model specifications, the consumption behavior is not based on an Euler equation where the real interest rate would directly steer the consumption-saving decision, but rather focuses on empirical relationships regarding the propensity to consume out of different sources of income and wealth. Second, the importance of asset price revaluations for private sector savings decisions are limited due to the existence of liquidity constrained consumers. Third, the backward-looking relationships do already feature a risk-adjustment factor as a stand-in for future income uncertainty and it is therefore a priori not clear if rational expectations would wash out or amplify the precautionary savings feature in the model.

This behavior of ECB-(RE)BASE is also found in the comparable class of central bank models. Figure 1 plots the effects from a monetary policy shock in comparison with the FRB/US model.[13] Model-consistent expectations, in both models, lead to a reduced response of output and respectively create a lower response of inflation.

Figure 1: Monetary policy shock (100bps)



Notes: Responses to an unanticipated increase in the short-term interest rate by 100bps. The horizontal axis shows time in quarters. The vertical axis depicts the output gap in p.p. deviation from the baseline and HICP inflation as p.p. deviation of the annual growth rate from the baseline value.

[13] Source of FRB/US simulation results: https://www.federalreserve.gov/econres/notes/feds-notes/overview-of-the-changes-to-the-frb-us-model-2018-20181207.html

We turn now to anticipated monetary policy shocks. Figure 5 shows the responses of the model economy across the various expectations settings to an increase in the short-term interest rate, five years ahead. For comparison, the figure also plots in shaded lines, the case of unanticipated shocks as in Figure 4. Because rational expectations are active in the financial block for all three expectations settings, the anticipated shock already creates adjustment during periods $t < 20$. The long-term interest rate reprices on announcement, leading to an increase in firms' and households' cost of borrowing. Investment and consumption, and hence GDP, start to decrease already prior to the actual hike in the policy rate. The value of nominal financial assets also declines immediately and further weighs on consumption. Under *Hybrid MCE*, price and wage adjustments occur faster during the anticipation phase. With *Full MCE*, the expectations on permanent income become much smoother, with a significant decrease during the anticipation phase before the shock occurs. This leads to consumption smoothing over the full cycle with a stronger decrease upfront but with a lower severity after the short-term interest rate actually did increase in $t = 20$.

Altogether, the anticipated shock generates less differences across expectations settings than in the case of unanticipated shocks. The *Full MCE* still displays more muted transmission but the peak effects get closer to the ones in other settings. Note that in the *Hybrid* or *Full MCE*, ECB-(RE)BASE is not subject to the forward guidance puzzle.

3.2.2 Central bank asset purchases

Beyond policy rate setting, unconventional monetary policy has become an integral part of central banks' toolkit, and in particular, asset purchases (denoted AP) which were extensively used since the Great Financial Crisis. The implementation modalities of such purchase programs usually involved the commitment to buy a flow of assets over a certain period of time, thereby triggering anticipation effects on the stock purchases. It is therefore particularly useful to analyze AP in forward expectations mode, even when employing a semi-structural model (Engen et al. (2015)).

In ECB-(RE)BASE, the effect of AP is modeled via its reduced-form impact tp^{AP} on the term premium of long-term interest rates. We consider a central bank intervention which mimics the ECB's initial purchase announcement following the January 2015 Governing Council. Long-term bond holdings gradually reached 10% of GDP after 2 years and followed a declining path due to hold-to-maturity redemptions thereafter. The impact of AP on the term premium is then calibrated to match the impact on the 10-year bond yield found in Eser et al. (2019). This calibration captures the degree of duration risk extraction in the bond market and the impact on the long-term interest rates.

Furthermore, we allow the AP to have an exchange rate channel by augmenting the UIP as follows:

$$i_t + \phi_{app} tp_t^{APP} = i_t^F + \mathbb{E}_t(s_{t+1} - s_t) \tag{28}$$

where ϕ_{app} is a scaling parameter that, in a reduced-form, captures global portfolio frictions on euro area bond holdings. This opens up for an exchange rate channel of AP. Our calibration of this parameter targets an exchange rate depreciation, conditional on a given yield response, that is equivalent to the analysis in Darracq Pariés and Papadopoulou (2020).

All in all, central bank asset purchases would trigger an easing of financing conditions (reminiscent of the portfolio re-balancing channel), an asset revaluation channel affecting household wealth and an exchange rate channel.

Figure 6 shows the effect of the AP shock. The figure again plots reactions across the expectations settings *Backward with financial and UIP MCE*, *Hybrid MCE* and *Full MCE*. Note that after the initial announcement, due to perfect foresight, agents immediately anticipate the full path of the envisaged purchases. As the financial block is forward-looking, the term premium wedge moves immediately and leads to a front-loaded adjustment of long-term interest rates. The short-term interest rate, following the Taylor rule, tightens in response to the expansionary shock, dampening somewhat the overall easing of financing conditions for firms and households.

Since the announcement of asset purchases implies an extended holding period of assets, the decline in the term premium and overall financing costs as well as the nominal exchange rate depreciation remains broadly constant over the simulation horizon, across all expectations settings. Therefore, the expansionary effect on output is long lasting. The real-side transmission of the AP mainly operates on investment and exports while consumption is depressed, albeit only marginally for the *Full MCE*. The expectations setting has indeed some significant implications for the behavior of households, notably regarding their permanent labor income. In the *Full MCE*, households anticipate a positive response of their labor income which otherwise turn negative in the other expectations settings. This translates into higher household expenditures and overall GDP, compared to the backward setting.

Turning to nominal allocation, in the *Hybrid MCE* setting, wage and price adjustments are more front-loaded but less persistent, compared to the VAR-based expectations. When considering the *Full MCE* setting, the effect of an AP announcement gets somewhat amplified rather than dampened as we have seen with the conventional monetary policy shock. With the more favorable assessment of the future outlook under *Full MCE*, agents are also more willing to increase their labor services and firms are ready to pay higher wages. The stronger demand stimulus leads to higher GDP deflator inflation than under the *Hybrid MCE* or the *Backward* expectations settings. The exchange rate channel of AP is an important determinant of consumer price inflation, and to some extent conceals the contribution of domestic sources of inflation stemming from excess demand. Under *Hybrid MCE*, this channel is somewhat stronger due to the more volatyle reaction of the short-term rate. The stronger easing stimulates investment and eventually GDP more than under the other settings.

Next, we also conduct an exercise that investigates the role of anticipation effects in the AP: the shock is an announcement at time $t = 1$ that asset purchases will start at $t = 20$, following thereafter the same design as in Figure 6. Figure 7 shows the responses of such an intervention while also reporting the impact of the AP with immediate start of purchases. At announcement, the term premium compression due to the AP is already anticipated before the actual purchases start. The immediate repricing of long-term bonds leads to lower cost of financing which spurs an increase in investment and GDP well ahead of the first purchases. Overall, the *stock effects* of AP dominate in the model: given that a considerable part of the financial transmission of the AP is already working during the pre-purchase phase, the difference in the macroeconomic impacts between immediate or delayed purchase paths are very limited. As before, the *Hybrid MCE* and *Full MCE* setting again creates a moderate amplified transmission compared to the other expectations settings.

3.3 Supply-side shocks

This section discusses the effect of supply shocks across our expectation settings. We consider two supply shocks of ECB-BASE. First, a productivity shock that shifts the ability of employees to produce more output per head (i.e. a labor augmenting technological shock). Second, an increase in the markup on imported energy prices which in the following is denoted as "oil price shock". The following exercises are conducted only with one simulation modality, namely with a fixed exchange rate and financial spreads.

Figure 8 shows the macroeconomic responses after an unanticipated shock to productivity, scaled such that potential GDP rises by 1% on impact. With higher potential, the output gap opens up significantly in the short run and triggers downward pressures on GDP deflator inflation via the Phillips-curve mechanism. Higher productivity leads to an increase in real wage claims which gradually adjust to this new target. The initial decline of the wage gap generates stronger wage claims despite weaker labor demand in the short run. On balance, household real income increases, thereby boosting consumption, production, and investment. As production grows, employment also catches up eventually, which further supports income and contributes to close the output and real wage gaps. Monetary policy accommodates the productivity shock transmission, with short-term interest rates below baseline over the simulation horizon. The consequential decline in borrowing costs facilitates the demand-side adjustments. The value of equity and housing assets increases as well and supports consumption out of wealth.

The *Hybrid MCE* setting leads to stronger nominal wages increase in the short run, than under VAR expectations. Domestic inflation declines slightly more in the first quarters but revert back to baseline more swiftly. The real side adjustment is broadly similar to the VAR-expectations case, except for a milder response on investment. This is partly due to a more moderate easing of monetary policy and overall financing conditions. With *Full MCE*, a striking difference with the other expectations settings concerns the employment response which displays a more pronounced and persistent initial downturn, reverting back to baseline thereafter. As a result, the expansion of permanent income is dampened, and the increase in consumption is smoother and more limited over the simulation horizon. Therefore, GDP also records a more moderate pick up than under the other expectations settings which leads to a longer lasting decline in inflation. The concomitant more persistent easing of financing conditions, counteract this result to some extent by giving more support to investment. Overall, under *Full MCE*, the labor market and relative price adjustments to the productivity shock are faster and the consumption response reflects a more efficient inter-temporal smoothing (notably regarding the permanent real labor income expectations) while under the other expectations modalities, consumption persistently overshoots its fundamentals.

Figure 9 shows the exercise for an anticipated productivity shock, announced at $t = 1$ but occurring at $t = 20$. As before, the financial features are forward-looking across all expectation settings such that the long-term bonds reprice already during the anticipation phase. The resulting lower financing costs, albeit by a small magnitude, help increase consumption and investment. Considering the *Hybrid MCE* expectations setting, the nominal wage growth implied by the anticipation of higher productivity gets front-loaded and amplified ahead of the shock materialization. But this does not translate into significant price increases during the anticipation phase, as the real-side adjustments remain marginal. With *Full MCE* however, income gains are fully anticipated before the shock hits, with permanent labor income gradually increasing over the simulation horizon. Consequently, consumption is smoothed over time and starts increasing right after the announcement. Excess demand builds up during the anticipation period which generates mild inflationary pressures thereby limiting the inflation undershooting later on, after the shock materializes.

We turn now to the second supply shock, the oil price shock. The responses are shown in Figure 10. This shock is an imported energy price shock with direct and indirect effects on consumer prices. The model transmission mechanism conceals limited second round effects through wage claims. Therefore, real income declines, dragging on consumption, investment and GDP. On balance, the Taylor rule prescribes a slight increase of interest rates. The resulting tightening of financing also weighs on investment reinforcing the negative implications of higher prices and the downturn.

When considering the *Hybrid MCE* setting, the effect of the price shock gets front-loaded and amplified, notably for the GDP deflator as well as nominal wages compared to the backward reference expectation setting: indirect effects of energy shocks are twice bigger in the short-run and keep inflation marginally higher through the end of the simulation horizon. The overall income perception is similar to the backward case resulting in comparable consumption expenditures. However, interest rates and financing costs are persistently higher than in the backward version which weight on investment and GDP. The *Full MCE* setting shares some of the nominal amplification features but displays more pronounced and lasting negative consequences for real permanent income and consumption therefore declines further.

Finally, Figure 11 presents the effect of an anticipated oil price shocks across expectations settings. When expectations are swapped to the *Hybrid MCE* setting, price and wage responses can react already before the actual shock occurs but limited action takes place during the anticipation phase. Given the stronger indirect effects and overall inflation responses, once the shock materializes, compared with the backward version, the yield curve and financing costs are repriced immediately higher, which drags right away on investment. Consumption response however is little affected, in total leading to a stronger decline in GDP compared to the backward version. Considering now the *Full MCE* setting, the responses are also amplified as in the unanticipated case but start to shift already earlier, in particular on the real side. The real income loss is anticipated in the permanent income evaluation. Households are then already reducing their consumption behavior in anticipation of the shock, leading some slight dis-inflationary pressures. Cumulative over the simulation horizon, the decline in consumption is twice larger than in the backward version. In the indirect and second round effects on inflation are more pronounced than in the backward version but slightly less than in the *Hybrid MCE* case. Overall the output-inflation trade-off stemming from the energy shock turns out to be quite exacerbated under the *Full MCE* setting.

3.4 Demand shocks

In this subsection we briefly discuss the implications of our expectation settings for the propagation mechanism of typical demand-driven economic disturbances. The following exercises are conducted only with a fixed exchange rate and financial spreads.

Figure 12 takes the public consumption shock as an exemplary demand shifter in the model. Focusing first on the *Backward* expectations setting, a sustained increase in government purchases directly affect GDP and stimulates production. The excess demand lifts up prices and leads to a tightening of nominal short-term interest rates. Investment and household consumption improve in the short run, benefiting from higher production and employment gains. However, tighter financial constraints, both from higher borrowing rates and due to negative asset valuation effects, contain the initial impulse. In the medium term, real incomes are adversely affected as the nominal and financial pressures dominate, with private consumption and investment being significantly crowded out by the public consumption increase.

Switching to the *Hybrid MCE* setting, creates a different price dynamics compared to the *Backward* case. The inflation response is somewhat subdued over the entire simulation horizon. Price and wage setters in the *Hybrid MCE* formulate lower inflation expectations. And the more limited price and wage adjustments give room to more favorable financing conditions in comparison with *Backward* expectations setting. This clearly benefits the investment dynamics which now remain persistently above baseline. Higher capital expenditures then lead to a stronger buildup of production capacity, reflected in higher potential GDP, thereby further contributing to the more muted inflation response. By contrast, the adjustment of employment, labor income and ultimately consumption remains broadly similar to the *Backward* case. Overall, the *Hybrid MCE* setting generates lower inflationary effects from government spending shocks together with stronger complementarity with business investment and therefore, more long-lasting output gains.

The *Full MCE* setting leads to a more expansionary and inflationary response to a public consumption shock, notably due to a limited crowding out of households expenditures. Compared to the other expectation settings, the employment response displays a more protracted increase, smoothly converging to the baseline without undershooting. The forward-looking behavior in the permanent income evaluation also creates a front-loading of future benefits from the aggregate demand stimulus. Higher households spending then leads to higher and more persistent price pressures. As in the *Hybrid MCE* case, business investment remains above baseline over the simulation horizon. The short-term interest rate increases by more than under the other expectation settings given the more pervasive price pressures.

As for the previous shocks, we also investigate the anticipation effects of announcing a future increasing in public consumption. Figure 13 presents the responses to an anticipated shock occurring in $t = 20$ across the different expectations settings. In the *Backward* setting, the long-term bond reprices already on announcement of the shock. The anticipated financial tightening leads to some decline in investment already during the anticipation phase but with limited repercussions for total output. With forward price and wage setting in the *Hybrid MCE* case, the nominal side already reacts during the anticipation phase of the shock. Once the shock occurs, the price pressures more rapidly dissipate. Finally, with the *Full MCE* setting, permanent labor income discounts the future expansion which leads to a consumption response already in the anticipation phase, and therefore more expansion of consumption. Overall, the *Full MCE* delivers higher GDP and inflation responses, through anticipation effects as well as more benign employment dynamics which supports households income.

