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How Major Central Banks Reacted to the Inflationary Wave of the Early 2020s – The Case of the ECB*

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From 2021 onwards, inflationary pressures around the world have forced most central banks to raise interest rates from a level that had long been around 0 per cent. However, some central banks, including the European Central Bank (ECB), have often been the subject of criticism for not paying enough attention to the emerging inflationary spiral. The author examines whether there is evidence that the ECB started to tighten monetary conditions later than it had done in the past. The interest rate rule widely applied by the academic community and the results of the pseudo-forecast based on this rule show that the ECB moved later than its historical behaviour would suggest, i.e. it started tightening three quarters later than indicated in the model; nevertheless, by the end of 2022, the actual and the theoretical rates were in line thanks to the intensive rate hikes.

Journal of Economic Literature (JEL) codes: E31, E52, E43, E47

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1. Introduction

After two decades of low, stable inflation, the coronavirus pandemic put the world under extreme price pressure from 2021 onwards (*Hardig et al. 2023*). Inflation in most developed countries rose to levels not seen for decades, while interest rates were slow to follow the surge (for the euro area, see *Figure 1*). The sudden change in the environment due to the pandemic and an uncertain future posed a major challenge for governments and central banks around the world, which announced ambitious stimulus packages to help the economy starting from spring 2020 (*Fenz and Valderrama 2023*). Partly thanks to the extensive fiscal stimulus, partly to vaccinations and thus the easing of the pandemic, developed economies have recovered unexpectedly quickly. The extra income injected into the economy

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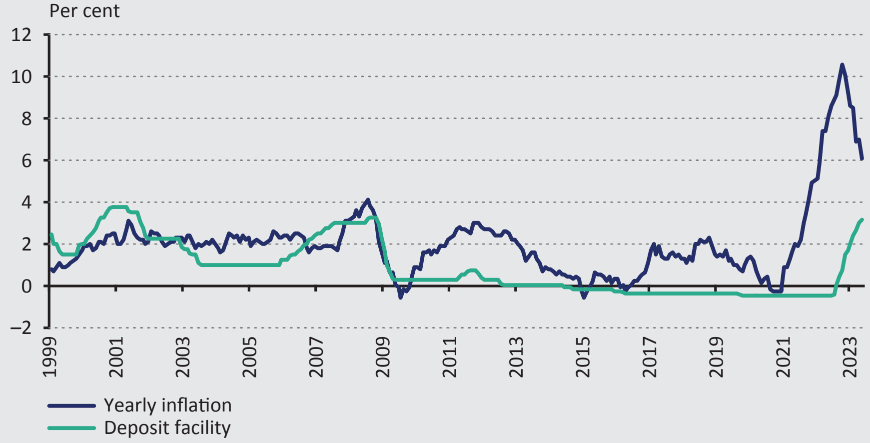
translated into a rise in demand, which may have contributed significantly to the higher inflation (*Cochrane 2022*).

Figure 1
Yearly inflation and deposit facility in the euro area



Source: Eurostat, FRED

In contrast to the rise in demand, there was a severe drop on the supply side due to fragmentation in global value chains. Excess demand was the result of stimulative monetary and fiscal policies, on the one hand, while households started to use up their previously accumulated forced savings during this period, on the other (*Ascari et al. 2023*). In addition, consumption shifted from services to goods with stronger demand for food, consumer durables, semiconductors, raw materials and energy (*Fenz and Valderrama 2023*). Demand for many products boomed when supply was the weakest. China's prolonged zero Covid policy further exacerbated the supply chain situation (because of its dominant role), and the Russia-Ukraine war that broke out in February 2022 worsened food and energy inflation (*Kryvtsov et al. 2023*). The increase in producer prices was easily passed on to consumer prices because high demand was able to absorb it (*Ascari et al. 2023*). The rise in inflation was initially triggered by external factors, but its persistence led to inflationary pressure spreading to more and more segments of the consumer basket (*Várnai 2022*).

Besides inflation, inflation expectations also started to move on an upward path from 2021 onwards, and this already called for central bank intervention (*Kryvtsov et al. 2023*). Most central banks around the world reacted quite similarly to the inflationary pressures that emerged in 2021: at first, practically all authorities disregarded them, leaving their monetary policy unchanged (*Beaudry et al. 2022*). With anchored expectations, a change in interest rates in response to a temporary price shock may take its toll on the real economy; hence, it does no good when central banks react to temporary surges if a credible monetary policy is pursued (*Ábel et al. 2014*). However, if inflation expectations are not rational, it is no longer optimal for the central bank to disregard mounting inflation; instead, it should take action to influence the inflation expectations of economic agents (*Beaudry et al. 2022*). The Magyar Nemzeti Bank (MNB, the central bank of Hungary) was the first central bank in Europe to initiate its rate-hiking cycle in June 2021.

Starting from 2021, an increasing number of central banks have come under fire for having been too slow to act as they believed for too long that the increases in inflation were temporary. Notably, the Federal Reserve (Fed) and the European Central Bank were the main focus of attention, since – due to their size – they play a key role in shaping international monetary policy. Both of these central banks left their monetary conditions unchanged for a long time, citing the temporary nature of the surge in inflation and uncertainties in the macroeconomic environment. Of the two, the Fed was the first to start normalising its monetary policy, as considering the extraordinary size of the government package, it made more sense to talk about inflationary pressures sparked by demand in the US (*Cochrane 2022*).