To close the description of demand shocks, we also briefly document the macroeconomic responses to shocks affecting other expenditures components of GDP. Figure 14 summarizes the macroeconomic propagation of the private consumption, business investment and world demand shocks. They are scaled to unfold the same ex-ante GDP increase such that their magnitude is comparable. For consumption and business investment, we consider one-period shock to the residuals of the respective behavioral equation. For world demand (which is an exogenous variable in the small open economy set-up of ECB-(RE)BASE)), the shock follows an AR(1) process[14]. The three shocks are typical demand shifters with a transmission mechanism to aggregate output and inflation broadly similar to the public consumption shock. Business investment directly improves the capital stock and therefore lifts potential GDP. The output gap increase is therefore smaller compared to the other shocks which triggers milder inflationary pressures and less tightening of the policy rate.

Across expectation settings, all demand shocks respond similarly to what we learned from the public consumption shock. The inflation responses are more subdued when considering the *Hybrid MCE* setting. The *Full MCE* setting increases somewhat the persistence of the aggregate demand stimulus due to more favorable income dynamics. For the business investment shock, the heterogeneity across expectations settings is more limited, notably as the potential output increase is broadly the same in this case.

[14] The autoregressive parameter is set to 0.9

4 Macroeconomic volatility since the pandemic and expectation formation

In this section, we use the model to evaluate scenarios that capture the main macroeconomic developments between 2020 and 2024 across the different expectation settings. The first phase of the scenario analysis covers the COVID-19 pandemic emergency period when lockdown measures constrained consumption opportunities and disrupted general economic interactions. The second phase is the sudden surge in inflation starting in 2022Q1: exceptionally strong price pressures from energy, food, producer to consumer prices, interacted with pervasive supply-side bottlenecks from the post-pandemic period.

4.1 Scenario design: shock calibration and anticipation modalities

We construct the scenarios as follow. We first filter the baseline dataset using the estimated backward (VAR-based) version of ECB-BASE. This is achieved by inverting the model onto the data, i.e. calculating the residuals of each equation that bridges the difference between the model equation and the observed data. This is straightforward in a semi-structural backward expectation model as there is a unique mapping between the model equation implied forecast and the observed data. We then select a few of those shocks/residuals only, starting in 2020Q1, instead of keeping all residuals of all equations in this large model. An advantage of the approach taken here is that each of the selected shocks that we activate has a clear model interpretation and can relate to the model properties exposed in the previous section of this paper. At the same time, with *Backward* expectations, simulations around the baseline growth path with this selected few shocks still account for the salient features of macroeconomic dynamics during the pandemic and during the inflation surge periods. The background Figure 19 shows the gap between the model channels triggered by the selected subgroup of shocks and the observed (detrended) data.

Figure 15 shows the scenario using the *Backward* expectations setting and decomposed into thematic shock families. Which equation residuals are grouped into forming those shock families can be seen in Table 2. We assume that monetary policy is temporarily constrained, and the short-term rate cannot move until 2022Q2. Thereafter, it follows the model's interest rate rule.

Table 2: Selected shocks from the filtered baseline data from ECB-BASE

Shock family	Residuals on equations
Pandemic demand	consumption, investment, exports
Pandemic productivity	productivity
Energy prices	HICP energy inflation
Domestic prices	GDP deflator, HICP food, HICP excl. energy and food
Interest rates	Short-term and long-term interest rate

Next, we keep the same sequence of shocks, but re-simulate the model under the different expectation settings defined in the previous section. We simulate the model with the extracted shock series under perfect foresight, around the balanced-growth path.[15] In each comparison across expectation settings, we keep the size and selection of shocks the same.

In the following, we consider two phases of the scenario separately. The pandemic phase exposes demand and supply shock transmissions while the inflation surge phase considers price markups and financial shocks. Because of the perfect foresight setting, all the shock sequences are fully anticipated by agents in the model at the start of the respective scenario phase: 2020Q1 for demand and supply shocks, 2021Q3 for price and interest rate shocks. This means, we assume that as soon as the pandemic starts, the agents have full knowledge of the lockdown waves in the future. In a second set of simulations, we then load the inflation markup shocks and again, those shock sequences are then perfectly anticipated for the simulation horizon as soon as agents become aware of them at the start of the exercise in 2021Q3. Finally, for completeness, we also consider the case of full anticipation of the two phases together.

4.2 Supply and demand conditions during the pandemic emergency

The first set of structural model wedges illustrates the main real-side economic features of the pandemic period. We consider demand shocks that decrease consumption, investment, and exports. Endogenously, these demand shocks alone have small long-term consequences for productivity, so that other structural wedges are needed to match supply-side scarring effects caused by the containment policies to fight the pandemic. We therefore create an additional productivity shock sequence as a synthetic wedge that summarizes a plethora of developments in this period ranging from workers being unable to get to their workplace to supply-chain bottlenecks and structural limitations in the reallocation of workers.[16] In order to calibrate this shock, we rely on the results of the ECB-BASIR model in Angelini et al. (2020), which introduced a pandemic module into ECB-BASE allowing to study the interaction of the macro-economy when agents are exposed, infected and recovered (SIR) from the COVID-19 virus. According to this study, due to containment measures and the resulting inability of employees to work, around 45% of the cumulative output loss is reflected into potential output. In our exercise, the structural changes accounting for the productivity decline are assumed to stay permanently even after the pandemic health crisis receded. In terms of macroeconomic outcomes, this supply shock counteracts the deflationary forces from the pandemic collapse in demand and tends to lift prices up until the end of our simulation horizon.

With *Backward* expectations setting in Figure 15, the pandemic wedges, depicted in dark blue bars for demand and light blue for supply, create a peak decline of GDP by around 15%

[15] Note that, non-linearities do not allow for a strict additive decomposition of data, especially when considering forward expectations at the Effective Lower Bound (ELB) constraint on nominal interest rates. The exercise is therefore to be understood as investigating macroeconomic dynamics when swapping expectation settings - while keeping the input flow to the model the same.

[16] Therefore, with respect to the productivity shocks, we deviate notably from the model-implied filtering of data.

compared to the baseline in 2020Q2. The demand pattern then follows roughly the lockdown waves when health measures where partially loosened and tightened again. Regarding price growth, on balance, the decline of demand marginally dominates over supply factors, leading to slight decline in GDP deflator and HICP inflation. As the demand pressures fade away, the persistent supply deterioration pushes up price growth after the end of the pandemic. The pervasive supply-side scarring after the pandemic emergency would imply an increase in the policy rate after the end of the ELB constraint imposed until 2022Q2. With exogenous risk spreads, overall financing conditions remain benign in this scenario. The model even signals an increase in financial wealth: equity pricing is forward looking and "look-through" the very short-term economic deterioration in 20Q2. Instead, the nominal asset valuations do price in the demand-driven economic momentum of the re-opening phase.

Let us now turn to discuss the different expectations settings. Figure 16 shows the responses of the model economy to the demand and supply factors of the pandemic scenario under *Backward* (consistent with the dark and light blue bars from Figure 15), *Hybrid MCE* and *Full MCE*. The simulations are run with endogenous monetary policy.

When considering the *Hybrid MCE* setting, the inflation response to the pandemic shock is higher than with *Backward* expectations. The forward-looking price setting mode leads to an increase in inflation throughout the simulation, notably as price setters anticipate the negative supply shocks. GDP deflator inflation is then above baseline during the first part of the pandemic episode while it turns negative under *Backward* expectations. HICP inflationary pressures gradually build up to reach above 0.3 p.p. by end-2023. Wage setters, in contrast, reduce their nominal wage claims more quickly in response to the pandemic restrictions. The wage recovery is also faster, alongside the higher inflation path. The real-side follows largely the expenditure shocks and is similar to the *Backward* setting. The stronger inflationary pressures in the *Hybrid MCE* setting also leads to a stronger monetary policy rate tightening, which is maintained above the magnitude from the *Backward* setting well beyond the actual pandemic lockdown phase.

Finally, if the economy follows a *Full MCE* setting, households smooth out the implications of the temporary lock-downs for their life-time income perception. In a notable contrast to the backward case, where permanent income moves with the lockdown pattern, permanent income declines less and recovers quickly. Private consumption is consequently falling to a lesser extent and so is GDP. The less severe demand repercussions in this expectation setting then leads to an even more positive inflation drift during the pandemic years. The model's interest rate rule would prescribe a mildly higher policy rate path in the short run than under *Hybrid MCE*.

4.3 Post-pandemic inflation surge

The second scenario is built by activating price shocks inverted on the inflation surge period, starting from 2021Q3 onward. Those price wedges consist of three factors. First, there is an increase to the price of imported energy. In the model, this is implemented via oil price shocks and is calibrated to mimic the rise of HICP energy inflation observed in the data. Furthermore, we introduce price markup shocks on HICP food, HICP excl. energy and food, as well as on the GDP deflator inflation.

Under the *Backward* expectations setting, the macroeconomic impact of these price wedges is displayed in Figure 15 through the dark green bars for energy markup shocks and light green bars for the other markup shocks. Those shocks generate inflation rates which are consistent with the peak of HICP inflation observed in the data. The price surge also triggers a repricing of the short-term interest rate following the model's Taylor rule which exits the ELB as of 2022Q2. Beyond this systematic response of interest rates, monetary policy and term-premium shocks are needed to match the magnitude of policy tightening observed in the €STR fixings over this period as well as to bring the long-term interest rate response to a magnitude comparable with the data (see yellow bars in Figure 15).

As before, we analyze the consequences of changing the expectation formation mechanism in Figure 17, assuming endogenous monetary policy. The *Backward with financial and UIP MCE* expectation setting serves again as the benchmark case. The increase in inflation due to international energy price shocks and domestic markup shocks leads to a substantial decline in real income and therefore a decrease in consumption. Without the constraint, the policy rate starts increasing as soon as 2022Q1 in response to the positive inflation gap. This leads to a repricing in the long term interest rates and eventually in borrowing costs as well, depressing investment and consumption. This channel has been compounded with the interest shocks included in this scenario. The substantial loss in bond value is reflected in the wealth positions of households which further weighs on consumption.

When considering the *Hybrid MCE* setting for the inflation surge scenario, the price increases are considerably front-loaded and amplified. On the same account, the nominal wage catch-up is strongly anticipated and more pronounced as wage setters augment more quickly the nominal claims to make up for the anticipated real wage losses. The stronger inflation response leads to a more aggressive monetary policy reaction (at the onset of the scenario, in 2021Q3) and tighter financing conditions in comparison with the *Backward* reference case. The concomitant stronger decrease of capital investments then also leads to an intensified decline in potential output. For households, however, the stronger price increases do not lead to more retrenchment in expenditures: one main driving factor is the adjustment in the residential sector which turns out more supportive of household wealth. Indeed, the house prices and housing wealth benefit more from the more inflationary response under *Hybrid MCE*. Also note that in this case, the residential sector adjustments are still operating with VAR-based expectations.

When simulating the inflation surge scenario under *Full MCE*, households anticipate and front-load the perceived real income loss. Different to *Hybrid MCE*, all adjustment costs are forward-looking in this setting and there is less support from the housing wealth channel. Overall, households curtail their consumption strongly under the *Full MCE* setting which leads to a sharper decline in GDP. Monetary policy then takes this into account and tightens the short-term rate by less than in the *Hybrid MCE* setting, but considerably stronger still than in the

Backward case.

For completeness, we simulate the pandemic and inflation surge scenarios at once, across the various expectations settings. The macroeconomic responses are presented in Figure 18. In line with the calibration strategy on observed developments over the period, we impose the lower bound on short-term interest rate until 2022Q2. Altogether, the *Hybrid* and *Full MCE* both imply higher inflation and nominal wage paths than in the *Backward* case over the simulation horizon. However, these alternative expectations settings deliver quite different outcomes on the real and financial side[17]. The *Hybrid MCE* setting creates a more benign consumption path after the pandemic on the back of the housing wealth channel. The *Full MCE* setting leads to lower consumption by end-2023 despite a more pronounced rebound from the pandemic trough. Under this setting, the nominal pressures of the scenario have more direct and persistent negative repercussions for employment and income dynamics. With *Hybrid MCE*, the monetary policy response is considerably more aggressive after exiting the ELB to contain the inflation increase above target. With *Full MCE*, monetary policy takes into account the more persistent negative pressures on expenditures, leading to a less aggressive tightening, which however is still well above the *Backward* case.[18] The more adverse financing conditions affect investment such that they bring investment considerably down in this counter-factual. For *Hybrid MCE*, this counteracts the benign consumption path and leads to overall GDP that is not too different from the *Backward* case.

All in all, the scenario exercises confirm that the model-consistent expectations can significantly alter the macroeconomic propagation mechanism of the semi-structural model, with critical implications for its policy use. While the *Full MCE* setting might constitute a useful version of ECB-(RE)BASE, considering hybrid VAR-based and MCE formulations together might seem somewhat arbitrary. The *Hybrid MCE* expectations setting used in this paper displays some properties which are not necessarily the "middle way" in between the *Backward* and the *Full MCE*: we leave for further work the analysis of alternative specifications of expectational heterogeneity across the ECB-(RE)BASE blocks.

5 Conclusion

ECB-(RE)BASE is rooted in the semi-structural model family of ECB-BASE/MC. It is a variant of the euro area model ECB-BASE that can be simulated under a model-consistent expectation setting. The approach presented here allows to mix different expectation settings at the same

[17] To fully document the contributions of all shock families underlying the results of the alternative expectation settings, appendix Figures 20 and 21 provide the decomposed details behind the yellow and red lines of Figure 18.

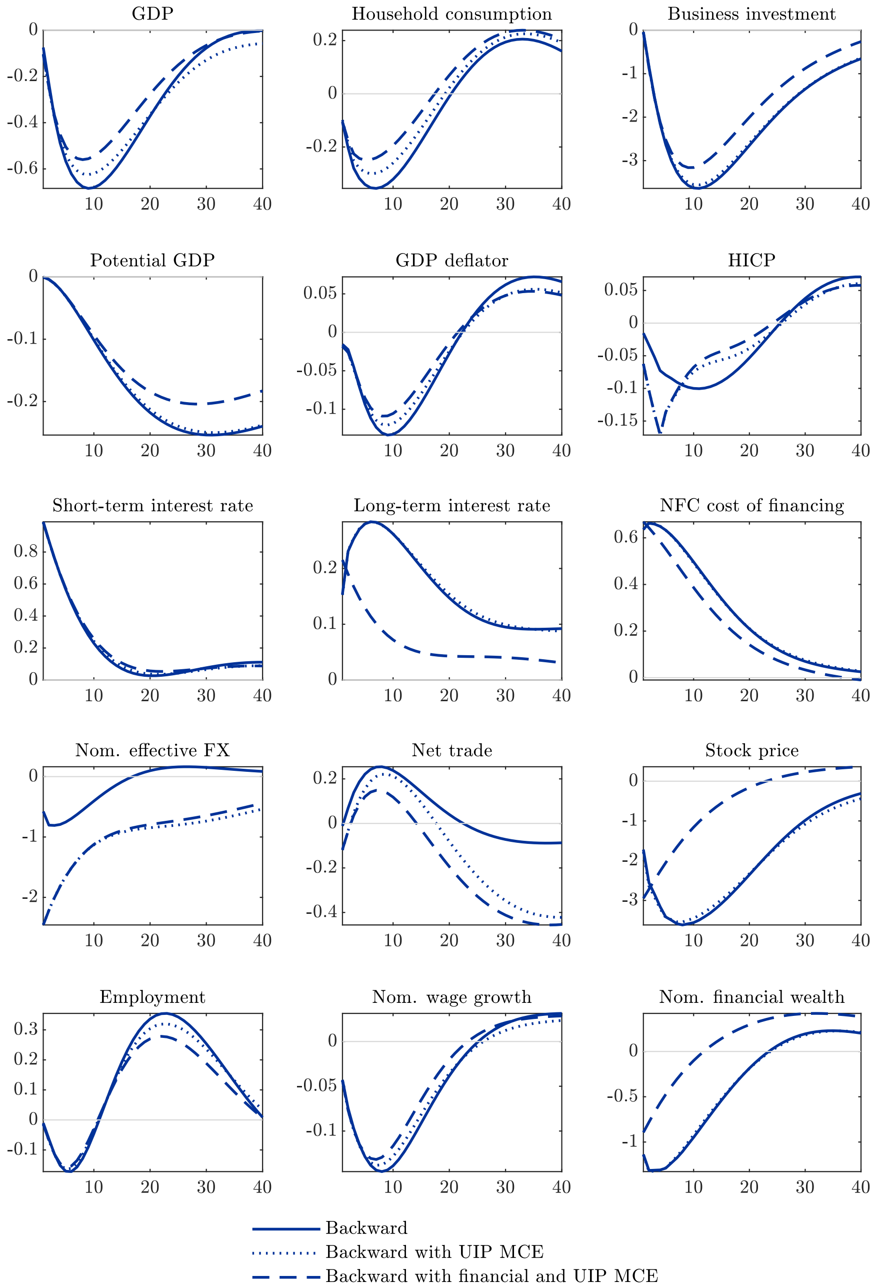
[18] In this context, it may also be interesting to consider a non-constrained monetary policy setting again. Figure 24 in the appendix plots the combined scenarios across the expectation settings without the ELB. The insights of the main text still prevail. The response of the nominal short-term rate is markedly stronger under more forward expectations taking into account the inflation surge markup shocks but also the productivity legacy of the pandemic.

time and therefore can create hybrid expectations where some model blocks are backward-looking and others forward-looking. The technical innovation of ECB-(RE)BASE pertains to the solution approach of the PAC equations, the way adjustment costs are modeled and thus determining all macroeconomic transmission features. Forward expectations further appear in the financial block, the wage-price nexus, and the consumption decision based on future income streams.

The expectation setting can significantly alter the transmission of shocks through the model economy. There is no one-directional change, however. Anticipation and amplification forces in the forward setting occur along-side smoothing and dampening forces. We have shown that forward expectations give rise to anticipation of shocks that occur in the future triggering macroeconomic adjustment already before.

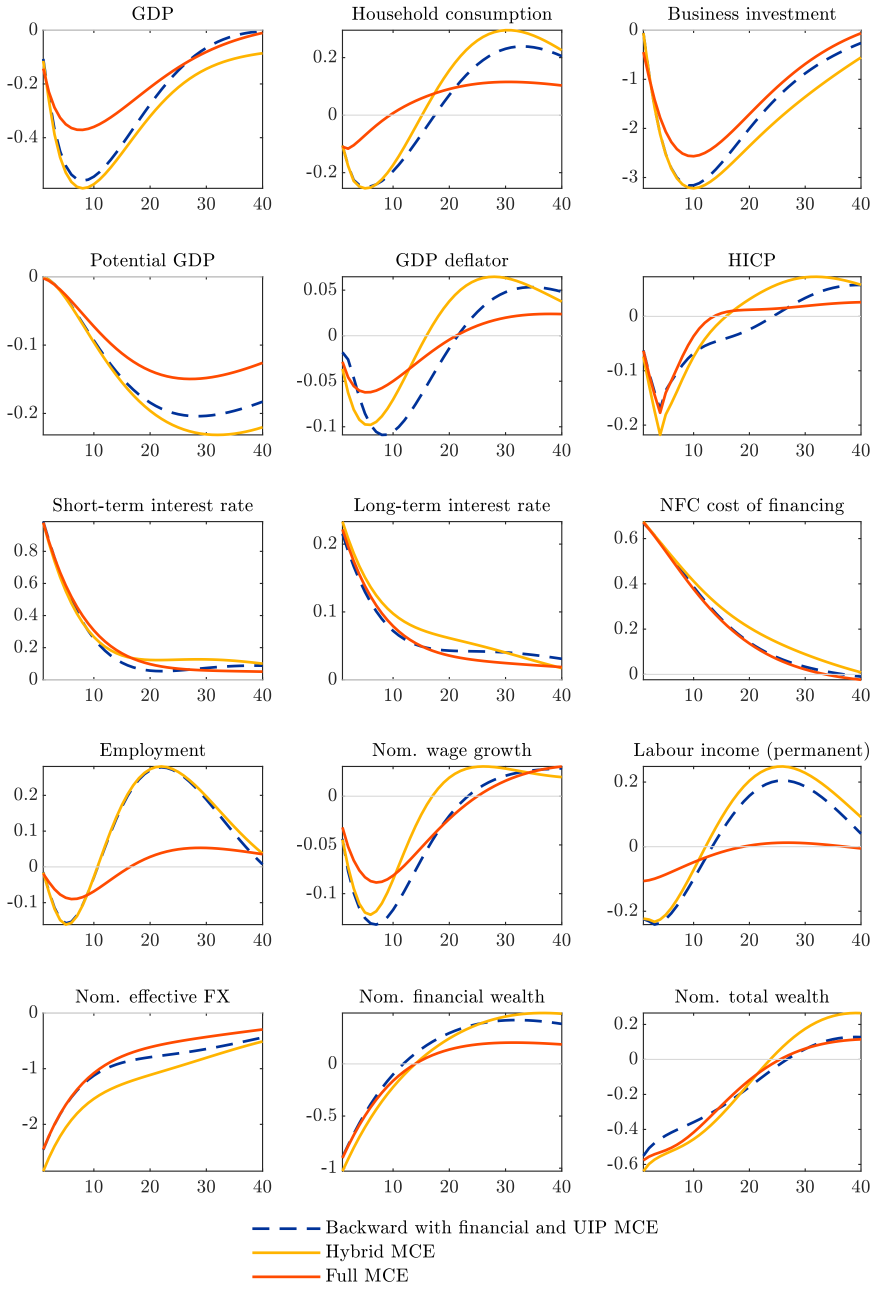
Finally, we have illustrated the implications of expectation settings for macroeconomic volatility on applied experiments. Model-consistent expectations lead to stronger upward price pressures from an anticipation of supply-side scarring effects triggered by the pandemic lock-downs. Households also smooth over the short-term implications of the lock-downs and curtail consumption by less when forward-looking. The markup shocks that drove up inflation in recent years on the other hand led to a stronger nominal responses, including higher nominal wage claims, under model-consistent expectations. The full forward looking settings also amplifies the negative repercussions of the real income loss from the inflation surge on expenditures.

Figure 2: Monetary policy shock (100bps)



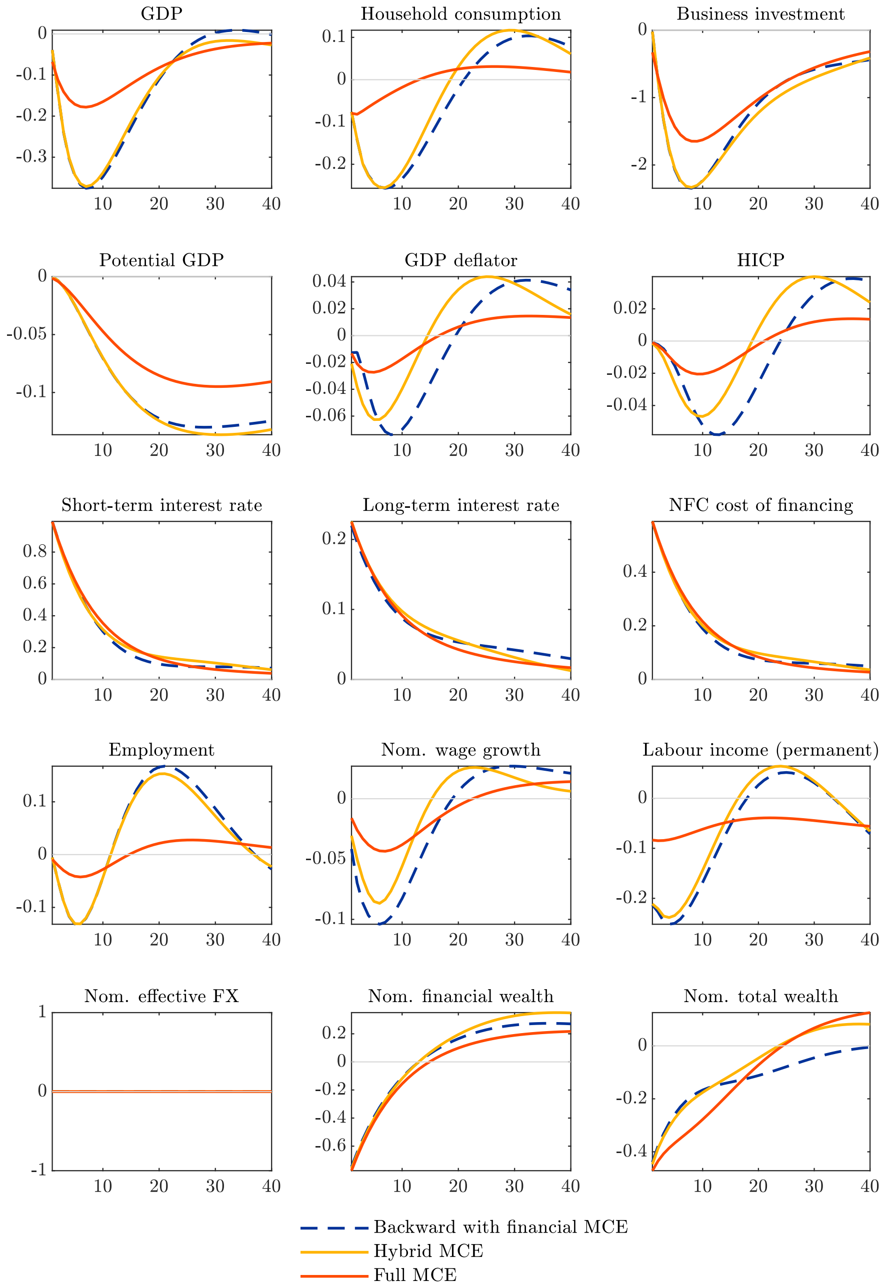
Notes: Responses to an unanticipated increase in the short-term interest rate by 100bps. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values.

Figure 3: Monetary policy shock (100bps)



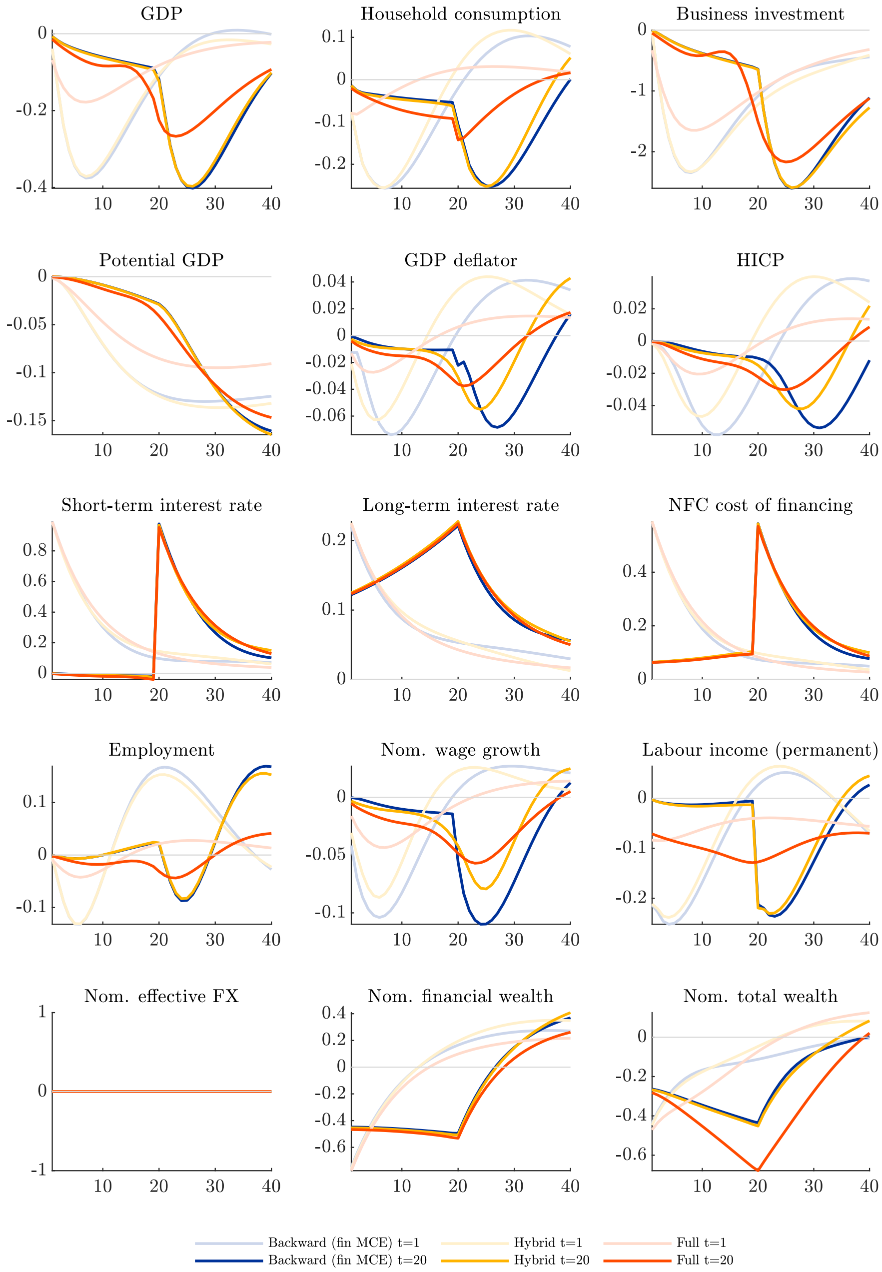
Notes: Responses to an increase in the short-term interest rate by 100bps. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values.