The ECB started tightening its monetary policy later than the other major central banks (such as the Fed or the Bank of England) and therefore drew even more criticism. (See, for example, *Koranyi and Meier 2022*,[1] *Nair 2022*,[2] *Böhme 2022*[3] or *Brzeski 2022*).[4] In its communication, the ECB long emphasised the temporary nature and external inflation factors. But as inflation continued to rise and new shocks made it increasingly clear that more persistent inflationary trends were occurring, the central bank also began its tightening cycle *(Fenz and Valderrama 2023)*. Later, ECB Vice-President Luis de Guindos also admitted that the central bank had underestimated inflation (*ECB 2023*).[5]

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[1] "Some economists argued that the ECB was already too late in tacking inflation so raising rates to the neutral level (…) will not be enough. 'The ECB remains behind the curve' Commerzbank chief economist Jörg Krämer said. 'It is not enough to just take its foot off the gas, it must also step on the brakes' Krämer said. The ECB's first rate hike in over a decade will still leave it trailing most of its global peers, including the U.S. Federal Reserve and the Bank of England." – *Koranyi and Meier* (*2022*): *paragraphs 17–20.*

[2] "All but one of the 63 economists polled July 8-15 expected the ECB to stick to its pre-committed quarter-point rise on Thursday. (…) But a majority of respondents to an extra question, 19 out of 35, said the ECB should abandon its negative interest rates policy now with a 50 basis point hike. (...) 'The ECB is far behind the curve and risks losing its credibility by not taking decisive action... It should rapidly abandon negative interest rates in July and then increase policy rates by another 50 basis points in September and October' said Martin Weder, senior economist at ZKB." – *Nair* (*2022*): *paragraphs 3–4 and 9.*

[3] "In the end, the pressure on the European Central Bank (ECB) became too great for its policymakers; they could no longer ignore skyrocketing inflation rates in the euro area and dismiss them as "a temporary phenomenon," as ECB President Christine Lagarde said as recently as in December." – *Böhme* (*2022*): *paragraph 2.*

[4] "Today's rate hike provides further evidence of the extreme paradigm change at the ECB. A year ago, ECB president Christine Lagarde said at a press conference that "the lady is not tapering". Now, the ECB has conducted the most aggressive rate hikes in its history, despite a war in Europe. (...) The current ECB, however, has woken up very late to the fact that even if inflation is driven by supply-side factors, too high inflation for too long can damage a central bank's credibility and plant the seeds for unwarranted second-round effects." – *Brzeski* (*2022*): *paragraph 6.*

[5] "Central banks and many other organisations believed for a long time that the increase in inflation was temporary. I have to admit: that was a mistake, but the level of uncertainty was enormous. We all underestimated the persistence of inflation." – *ECB* (*2023*): *paragraph 10.*

With the help of models, I examine the topical issue of whether the view that the ECB started monetary tightening amidst the inflationary pressures of the 2020s later than it had done in the past is correct. To do so, I first estimate interest rate rules of different specifications for the ECB with the OLS method, and then use the results to determine how to interpret the ECB's interest rate policy since the coronavirus pandemic. Do these results show that the ECB acted later than had been customary of it in the past in order to curb inflation? I use the models above to run a pseudo-forecast for the last quarters to obtain an objective, data-based assessment to support my answer.

In *Section 2*, I review the literature to gain an insight into some common interest rate rules derived from the Taylor rule. In *Section 3*, I present the data used for this research, and in *Section 4*, I review the calculations made with the data and the interpretation of the results. Finally, I draw the conclusions.

2. Literature review

In the 1980s, the world experienced extreme inflationary pressures, and thus identifying what factors can help to achieve stable inflation became a common research topic (*Owusu 2020*). In addition, the factors influencing central bank decisions also came to be the subject of examination. In general, monetary policy decisions can be grouped into two broad categories: ad hoc decisions and rule-driven decisions (*Hidi 2006*). With ad hoc decisions, central banks always decide on monetary policy on the basis of newly available data, invoking the data-dependent approach. For rule-driven decisions, a so-called reaction function can be set up to describe the general behaviour of central banks.

One possible course of reaction functions is the simple interest rate rule. It describes how central banks react to changes in the various macroeconomic variables or, to put it another way, how monetary authorities should react (*Owusu 2020*). Typically, most central banks do not explicitly follow any decision model, so the interest rate rules defined by economists can at best be approximations, but in some cases one can find very accurate reaction functions that can provide useful information. Moreover, it is important to stress that the interest rate rule is never a strict constraint, as there are many phenomena that can occur in the economy which are difficult to quantify and thus cannot be compressed into a simple reaction function (*Hidi 2006*). To sum up, the strength of interest rate rules is that they explain the evolution of interest rates in a simple and transparent way and serve as a good guiding principle. However, as with all models, simplifications have to be made, and the suggestions should therefore be treated with careful consideration.

2.1. The Taylor rule

The most common interest rate rule used in academic literature was created by John Taylor in 1993. In his research, Taylor found that the US short-term nominal policy rate (Federal Funds Rate) over the period 1987 to 1992 could be described quite well by the inflation and output gaps *(Taylor 1993)*. Furthermore, he complemented his model with the equilibrium real interest rate, which then took the following form:

$$i_t = r^* + \pi_t + 0{,}5 * (\pi_t - \pi^*) + 0{,}5 * (y_t - y_t^*), \tag{1}$$

where i_t is the nominal policy rate for a given period, r^* is the equilibrium real interest rate, π_t is the actual rate of inflation for a given period, π^* is the central bank's inflation target, y_t is output, and y_t^* is the theoretical potential output for a given t period (*Sauer and Sturm 2007*). Since the Taylor rule includes both inflation and output gaps, it reflects the classic economic policy trade-off between low inflation and economic growth. By its very design, it can be used to examine both demand and supply shocks in a transparent and simple way. However, it is important to stress that Taylor himself warned that the reaction function he estimated was not a rule to be followed mechanically, but rather a guiding principle for monetary policy (*Regős 2013*). The interest rate rule can not only help central banks with their decision-making; it can also make monetary policy actions more transparent to private economic agents (*Owusu 2020*).

By regrouping the members of the original formula as follows, we get the form below which is more widespread in academic literature and is used as reference from here on in this paper:

$$i_t = (r^* + \pi^*) + 1{,}5 * (\pi_t - \pi^*) + 0{,}5 * (y_t - y_t^*). \tag{2}$$

The Taylor rule can be interpreted in two ways. First, it connects the monetary policy stance with real variables, i.e. it establishes a link between the considerations and the regularities in accordance with which monetary policy decides on interest rates and the potential reaction of central banks to changes in macroeconomic fundamentals (*Abaligeti et al. 2018*). Second, the model can be used to determine whether the current interest rate is lower or higher than the theoretical rate, i.e. if a given central bank pursues a looser or tighter monetary policy based on the macroeconomic fundamentals (*Hidi 2006*).

2.2. Common interest rate rules derived from the Taylor rule

Since Taylor's 1993 paper, a number of modifications to the Taylor rule have been proposed with the aim of capturing the monetary policy stance of central banks more precisely and comprehensively (*Belke and Klose 2011*). Today, most models are supplemented with projections, are based on real-time data and/or include an interest rate smoothing parameter (see the rest of this section for details). In addition, other variables may also be relevant for the estimation, such as exchange rate, foreign reference rate or changes in money supply (*Owusu 2020*). Furthermore, if we want to estimate the interest rate rule of a small open economy, the model may best be complemented by foreign trade variables or the risk premium (see e.g. *Hidi 2006* or *Regős 2013*).

Examining *equations (1) and (2)*, we see that the original Taylor rule has only present-time members and no forward-looking variables. However, according to the standard practice of central banks, policymakers place at least as much emphasis on the projected data as on the historically observed data. Monetary policy has some inertia because, due to the nature of monetary transmission, central bank decisions typically have a delayed impact on the economy (*Owusu 2020*). So, if a monetary authority were to rely exclusively on present and past data, it would be constantly lagging behind reality on account of this inertia, and would thus tend to make inappropriate decisions (*Belke and Klose 2011*).

Considering the above, it is worth adding expectations to the original Taylor rule (*Svensson 2003* or *Clarida et al. 1998*). If, instead of actual figures, projections are used, the original equation takes the following form:

$$i_t = (r^* + \pi^*) + \beta_\pi * \left[E\left(\pi_{t+j} \middle| \Omega_t\right) - \pi^* \right] + \beta_y * (y_t - y_t^*), \tag{3}$$

where $E\left(\pi_{t+j} \middle| \Omega_t\right)$ is the predicted value of inflation j later based on the set of information (Ω_t) available in the period t. The literature contains not only inflation forecasts but also output forecasts; however, this paper focuses only on inflation forecasts. One possible way to improve this research would be to use output gap projections in the estimation.

The interest rate smoothing parameter is also regarded as a standard addition. Historically, central bankers have tended to be reluctant to take big interest rate decisions abruptly, as unpredictability can cause considerable turbulence (*Sauer and Sturm 2007*). For example, even if the interest rate rule or macroeconomic conditions warrant a drastic increase in interest rates at once, central banks typically prefer to do so in smaller steps to ensure predictability. Interest rates have therefore a certain stickiness or persistence, which is why an interest rate smoothing parameter, as one of the most ordinary extensions of the Taylor rule, should be added to the original reaction function (*Gorter et al. 2008*). Technically, this means that the model will converge towards the rate of the previous period with some weight (λ), and will prevent it from freely adjusting to the level justified by the model. Where an interest rate smoothing parameter is included in the reaction function, the original equation changes as follows:

$$i_t = \lambda * i_{t-1} + (1-\lambda) * \left[(r^* + \pi^*) + \beta_\pi * (\pi_t - \pi^*) + \beta_y * (y_t - y_t^*)\right]. \quad (4)$$

Predictability is not the only reason though why the use of the interest rate smoothing parameter can give us a picture that is closer to reality: in the case of an economic shock, not even central banks have a perfect set of information at their disposal; hence, they tend to modify interest rates cautiously and hold off to avoid causing more trouble (*Owusu 2020*).

The literature distinguishes between real-time data (available at the time of the decision) and ex-post data (*Sauer and Sturm 2007*). Macroeconomic data are usually only available with some delay; for example, when a quarter ends, the GDP data for that quarter will only be known 1.5 to 2 months later, which means that central banks cannot use such data to guide their decision. Furthermore, data are revised periodically, for instance, because of a previous error, new information or seasonality. Statistical offices may also revise their estimation method from time to time; hence, data can change retrospectively in response to the modified methodology. It should be noted, however, that these ex-post adjustments do not always represent a significant difference relative to the previous data.

The use of real-time data only is another option that could make the estimation of the Taylor rule more realistic. The above considerations imply that the data series available when a central bank decides on interest rates do not necessarily correspond to the actual statistics at the time. For this reason, it may be useful to include in the model only (real-time) data that were actually available to the central bank at the time of the decision (*Belke and Klose 2011*). This way, we can better simulate the circumstances of a given central bank decision.

3. Presentation of the data used in the research

Based on the considerations presented in the introduction, different interest rate rules can be calculated for the ECB which will later help us understand the interest rate policy the central bank followed from 2020 onwards. The research uses quarterly data and its time horizon extends from 1999 Q2 to 2022 Q4, covering a total of 95 observations.

The literature review above cited an argument that real-time data make the estimation of the interest rate rule more realistic. However, this approach is applied here with limited scope due to the assumption that it only changes the values minimally, and the ex-post data reflect the underlying economic processes in an unbiased way. Nevertheless, one possible way to improve this research is to produce estimates using only real-time data, as this would make the results more reliable.

- *Output gap* $(y_t - y_t^*)$ – The output gap is the difference between actual GDP and potential output expressed as a percentage. The European Commission gives an annual frequency estimate of potential output for the euro area using a production function, which is published in its *AMECO* database alongside actual GDP (*Havik et al. 2014*). Annual frequency data can be easily converted to quarterly frequency data by linear interpolation, and the difference of the logarithms of the two data series is the output gap.

  This research was based on the assumption that the information obtained from the output gap in period *t* can be used by the central bank when deciding on interest rates in period *t*. Although at the end of a quarter we do not yet know the actual data for the quarter concerned, high-frequency business cycle indicators (such as the Purchasing Managers' Index) can provide central banks with a good approximation of GDP trends.

- *Inflation gap* $(\pi_t - \pi_t^*)$ – Quarterly frequency, year-on-year inflation figures are taken from the ECB's data warehouse (*ECB Data Portal*[6]), which are based on Eurostat monthly data. The ECB originally aimed at maintaining an annual inflation rate below but close to 2 per cent, and thus an inflation target approaching a limit from below was set. However, an important change in methodology is that from 8 July 2021, the ECB wanted to see a symmetric inflation target of 2 per cent in the medium term, rather than one below but close to (*Benigno et al. 2021*). Regarding the period prior to July 2021, *Paloviita et al.* (*2021*) concluded that the ECB's effective (*de facto*) inflation target ranged from 1.6 to 1.8 per cent. In view of the authors' findings, it seems reasonable to assume a hypothetical inflation target of 1.7 per cent, and 2 per cent after the revision of the methodology until the very end of our time horizon. The resulting time series shows by how many percentage points actual inflation in the euro area deviated from the inflation target in the quarter reviewed.