Figure 4: Monetary policy shock (100bps) - exogenous exchange rate and spreads



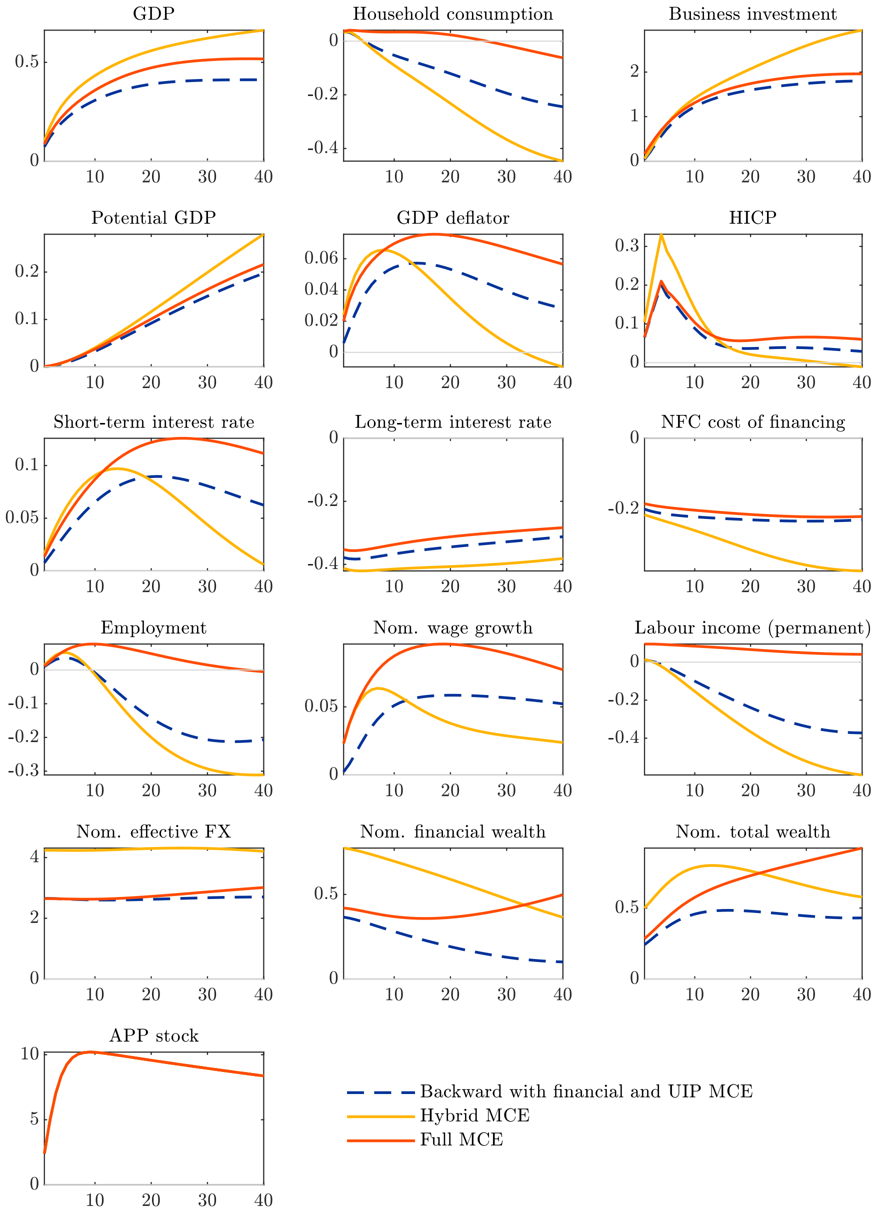
Notes: Responses to an increase in the short-term interest rate by 100bps. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values.

Figure 5: Anticipation of monetary policy shock (100bps) - exogenous exchange rate and spreads



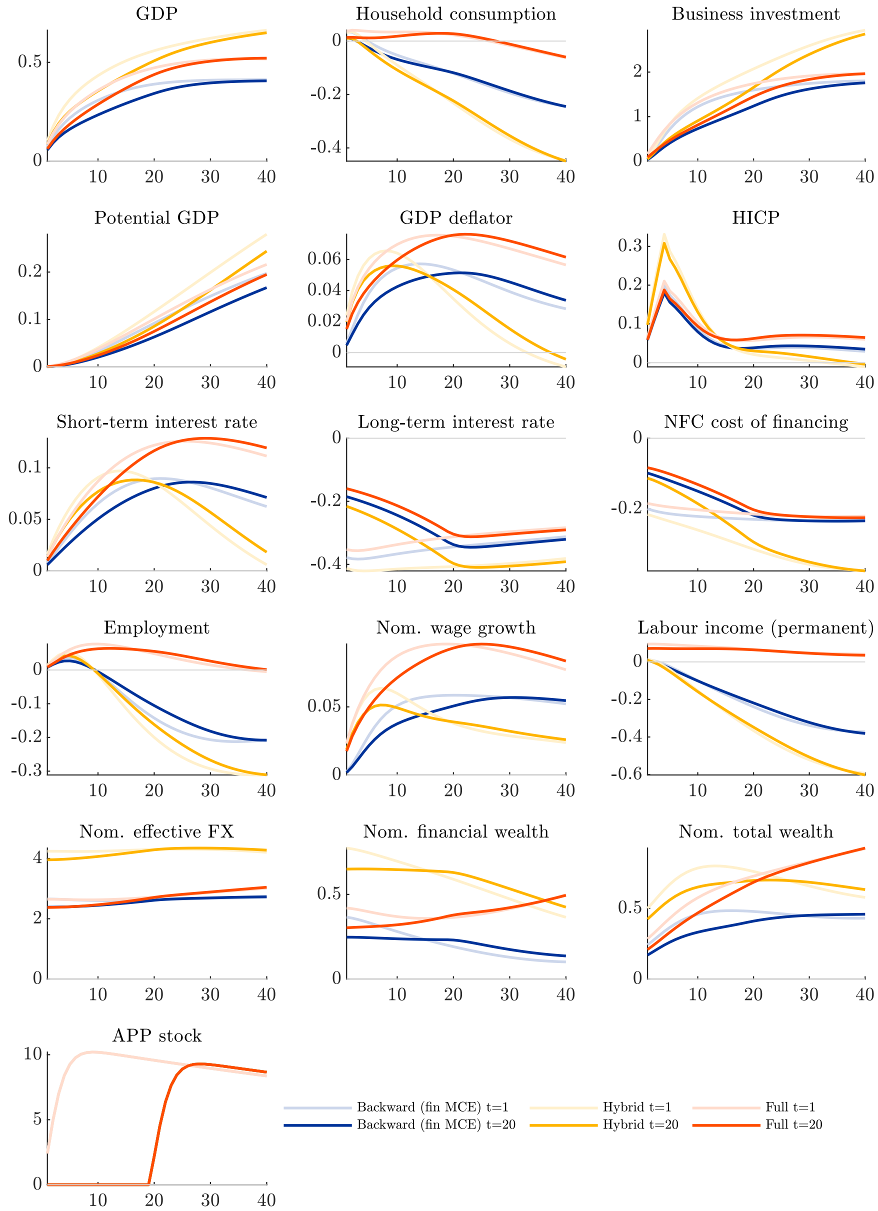
Notes: Responses to an anticipated increase in the short-term interest rate by 100bps starting in 5 years. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values.

Figure 6: CB asset purchase shock (10% of GDP)



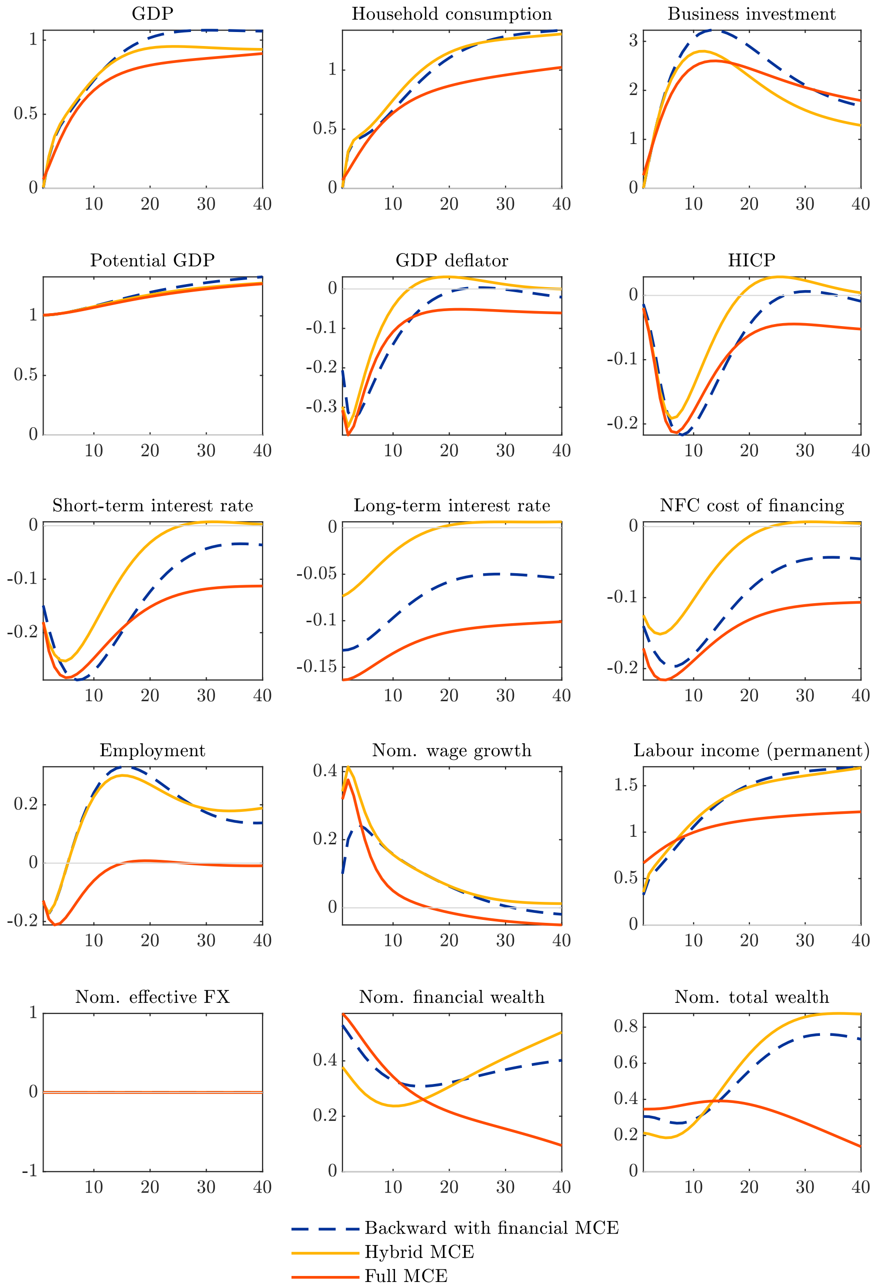
Notes: Responses to an increase in Central Bank asset purchases reaching 10% after 2 years with a gradual redemption profile thereafter. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values.

Figure 7: Anticipation of CB asset purchase shock (10% of GDP)



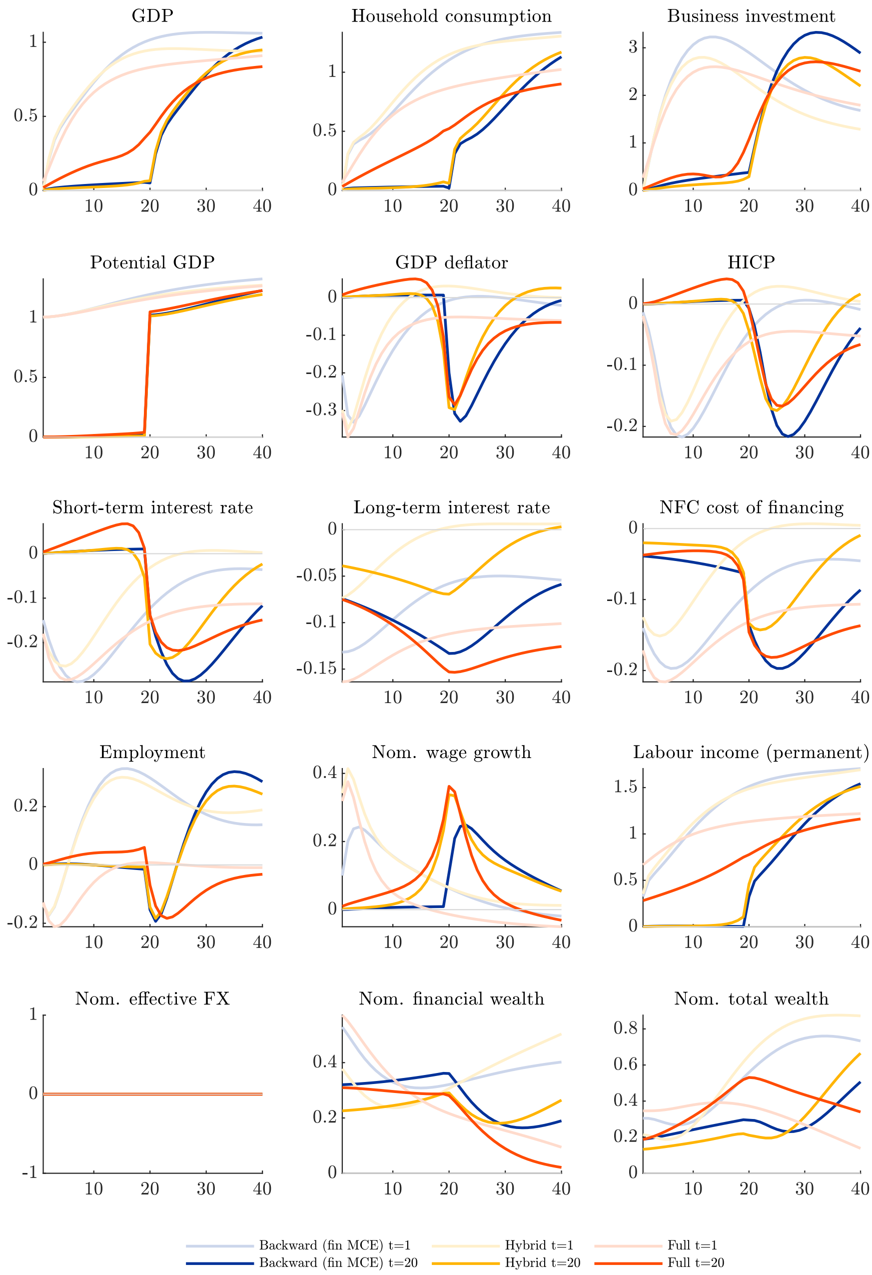
Notes: Responses to an anticipated increase in central bank asset purchases, starting in 5 years, reaching 10% after an additional 2 years with a gradual redemption profile thereafter. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values.

Figure 8: Productivity shock (1% potential GDP increase) - exogenous exchange rate and spreads



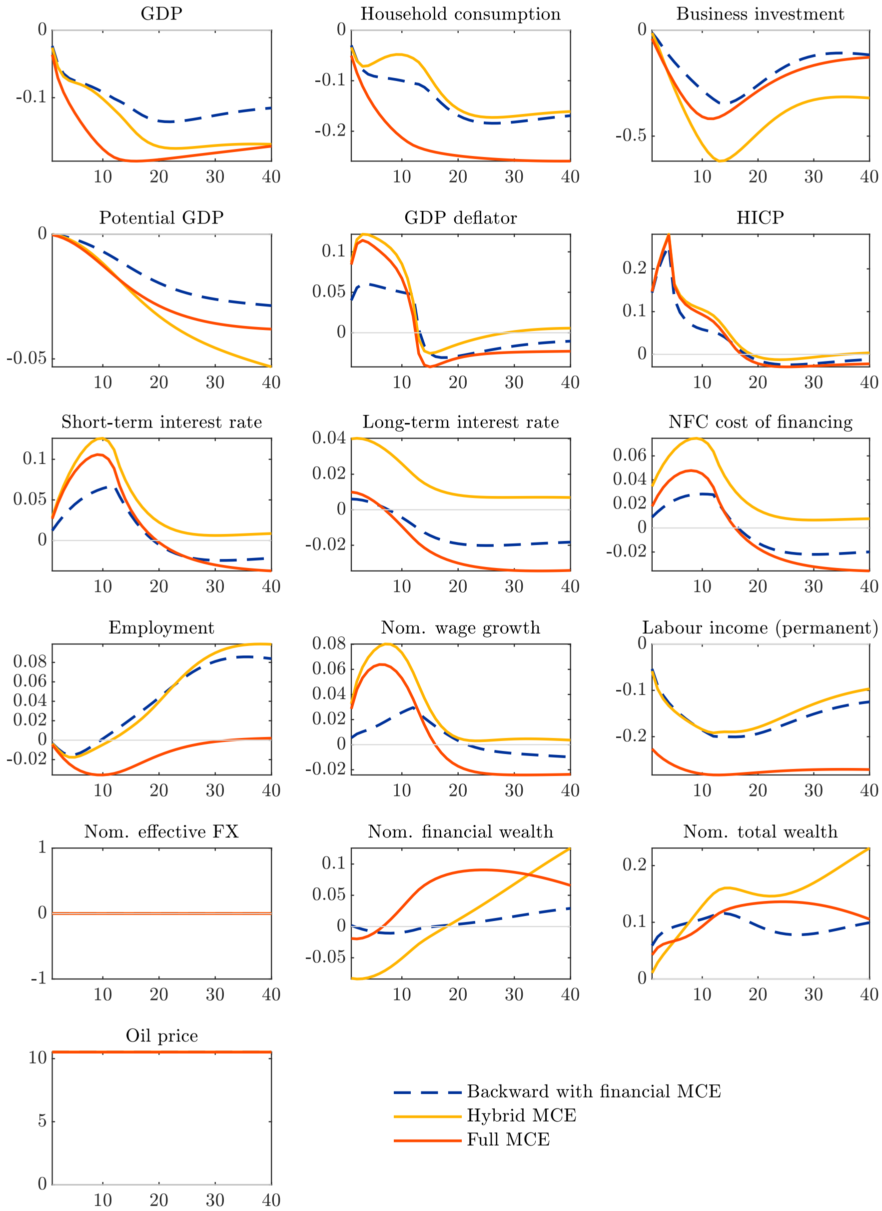
Notes: Responses to an increase in productivity by 1%, sustained over 200 periods. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values.

Figure 9: Anticipation of productivity shock (1% potential GDP increase) - exogenous exchange rate and spreads



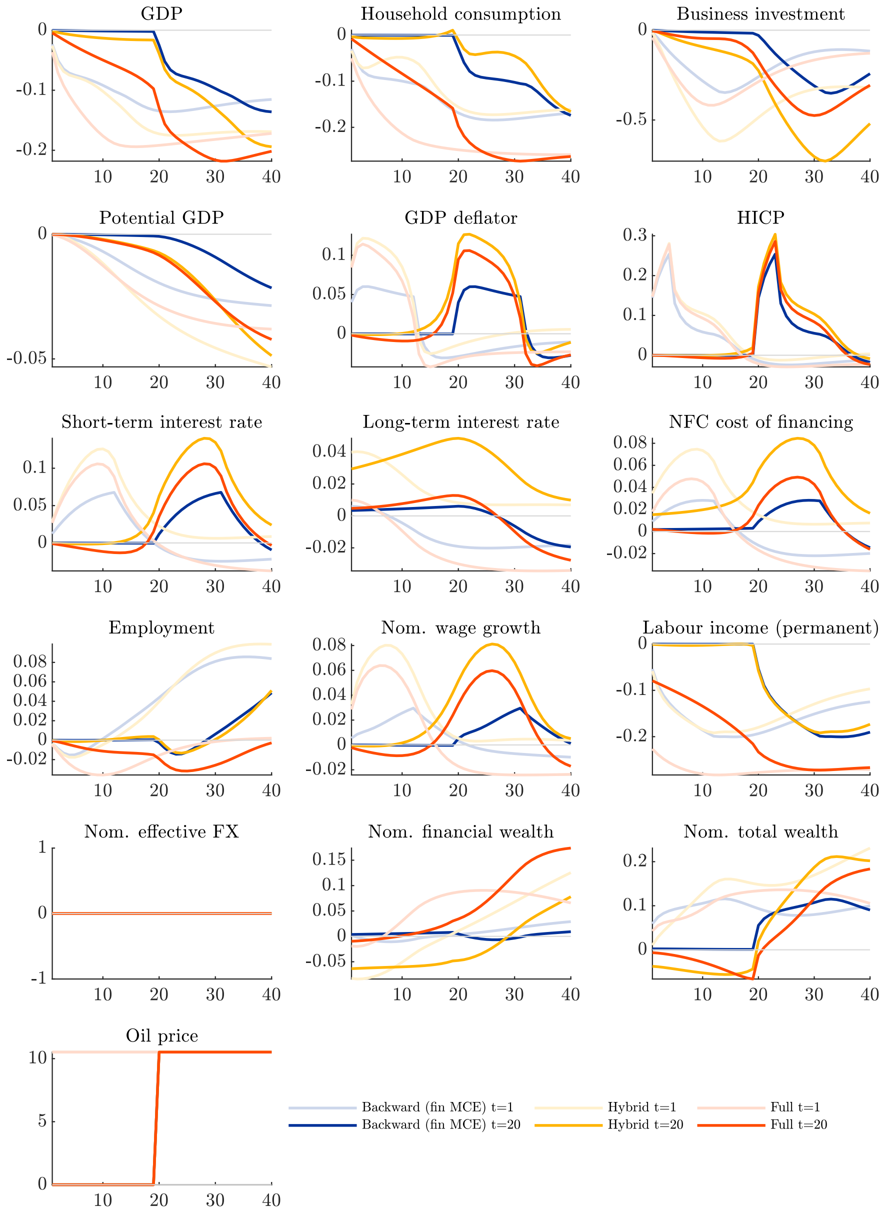
Notes: Responses to an anticipated increase in productivity by 1% starting in 5 years, sustained over 200 periods. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values.

Figure 10: Oil price shock (10%) - exogenous exchange rate and spreads



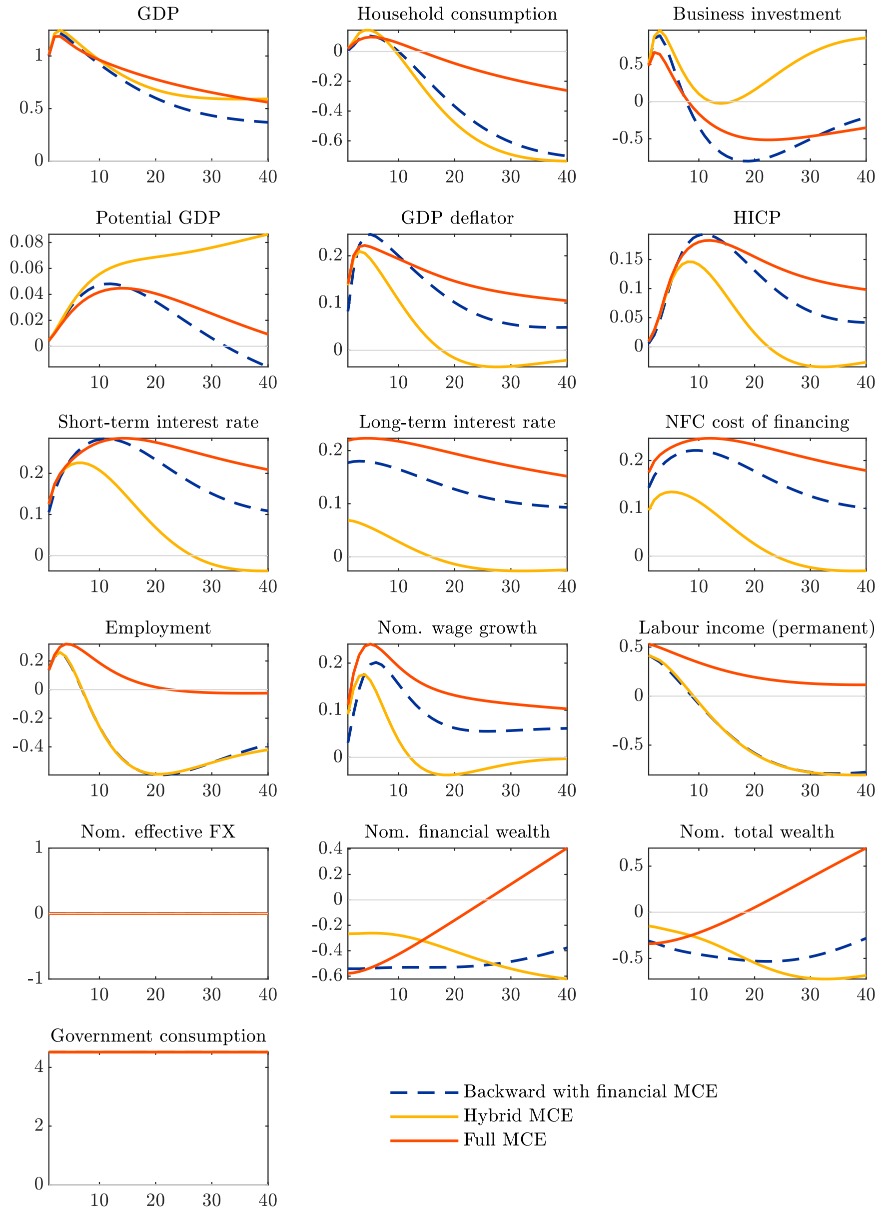
Notes: Responses to an increase in the oil price by 10%, sustained over 200 periods. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values.

Figure 11: Anticipation of oil price shock (10%) - exogenous exchange rate and spreads



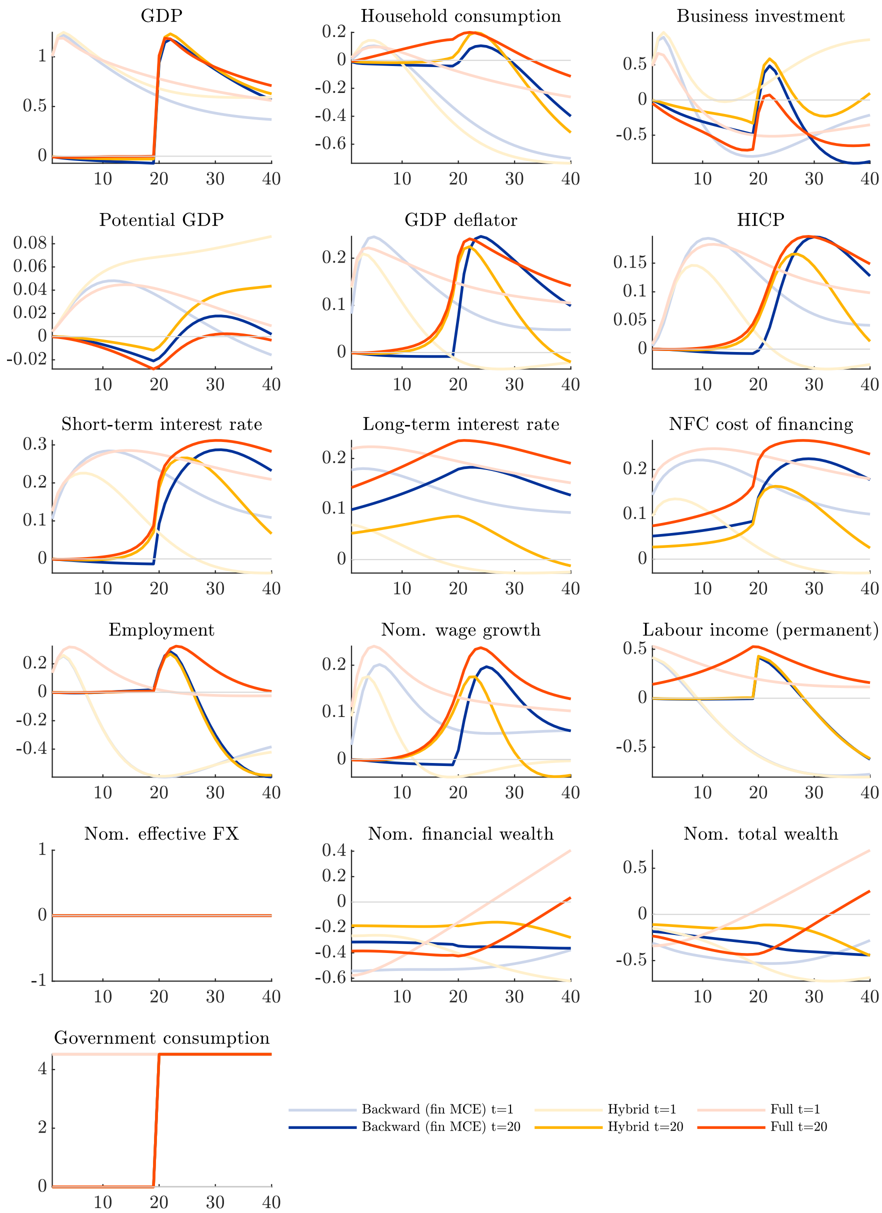
Notes: Responses to an anticipated increase in the oil price by 10% starting in 5 years, sustained over 200 periods. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values.