  As with the output gap, it can be assumed that the information obtained from the inflation gap in period *t* can be used by the central bank when deciding on interest rates in period *t*. Although the central bank cannot yet know the value of actual inflation for the whole quarter at the end of the quarter, it can estimate it with a high degree of accuracy from the figures of the other two months.

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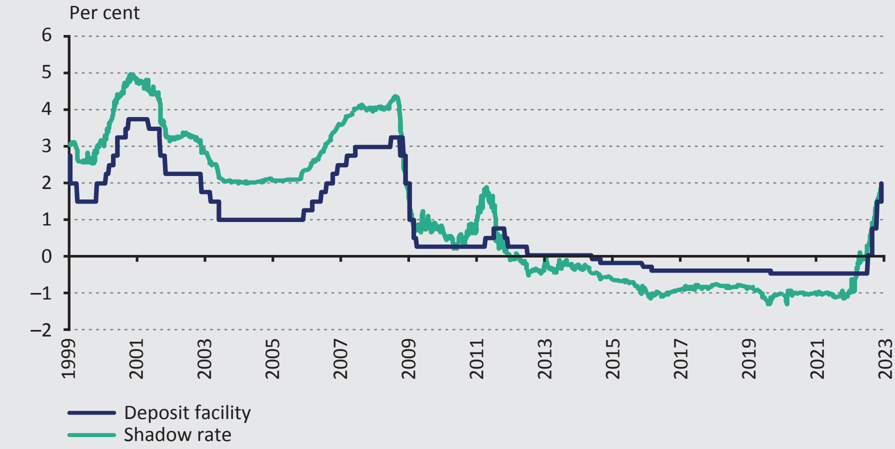
[6] https://data.ecb.europa.eu/, previously ECB Statistical Data Warehouse (ECB SDW)

- *Inflation forecasts* ($E(\pi_{t+h}|\Omega_t)$) – Previous studies clearly show that it is appropriate to include forecasts in the interest rate rule for a more realistic outcome. It is standard practice for the ECB to make quarterly macroeconomic projections at the end of each quarter, which are also available in the ECB's data warehouse (*ECB Data Portal*[7]). The exact use of this variable will be discussed later under the model specifications because of its significance.

Figure 2
The ECB deposit facility rate and the shadow rate used in the research



Source: FRED, De Rezende and Ristiniemi (2022), Bloomberg

- *Shadow rate* (i_t) – The outcome variable of the interest rate rule requires some short-term interest rate that is influenced by the ECB. However, in the second half of the 2010s, the ECB's policy rates hardly changed due to the phenomenon of the zero lower bound, and the central bank chose to shape the monetary policy of the euro area by unconventional means. This bias can be overcome, for example, by using a calculated rate that takes into account other monetary policy actions of the ECB, rather than the actual key rates. For this purpose, I adopted the shadow rate from the study of *De Rezende and Ristiniemi* (*2022*), which is derived from the 1-month OIS rate. The purpose of the shadow rate is to reflect not only the central bank's conventional interest rate moves, but also the ECB's unconventional policy. This reveals a much more realistic picture of the monetary policy stance of the central bank, which is a major benefit for my modelling exercise.

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[7] https://data.ecb.europa.eu/data/datasets/MPD

The rate calculated by the authors applies from 1999 Q1 to 2022 Q2. For the last two quarters missing from the time horizon of the research, the ESTR (Euro Short Term Rate)[8] is used, taken from the *Bloomberg* database. The ESTR aptly captures the short-term financing conditions in the euro area, and is calculated similarly to the one in *De Rezende and Ristiniemi* (*2022*). *Figure 2* shows the difference between the shadow rate calculated in the paper and the deposit facility rate in the euro area *(FRED)*.

- *Equilibrium real interest rate* (r_t^*) – In the vast majority of interest rate rules, the equilibrium real interest rate is assumed to be constant over the entire time horizon (as in the original Taylor rule). However, many studies (e.g. *Belke and Klose 2011*) warn that the real interest rate can also change dynamically, and therefore it is inaccurate to consider it to be constant. Following the practice of the authors, a forward-looking real interest rate is obtained using the Fisher equation by subtracting one-year projected inflation from the nominal interest rate (which, in our case, is the shadow rate), and determining the trend of the time series with the help of the HP filter.[9]

4. Results

4.1. Model specifications

An objective assessment of the ECB's monetary policy of recent years requires an interest rate rule that aptly represents the functioning of the central bank. For this reason, I estimated different Taylor-type model specifications using the method of ordinary least squares (OLS). The estimate covers the entire available sample, assuming that the ECB's monetary policy stance has not changed since 1999. One possible way to develop this research further is to estimate a time-varying rule (see, for example, *Abaligeti et al. 2018*).

An obvious question that arises when constructing models is the endogeneity of variables. Endogeneity may be present in the model because the forecasts of central banks are made along an endogenous policy path, i.e. the future decisions of central banks are expected to shape the macroeconomic environment in a way so that the

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[8] The shadow rate data series ends in 2022 Q2, from then on I prorated the daily changes (differences) in the ESTR so that by the end of the time horizon of the analysis, 31 December 2022, the extended shadow rate equals the original ESTR.

[9] For quarterly data, a filtering parameter of $\lambda = 1600$ is recommended. It should be noted that, due to the specificity of the HP filter, endpoint uncertainty may occur, so the result of filtering may be doubtful at the end of the sample. In addition, because of the HP filter calculation, each data point is calculated using the entire sample, which violates the principle of using real-time data as mentioned in *Subsection 2.2.* This research could possibly be improved by applying a filtering method that tackles endpoint uncertainty and uses only real-time data.

variable follows the indicated path over the forecast horizon, where future inflation is a function of interest rate decisions. The explanatory variables are therefore not independent but correlate with the error term, since besides affecting the interest rate, they themselves are affected by the interest rate, in which case the results may be biased.

However, in the shorter term, this effect is not yet reflected in the forecasts due to the specificities of monetary transmission, as in the short run central banks may consider expected inflation as given, exogenous. *Romer and Romer* (*2004*) also argue that in the very short run (0 to 2 quarters), central bank forecasts do not contain any inside information on the expected monetary policy trend; therefore, they used a 2-quarter inflation forecast for their research. In addition, *Jarociński and Karadi* (*2020*) also showed that the immediate impact of a monetary policy shock on GDP and the GDP deflator is practically negligible. Precisely in order to minimise any endogeneity bias, I myself used the inflation forecast two quarters ahead (t+2) in the model.

It is important to stress, however, that the forward-looking operation of central banks typically exceeds half a year due to the specificities of the transmission mechanism, and, as mentioned in the introduction, there may be real economic loss if a central bank adjusts interest rates in response to a temporary price shock. Accordingly, longer-term forecasts would yield a more realistic interest rate rule, but this demands more caution because of the endogeneity problem just mentioned.

Overall, as an alternative estimation, it may be worth examining an interest rate produced by the model using projections for t+4. This is a time horizon where the bias from endogeneity is not yet too large, but – in line with the central bank's operation – it covers a longer time span. If the two specifications yield similar results, this proves the robustness of the model, since there is no significant difference compared to the model with a longer time horizon when the t+2 model is used, and it even ensures the exogeneity of the variables, which makes the t+2 model a reasonable choice.

In addition to OLS, the literature typically uses instrumental variable (IV) models to estimate interest rate rules. IV models are useful because if the appropriate instruments are specified, endogeneity in the model can be eliminated (*Baum et al. 2003*). Instruments are usually introduced to interest rate rules that have expectations. Although the interest rate rule estimated in this paper does contain inflation expectations, they are of such a short horizon – as explained above – that it renders the endogeneity bias negligible. Instruments are, on the other hand, usually introduced to interest rate rules that have variables that respond quickly to interest rates, such as the exchange rate (*Hidi 2006*); this research, however, does not estimate interest rate rules with such variables. Consequently, it is appropriate to use OLS to estimate the interest rate rule under this specification. For the sake of robustness, one possible way to improve this research would be to use IV estimation in addition to OLS.

The models were run using the HAC weighting matrix created by *Newey and West* (*1987*), which has since been enhanced by researchers on several occasions. As a result, the t-statistics computed in the model remain robust even in spite of the heteroskedasticity and autocorrelation of the error term. All of this is necessary for us to be able to make an informed decision about the significance of the explanatory variables.

This paper tests the relevance of two different inflation variables: the inflation gap in a given period (also included in the original Taylor rule) and the inflation gap forecast for period t+2.[10] Furthermore, based on the considerations in the relevant literature, it seemed sensible to include an interest rate smoothing parameter, which represents the t–1 value of the outcome variable as an explanatory variable. I examined a total of four specifications which are summarised in *Table 1*.

Table 1
Variables of the model specifications used in the research

	1 – current inflation gap	**2 – forward-looking inflation gap**
(a) baseline models	**a1** output gap + real interest rate + current inflation gap	**a2** output gap + real interest rate + forward-looking inflation gap
(b) baseline models + interest rate smoothing	**b1** output gap + real interest rate + current inflation gap + interest rate smoothing	**b2** output gap + real interest rate + forward-looking inflation gap + interest rate smoothing

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[10] The model with t+4 forecasts was only run to test robustness (see below).

The equations of the models are shown below:

a1) $$i_t = \alpha + \beta_y * (y_t - y_t^*) + \beta_r * r_t^* + \beta_{\pi 1} * (\pi_t - \pi_t^*) + \epsilon_t \qquad (5)$$

a2) $$i_t = \alpha + \beta_y * (y_t - y_t^*) + \beta_r * r_t^* + \beta_{\pi 2} * [E(\pi_{t+2}|\Omega_t) - \pi_{t+2}^*] + \epsilon_t \qquad (6)$$

As seen in *equation (4)*, inclusion of the interest rate smoothing parameter changes all coefficients of the original model to be higher by a factor of $(1-\lambda)$. Thus, the parameters estimated with the OLS method do not yet show the pure effect of the variables, but rather the value adjusted for interest rate smoothing. To retrieve the pure effect, the regression coefficients of the original model are divided by $(1-\lambda)$, which gives us the following equations:

b1) $$i_t = \frac{\alpha}{1-\lambda} + \frac{\beta_y}{1-\lambda} * (y_t - y_t^*) + \frac{\beta_r}{1-\lambda} * r_t^* + \frac{\beta_{\pi 1}}{1-\lambda} * (\pi_t - \pi_t^*) + \lambda * i_{t-1} + \epsilon_t \qquad (7)$$

b2) $$\begin{gathered} i_t = \frac{\alpha}{1-\lambda} + \frac{\beta_y}{1-\lambda} * (y_t - y_t^*) + \\ \frac{\beta_r}{1-\lambda} * r_t^* + \frac{\beta_{\pi 2}}{1-\lambda} * [E(\pi_{t+2}|\Omega_t) - \pi_{t+2}^*] + \lambda * i_{t-1} + \epsilon_t \end{gathered} \qquad (8)$$

In these equations, ϵ_t denotes the error term which represents the exogenous monetary policy shock. This variable is intended to grasp why the actual interest rate in a given period may differ from that suggested by the model. This may be because the decision-making body of a central bank does not operate as a simple equation, but is a complex outcome of individual opinions and perceptions which may change constantly. In addition, central bankers take into account unquantifiable or difficult-to-quantify factors in their decisions, which may result in deviations from the model. Central banks may also change their behaviour over time, shift their attention to other factors, or may reconsider the weights assigned to the various variables according to their importance, which may also cause interest rates to vary (*Edelberg and Marshall 1996*).

4.2. Regression results

Table 2 shows the regression results of the four models. At a significance level of 10 per cent, most explanatory variables significantly explain the changes in the shadow rate between 1999 Q2 and 2022 Q4. The hypothesis that the coefficient of the output gap in model a2 and the coefficient of the equilibrium real interest rate in model b1 is 0 in reality (apart from the intercept) cannot be clearly rejected.