Figure 12: Public consumption shock (1% of GDP) - exogenous exchange rate and spreads



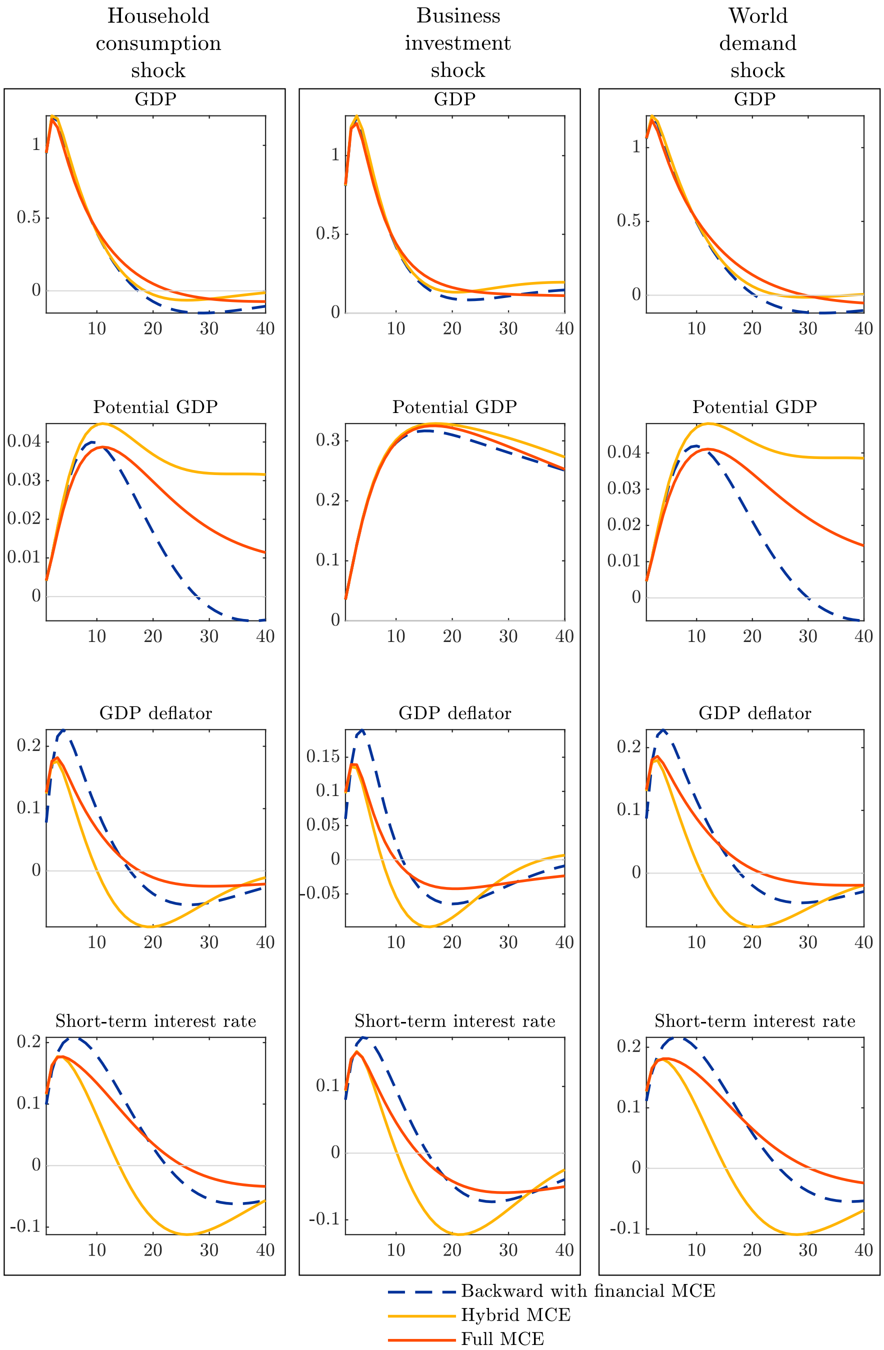
Notes: Responses to an increase in government consumption by 1% of baseline GDP, sustained over 200 periods. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values.

Figure 13: Anticipation of public consumption shock (1% of GDP) - exogenous exchange rate and spreads



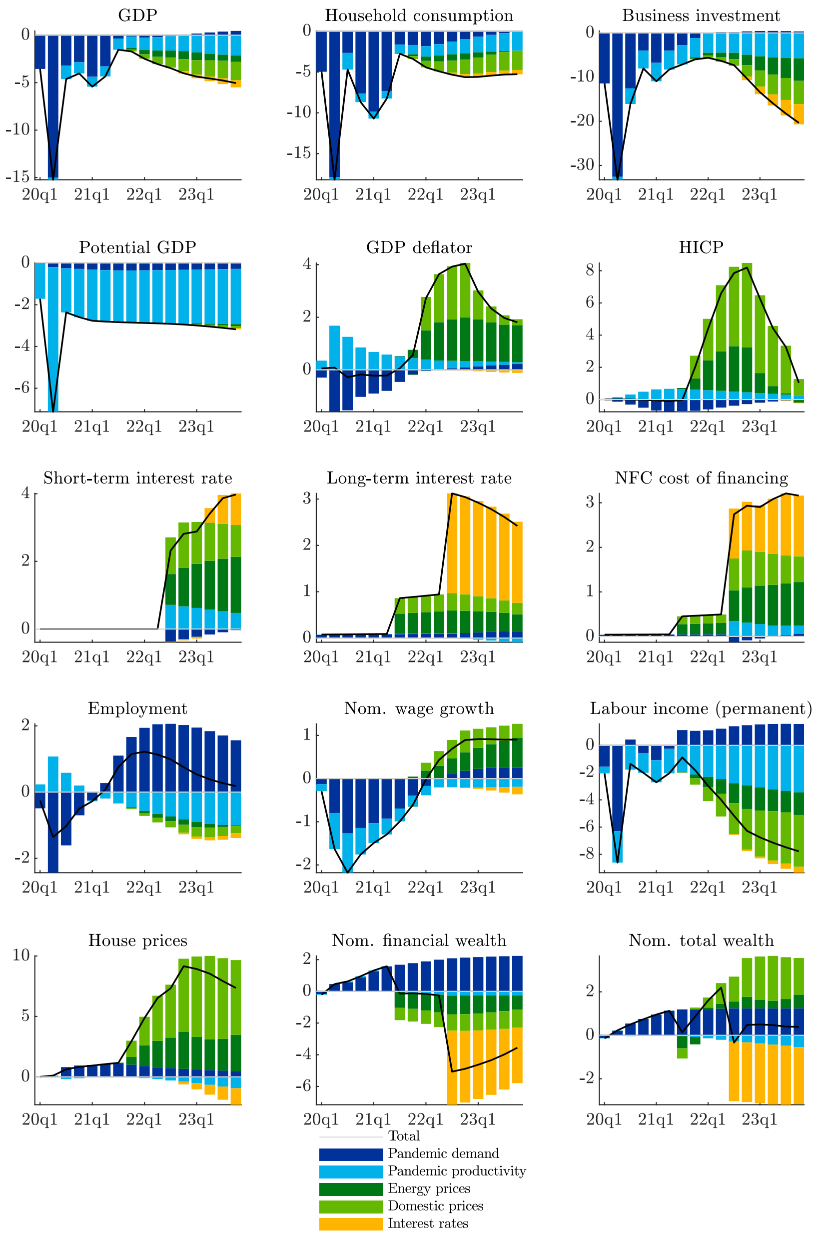
Notes: Responses to an anticipated increase in government consumption by 1% of baseline GDP starting in 5 years, sustained over 200 periods. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values.

Figure 14: Other main demand shocks (1% of GDP) - exogenous exchange rate and spreads



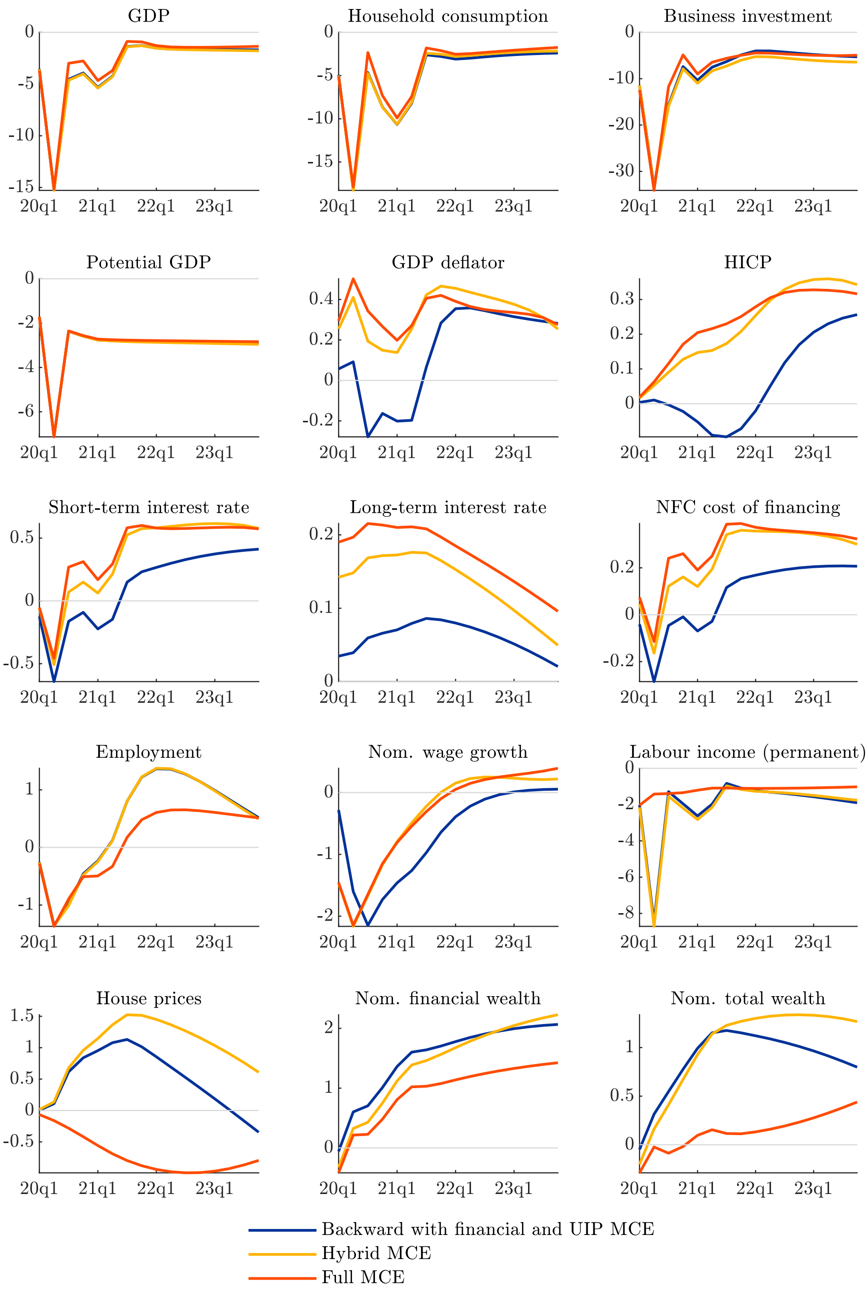
Notes: Responses to shocks to the demand drivers of GDP where each shock is scaled to create a 1% of GDP ex-ante impulse. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values.

Figure 15: Scenario construction from underlying shocks - Backward with financial and UIP MCE



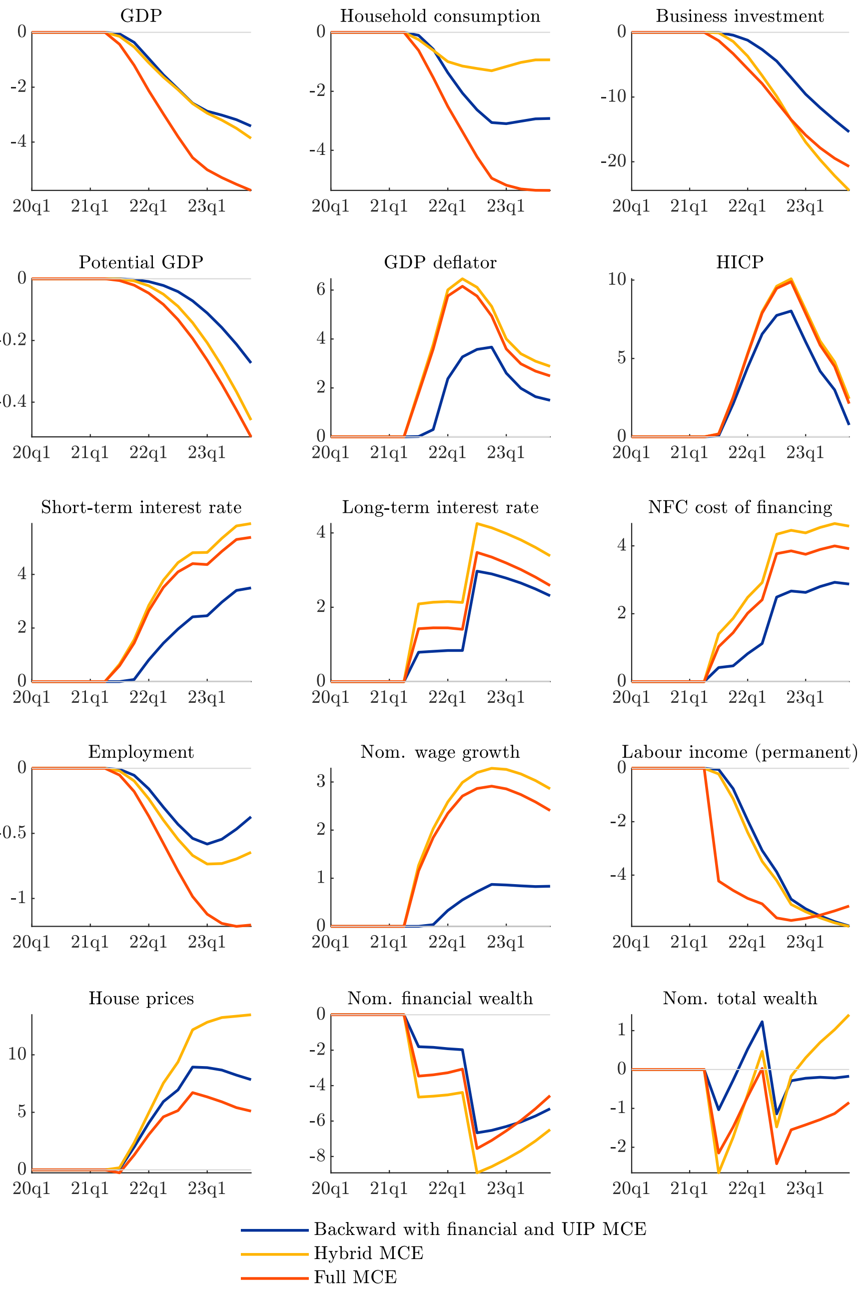
Notes: Responses to a stylized decrease in demand and productivity as observed during the pandemic as well as an increase of prices due to energy and other producer and consumer price factors which hits the economy unanticipated in 21Q3. The policy rate is assumed to be constrained until 22Q2. Thereafter, it follows the model's Taylor rule and a term premium shock increases the long-term interest rate. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values. Further simulation setting: exogenous exchange rate and spreads.