The information criteria show that the accuracy of the models marked b is substantially better than that of the specifications without interest rate smoothing. The fairly high values of the t-quotients calculated from the table indicate that the interest rate smoothing parameter is very significant in the interest rate rule and is worth including. Of the specifications examined, the b2 model provided the best fit, signifying that the forward-looking inflation gap is a useful element in the model for interest rate smoothing. Based on the past, this model shows that if the ECB forecasted a negative inflation gap of 1 percentage point two quarters ahead, then, *ceteris paribus*, the ECB's move typically reduced the shadow rate by 78 basis points.

The results obtained differ from the interest rate rules previously estimated for the ECB. *Belke and Klose (2011*) added an interest rate smoothing parameter to their model and arrived at an interest rate persistence of 0.83 and an inflation coefficient of 0.6. Replacing the original inflation member with the 6-month inflation forecast, they estimated a substantially higher parameter of 1.83, while the interest rate smoothing coefficient equalled 0.61. *Sauer and Sturm* (*2007*) found that when the Taylor rule was augmented with the interest rate smoothing parameter, the inflation coefficient did not deviate significantly from 0 between January 1991 and October 2003. However, when 12-month forecasts were added, significant variables were obtained: 1.85 for the inflation parameter and 0.87 for the interest rate smoothing parameter. *Owusu* (*2020*) calculated estimates for the euro area from 2003 to 2018: the model with an interest rate smoothing parameter and a 3-month inflation forecast estimated an inflation coefficient of 1.1 and an extremely high interest rate smoothing parameter of 0.98. *Gorter et al.* (*2008*) obtained similar results: they also estimated the interest rate smoothing parameter to be high, at 0.98 between January 1997 and December 2006, and 1.35 for the projected inflation parameter.

It should be noted that the models marked b bespeak multicollinearity. This is due to the fact that the equilibrium real interest rate and the first lag of the outcome variable correlate and explain each other. This phenomenon entails that the effects of the variables intermingle, which translates into greater variance and uncertainty. However, as the VIF indicators were (though by a small degree) below 10, it is not necessary to address this phenomenon (see *Table 3* in the *Appendix*).

Table 2
Regression results of the different model specifications

	a1 equation (5)	a2 equation (6)	b1 equation (7)	b2 equation (8)	b2” equation (8)
	1999 Q2 – 2022 Q4				1999 Q2 – 2019 Q4
Intercept α	1.5954 *** (0.1266) –	1.0204 *** (0.1475) –	0.2719 ** (0.1244) *1.4453*	0.0237 (0.0922) *0.1242*	–0.0695 (0.1382) *–0.3000*
Output gap β_y	0.0974 * (0.0586) –	0.0835 –0.0580 –	0.0808 ** (0.0358) *0.4296*	0.0666 ** (0.0305) *0.3490*	0.0859 *** (0.0298) *0.3709*
Equilibrium real interest rate β_r	0.9824 *** (0.0624) –	0.9976 *** (0.0653) –	0.1258 (0.0768) *0.6691*	0.1411 * (0.0761) *0.7392*	0.1580 ** (0.0706) *0.6824*
Current inflation gap $\beta_{\pi1}$	0.2733 *** (0.0515) –	–	0.0942 *** (0.0269) *0.5007*	–	–
Forward-looking inflation gap $\beta_{\pi2}$	–	0.3492 *** (0.0655) –	–	0.1498 *** (0.0362) *0.7847*	0.2429 ** (0.1023) *1.0490*
Interest rate smoothing parameter λ	–	–	0.8119 *** (0.0822) –	0.8091 *** (0.0786) –	0.7685 *** (0.0721) –
Observations	95	95	95	95	83
Global F-test	102.17 ***	98.48 ***	484.78 ***	631.35 ***	613.11 ***
Adjusted R^2	90.42%	90.17%	97.54%	97.79%	97.94%
BIC	185.89	188.37	60.39	49.93	38.68
HQIC	179.80	182.28	52.78	42.32	31.45

Note: The table shows the regression output of equations (5) to (8). All estimates were made using OLS, the outcome variable in each case being the shadow rate calculated for the ECB in the study of De Rezende and Ristiniemi (2022). In all cases, the top value of the explanatory variables is the raw regression coefficient of the variable, with an asterisk next to it indicating the significance of the variable (significant at 10 per cent, ** significant at 5 per cent and *** significant at 1 per cent), the middle value in brackets shows the standard errors calculated with the HAC matrix, and the bottom value in italics is the regression coefficient adjusted for interest rate smoothing (see equations (7) and (8)). The latter is only meaningful in the models marked b, but obviously not in the row of the interest rate smoothing parameter. The global F-test row shows the test statistic value and, using the markings mentioned above, the significance of the test.*

Next, I compare the actual monetary policy of the ECB with the rate justified by the model. In this case, the estimated interest rate rule can be seen as the standard central bank behaviour in the almost 25 years of the ECB's history, which encapsulates how the central bank usually reacts to different shocks. Comparison with the actual interest rate enables us to assess how far the ECB has deviated from its own historical standard behaviour in the recent inflation period. To do so, I used the results of the b2 model, as this specification ensured the best fit over the whole period, and therefore this model is the most suitable to describe the ECB's decision-making process.

To compare actual and theoretical interest rates, I used a pseudo – out-of-sample – estimation. The main idea of this method is that even if a longer sample was available, parameter estimates would still be made for a somewhat shorter period. The model is then run for the period not used for parameter estimation, and a forecast is produced where the behaviour of the model can be examined. In the context of interest rate rules, this method is convenient because the model does not use data from the future, so the extracted data series can be directly compared with real data.

As above, I re-estimated the b2 model for the period from 1999 Q2 to 2019 Q4 (83 observations). Thus, the time horizon used for the pseudo-forecast is the period from 2020 to the end of 2022 (12 observations). The reason for splitting the sample at this point is that before 2020, there was no sign of a coronavirus epidemic, supply chain difficulties or a sharp rise in energy prices in the euro area. Therefore, this provides a good benchmark of the central bank's behaviour before the turbulences of recent quarters. For the re-estimation, I used the OLS estimation as in the previous runs, with the standard errors again weighted with the HAC weighting matrix. If we look at the regression results of the interest rate rule estimated on the shorter sample in the last column of *Table 2*, we see that it is equally significant. This may prove that inflation forecasts have not only become important in the context of the extraordinary inflationary pressures of recent quarters, but they also play a fundamental role in the ECB's interest rate policy.