Figure 16: The pandemic scenario under different expectations settings (unconstrained monetary policy)



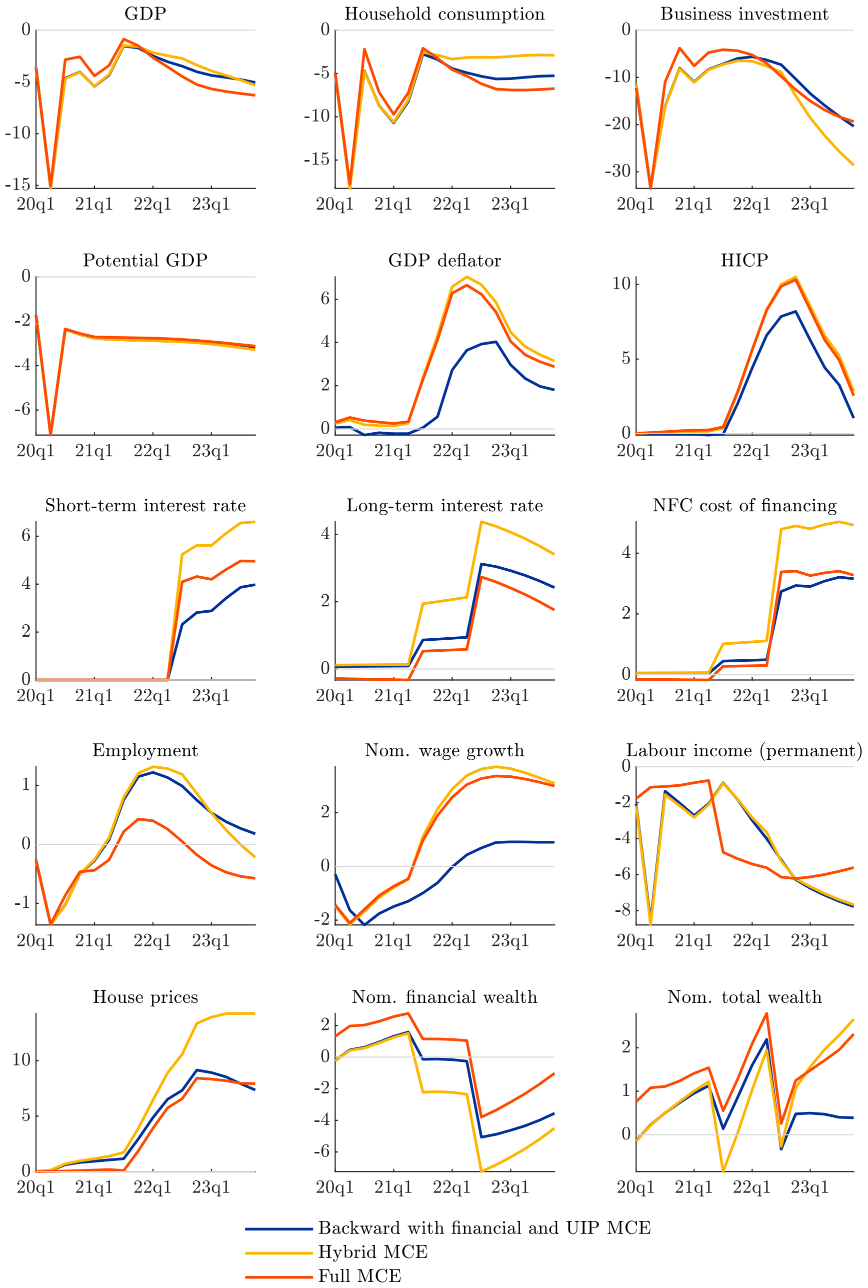
Notes: Responses to a stylized decrease in demand and productivity as observed during the pandemic. The policy rate is assumed to be constrained until 22Q2. Thereafter, it follows the model's Taylor rule and a term premium shock increases the long-term interest rate. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values. Further simulation setting: exogenous exchange rate and spreads.

Figure 17: The inflation surge scenario under different expectations settings (unconstrained monetary policy)



Notes: Responses to a stylized increase of prices due to energy and other producer and consumer price factors which hits the economy unanticipated in 21Q3. The policy rate is assumed to be constrained until 22Q2 and follows the model's Taylor rule thereafter. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values. Simulation setting: Further simulation setting: exogenous exchange rate and spreads.

Figure 18: The combined scenario under different expectations settings



Notes: Responses to a stylized decrease in demand and productivity as observed during the pandemic as well as an increase of prices due to energy and other producer and consumer price factors which hits the economy unanticipated in 21Q3. The policy rate is assumed to be constrained until 22Q2. Thereafter, it follows the model's Taylor rule and a term premium shock increases the long-term interest rate. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values. Further simulation setting: exogenous exchange rate and spreads.

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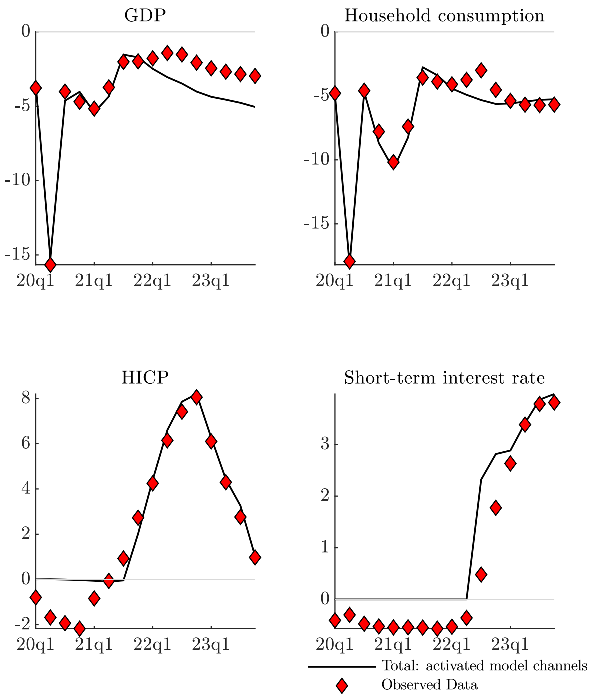
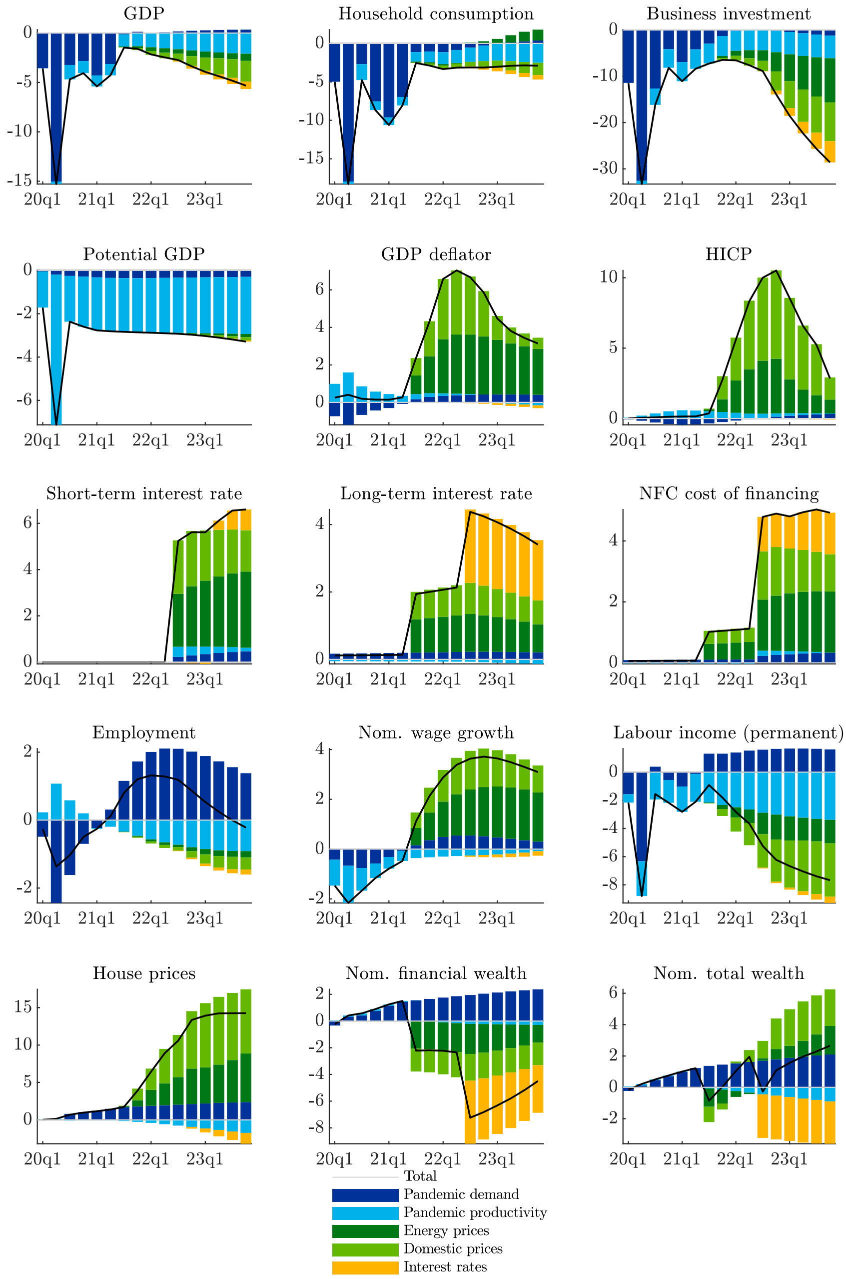
A Background charts

Figure 19: Structural model wedges in scenario vs data - Backward with financial and UIP MCE



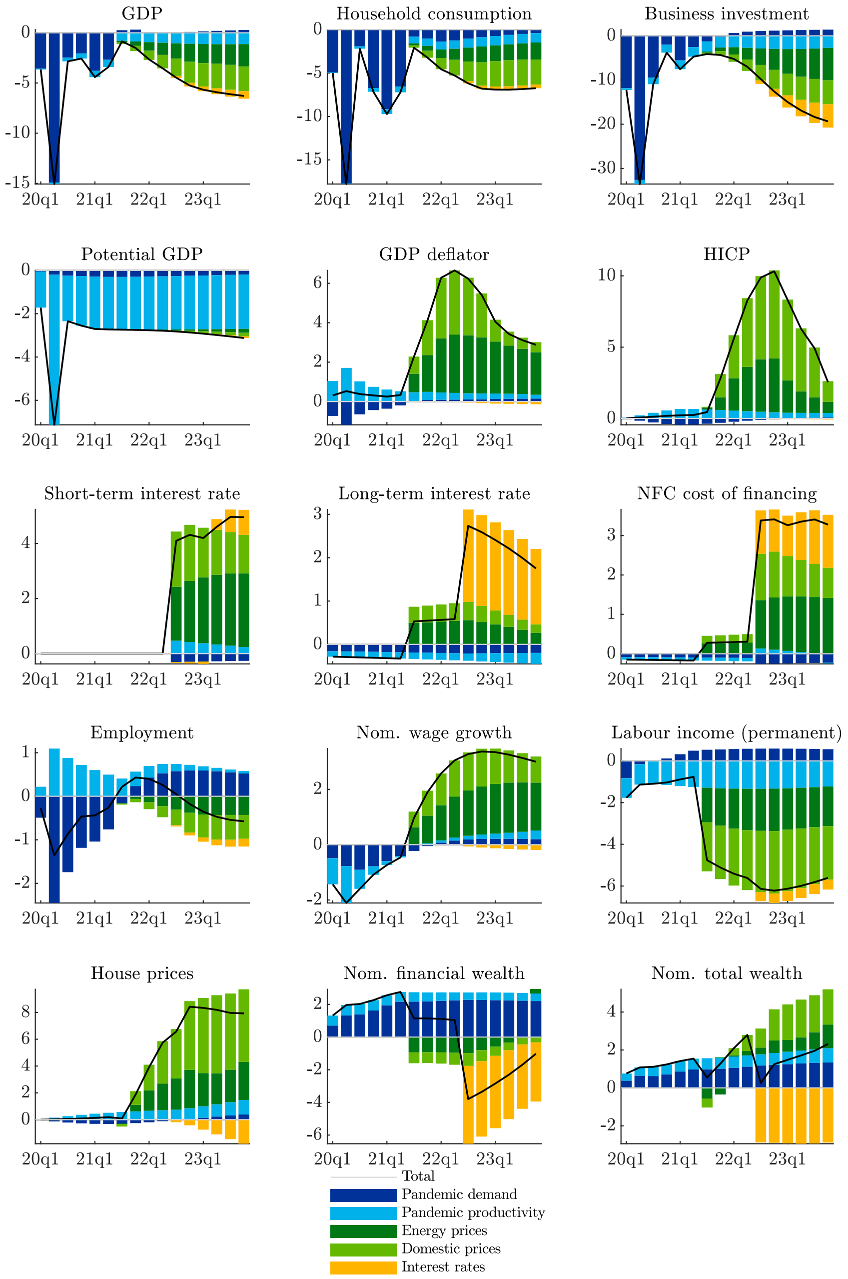
Notes: Total: activated model channels refers to the total set of simulations as shown in chart 15. The horizontal axis shows time in quarters. For the depiction of model channels, HICP inflation and short- and long-term interest rates as annualized p.p. deviation from their baseline values and all other variables as percent deviation from their baseline values. For the depiction of data, HICP inflation is shown as deviation from 2pp annualized rate. The annualized short- and long-term rate are not transformed. All other variables are shown as a cumulation of growth rate deviations from the model's trend growth in percent. Further simulation setting: exogenous exchange rate and spreads.

Figure 20: Scenario construction via underlying shocks - Hybrid MCE



Notes: Responses to a stylized decrease in demand and productivity as observed during the pandemic as well as an increase of prices due to energy and other producer and consumer price factors which hits the economy unanticipated in 21Q3. The policy rate is assumed to be constrained until 22Q2. Thereafter, it follows the model's Taylor rule and a term premium shock increases the long-term interest rate. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values. Further simulation setting: exogenous exchange rate and spreads.

Figure 21: Scenario construction via underlying shocks - Full MCE



Notes: Responses to a stylized decrease in demand and productivity as observed during the pandemic as well as an increase of prices due to energy and other producer and consumer price factors which hits the economy unanticipated in 21Q3. The policy rate is assumed to be constrained until 22Q2. Thereafter, it follows the model's Taylor rule and a term premium shock increases the long-term interest rate. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values. Further simulation setting: exogenous exchange rate and spreads.