For robustness checks, I also ran the b2" model with t+4 inflation forecasts in view of the considerations mentioned above and made a pseudo-forecast in the same way. The resulting values are basically the same as the original regression results, and the trend remains unchanged. The variables are significant also in the alternative model (again, the intercept is not significant). Among the significant variables, the only main shift is observed in the coefficient of the modified inflation parameter: while in the past the ECB typically responded to one unit of inflation gap widening expected to occur six months later by adjusting the interest rate by 105 basis points, the same shift usually triggered a 184-basis point change in interest rate conditions over a one-year horizon. The higher inflation coefficient was to be expected, given that a jump in inflation expected a year later is a sign of more drastic and lasting change in the inflation environment than if it occurred over a six-month horizon, and could thus spur a stronger central bank reaction. As previously argued, because the original and the alternative models produce similar results, the results of the original model are reliable and the analysis can be continued (the results of the alternative model are shown in *Table 4* and *Figure 7* in the *Appendix*).

Figure 3
The shadow rate estimated by the b2 model and the actual shadow rate

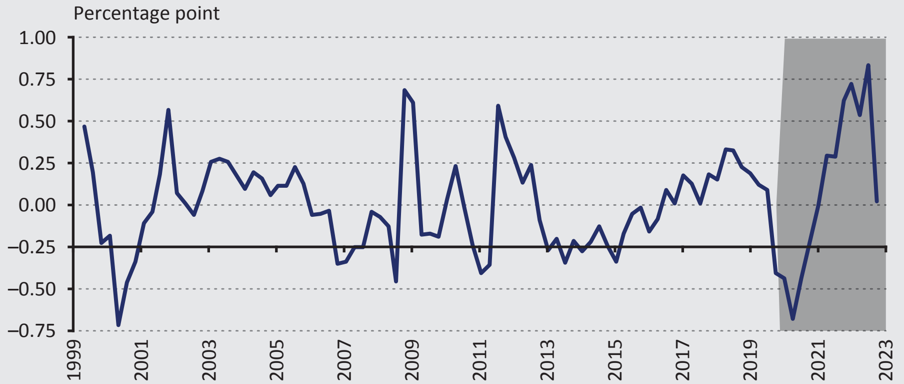
Note: The regression results are taken from model b2" in Table 2. Starting from 2020 Q1, I used a pseudo-forecast based on data available from 1999 Q2 to 2019 Q4. The grey band indicates the 95 per cent confidence interval of the forecast.

The pseudo-forecast (*Figure 3*) and the resulting residuals (*Figure 4*) call for several points to be considered. The interest rate rule suggested significantly looser monetary conditions from the beginning of 2020 during the coronavirus pandemic than the ECB actually implemented. It should be noted that, going into the coronavirus pandemic, both the actual rate and the calculated shadow rate were already in the negative range (*Figure 2*). Moreover, the ECB launched an ambitious pandemic emergency purchase programme (PEPP) in response to the pandemic, in addition to its existing asset purchase programme (APP) to further ease monetary conditions (*Blot et al. 2020*).

As the economy recovered, the theoretical interest rate rule proposed gradual tightening. After the pandemic waves, the negative output gap in the euro area closed gradually as the economy recovered, while inflation started to rise as demand-supply frictions intensified. The model first indicated tighter conditions in 2021 Q2 compared to the shadow rate at the time, and from then on until the end of the forecast horizon it suggested a level higher than the one that actually materialised. The interest rate rule implicitly indicates that in the past, when the ECB saw a surge in six-month forecasts of this kind, it typically responded by raising the rates, but this time this happened later.

The ECB started tightening later than the theoretical level, but by the end of 2022 the two rates were nearly equal. Contrary to the model, the actual shadow rate started to increase in 2022 Q1, three quarters later, when the central bank announced that it would trim its asset purchase programmes. The first actual rate hike was effected by the monetary authority in July 2022, so we see a later reaction compared to its historical practice, but by the very end of the time horizon of the analysis, in 2022 Q4, the actual rate had almost reached the theoretical rate. Although the model predicted an earlier rate hike based on past behaviour, by the end of 2022 the ECB had arrived at a level consistent with its own historical behaviour, thanks to rigorous tightening.

Figure 4
Differences between the shadow rate estimated by the b2" model and the actual shadow rate



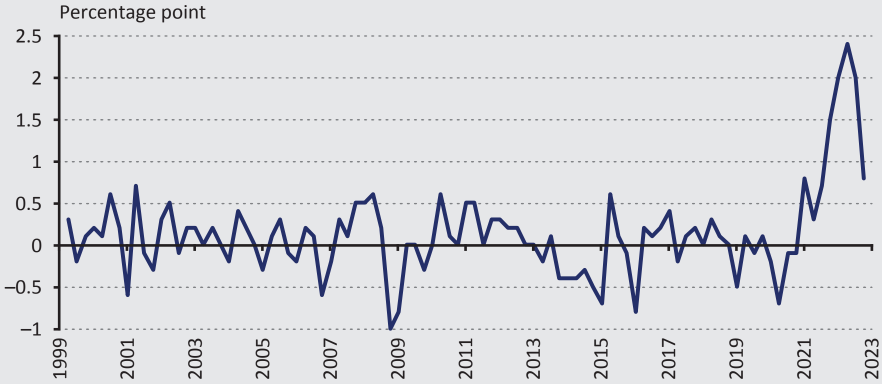
Note: The residuals are taken from model b2" in Table 2. The pseudo-forecast period starts from 2020 Q1 (grey band). If the value is positive (negative), the rate estimated by the model is higher (lower) than the actual value.

4.3. Possible explanation for the ECB's actions

In theoretical terms, the interest rate rule indicates that in the past, such a change in the macroeconomic environment prompted the ECB to raise interest rates earlier relative to the steps it actually took. To conclude this study, we should examine why the ECB might have decided to intervene later. The central bank's behaviour may, among other factors, be explained by the accuracy of the forecasts, the uncertain economic environment or inflation expectation trends.