Figure 22: The pandemic leg of the scenario under different expectations settings

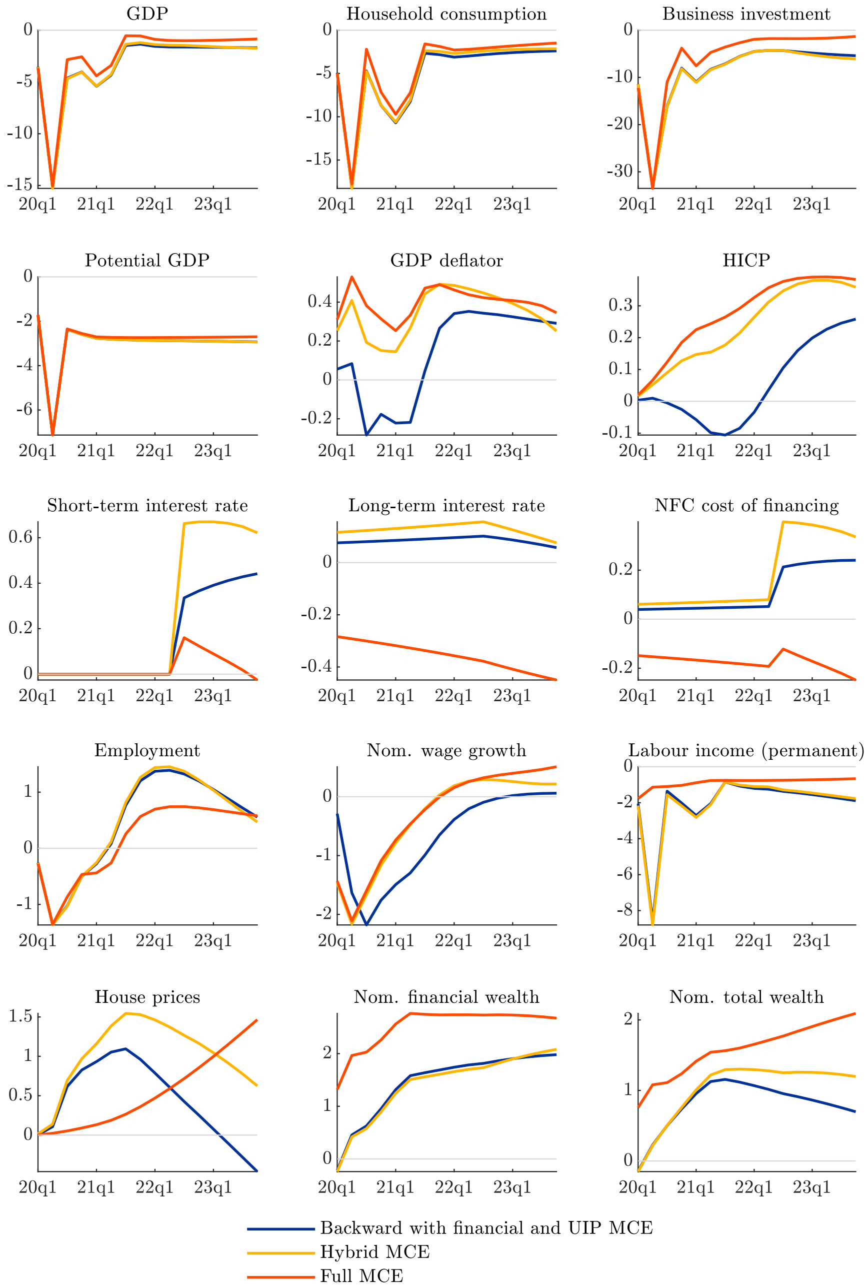


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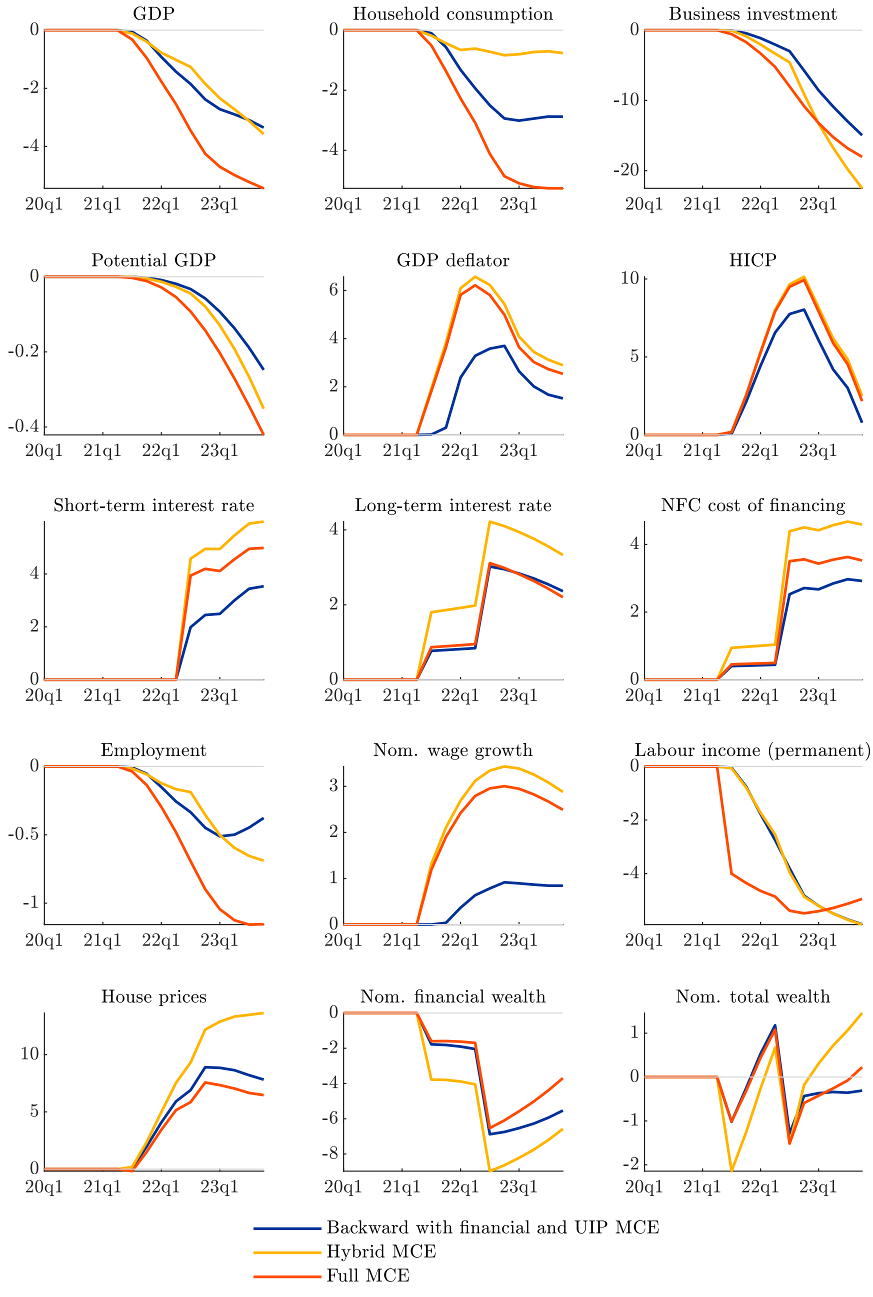
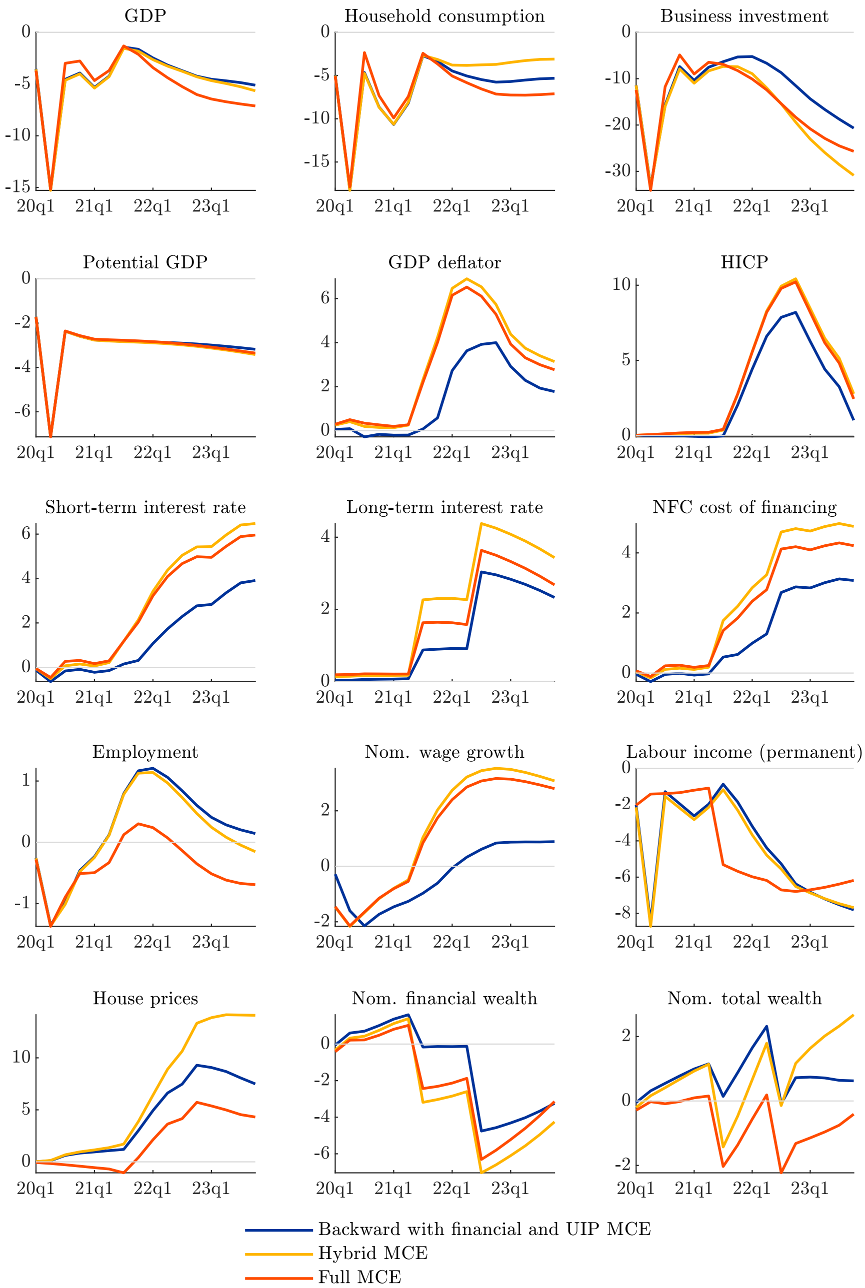
Figure 23: The price surge leg of the scenario under different expectations settings



Notes: Responses to a stylized increase of prices due to energy and other producer and consumer price factors which hits the economy unanticipated in 21Q3. The policy rate is assumed to be constrained until 22Q2 and follows the model's Taylor rule thereafter. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values. Simulation setting: Further simulation setting: exogenous exchange rate and spreads.

Figure 24: The combined scenario under different expectations settings (unconstrained monetary policy)



Notes: Responses to a stylized decrease in demand and productivity as observed during the pandemic as well as an increase of prices due to energy and other producer and consumer price factors which hits the economy unanticipated in 21Q3. The policy rate is assumed to be constrained until 22Q2. Thereafter, it follows the model's Taylor rule and a term premium shock increases the long-term interest rate. The horizontal axis shows time in quarters. The vertical axis depicts GDP deflator inflation, short- and long-term interest rates, NFC cost of financing and nominal wage growth as annualized p.p. deviation from their baseline values. HICP inflation is shown in p.p. deviation from the year-on-year growth in the baseline. All other variables are in percent deviation from their baseline level values. Further simulation setting: exogenous exchange rate and spreads.

B Tables

Table 3: The balanced growth path

Type of variable	trend/constant
Residuals	0
Population, employment growth	$\gamma_n = 0.2\%$
Productivity growth = per capita wage growth	$\gamma_a = 0.3\%$
GDP trend growth = growth of real GDP, consumption, investment etc.	$\gamma_n + \gamma_a = 0.5\%$
Long-term inflation expectations = price growth	$\gamma_p = 0.5\%$
Slack measures in PCs, gaps in Taylor rule and permanent income gaps	0
Unemployment rate, NAIRU	8.7%
Labor force participation rate	49.3%
Nominal short-term interest rate	$\overline{i} = 3.2$ pp ann.
Long-term interest rate	$\overline{i^{10Y}} = 4.7$ pp ann
Corporate bond rate	$\overline{i^{CB}} = 5.0$ pp ann
Cost of equity	$\overline{i^{COE}} = 10.1$ pp ann
Nominal short-term interest rate, foreign economy	$\overline{i^{F}} = 3.2$ pp ann.
Business investment share	$\overline{I/K} = 0.12$
Capital ratio	$\overline{K/Y} = 3.97$
Total income to GDP ratio	$\overline{\theta} = 0.65$
Share of labor income in total	$\overline{\theta^L} = 0.72$
Share of property income in total	$\overline{\theta^P} = 0.20$
Share of transfer income in total	$\overline{\theta^T} = 0.08$

C Updates to the ECB-BASE Model Post-Working Paper Publication

Following the publication of the initial working paper on the ECB-BASE model, a series of updates and enhancements have been implemented to improve its forecasting accuracy and simulation capabilities. The forthcoming paper on version 2 of the ECB-BASE model will provide a detailed discussion of these updates, alongside newly estimated parameters. Here we only aim to provide an overview of the principal alterations made since the publication of the initial working paper. These changes reflect the latest economic insights and data availability, and are summarized below:

- **Base VAR Expectations:** Enhancements in the VAR section are based on experiences with multi-country estimation. To address the issue of a short estimation sample, additional information has been imposed through Bayesian estimation. This estimation relies on US data, which is characterized by much longer time series. Further details about changes to the estimation will be documented in forthcoming publications.

- **Wage and Price Blocks:** The model now directly models nominal wages instead of real wages, as was done in the previous version. Additionally, energy prices have been included directly in the Price Phillips curve to capture marginal cost increases when energy prices rise, thereby directly affecting core prices. The exact specifications can be found in Section 2.2.1.

- **Trade Block:** The focus has shifted to modeling external imports and exports, which depend on external prices and demand indicators. Only extra trade balance is considered in the GDP identity, emphasizing the importance of external sector dynamics in the overall model.
- **Other Changes:**
  - The consumption deflator is now directly linked to HICP inflation, enhancing the model's ability to capture inflation dynamics more accurately.
  - HICP food prices are modeled directly, reflecting the significance of food prices in the inflation measurement.
  - Additional re-estimations have been conducted for the consumption and residential investment blocks, ensuring that these components of the model reflect the latest economic data and insights.
  - The process for the long-term inflation expectations is parameterized such that it is more anchored, in line with the latest evidence. This change reflects observations that, although prices have increased, the long-term inflation expectations remained anchored.

Acknowledgements

This paper builds on Angelini et al. (2019) who introduced the original ECB-BASE model.
Any views expressed represent those of the authors and not necessarily those of the European Central Bank or the Eurosystem.
Any remaining errors are the sole responsibility of the authors.

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