The perception that inflation is transitory is one possible explanation for the central bank's actions. For a long time, the central bank took the position in its decisions that although in the short run inflation may appear to be rising, its experts deemed this to be a temporary phenomenon not requiring monetary policy intervention. The same thinking prevailed in the justification given by the Fed or the Bank of England. As a result, the ECB's longer-term forecasts (on which its monetary policy decisions primarily rest) did not reflect the elevated inflation environment. This may explain why we saw a later reaction from the central bank compared to its historical behaviour.

Figure 5
ECB forecast errors for t+2 inflation



Note: The figure shows the forecast error of the ECB for t+2 inflation. If the value is positive (negative), the t+2 actual figure ended up being higher (lower) than the ECB forecast, meaning that the central bank underestimated (overestimated) inflation.

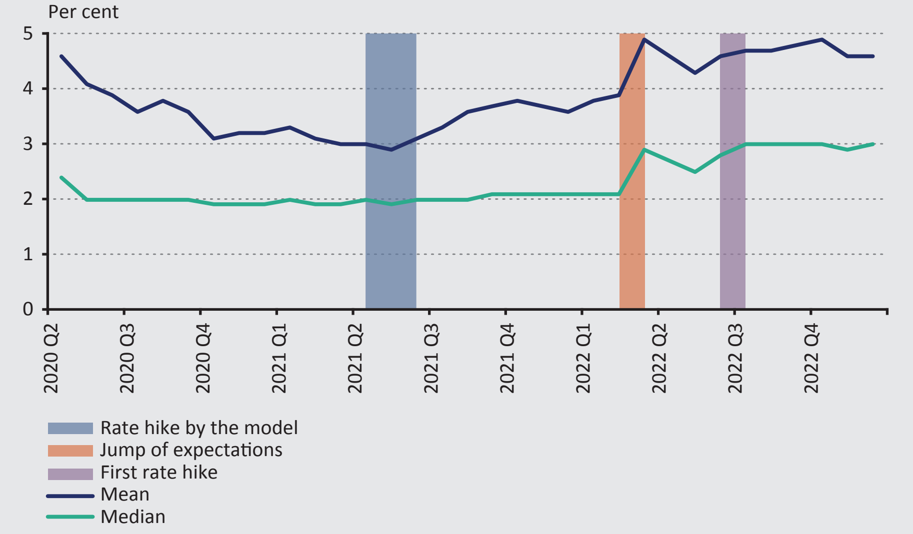
Source: ECB Data Portal

Inflation forecasts have recently lost much of their accuracy, which may have affected the euro area's policy rate path. New, unexpected shocks pushed inflation higher than anticipated, and the situation continued to fail to normalise. The error of the inflation forecast for t+2 in this paper hovered around 0 for almost the entire period under review, showing a nearly constant standard deviation; from 2021 onwards, however, the central bank's forecast accuracy worsened in an unprecedented way (*Figure 5*). The underestimated inflation path could be one reason why the ECB moved later compared to its historical behaviour.

Poorer forecast accuracy may be attributed primarily to the uncertain macroeconomic environment. Central banks were in a quite difficult situation:

demand and supply factors in the 2020s intermingled, making it difficult to tell what central bank action would be appropriate, since a tight monetary policy could have easily stalled economic recovery. A burning question over the time horizon of this paper's analysis was how the coronavirus pandemic would evolve, whether there would be further waves, and incorporating these processes into forecasts and decisions represented a new challenge. In addition, the Russia-Ukraine conflict that erupted in February 2022 added to the uncertainty of the macroeconomic environment. As a result, not only the ECB's forecasts, but also those of other central banks proved to be less accurate than before. All things considered, the uncertain economic environment may also explain why the ECB acted later compared to its previous practice.

Figure 6
Long-term (3-year) inflation expectations of euro area consumers



Source: ECB Consumer Expectations Survey

The evolution of inflation expectations could also justify the central bank's behaviour. The median long-term inflation expectation of euro area consumers remained stable around the target for a long time, but then increased significantly in March 2022 (*Figure 6*). The interest rate rule first indicated a higher interest rate than the actual rate in 2021 Q2, when median expectations were still around 2 per cent. In reality, the ECB decided to raise interest rates for the first time in July 2022 when median expectations rose to almost 3 per cent. The fact that consumer inflation expectations remained anchored for a long time could be another reason why the ECB moved later than it had in the past.

The Fed started tightening earlier than the ECB, but this different timing can be explained by, among other things, the different macroeconomic environment. While both central banks stressed the temporary nature of inflation, the ECB tightened later than the Fed in several respects. While the Fed ended its asset purchase programmes and started its rate-hiking cycle in March 2022, the ECB stopped expanding its balance sheet in June 2022 and began raising interest rates in July. Quantitative tightening started in June 2022 in the US, but only in March 2023 in the euro area. Nonetheless, it should be stressed that a different macroeconomic environment may warrant a different central bank response. Thanks to the massive government programme, the US recovered from the crisis more quickly, and the recovery of the countries in the euro area was heterogeneous. In addition, there were profound differences among the inflation rates of euro area countries, which could also justify slower but more prudent decision-making. All of this made the ECB's situation more difficult. Moreover, the Russia-Ukraine war that broke out in early 2022 had a more severe impact on Europe than it had on the United States. Hence, all things considered, the different timing between the Fed and the ECB should come as no surprise.

5. Summary and conclusions

This paper looked at how the ECB's monetary policy responded to inflationary pressures in the 2020s. In my research, I examined whether there was *any evidence that the ECB started tightening monetary conditions later than it had done in the past*. To provide an objective analysis, I applied the interest rate rule frequently used in the literature, which, by describing the general behaviour of central banks, serves as a good benchmark for evaluating actual monetary policy.

First, I gave a brief insight into the origin and meaning of the Taylor rule in my literature review, and looked at how it could be improved. I then presented the variables used for the research and the transformations performed on them. I used the resulting database to create different specifications based on the literature, and tested their fit to the data using the OLS method. The results show that the best fit is obtained when the equation includes an interest rate smoothing parameter and uses forecasts instead of a real-time inflation term.

I then made a pseudo – out-of-sample – forecast to test what theoretical interest rate the model would suggest based on the data for the years 2020–2022, the focus of the study. The results show that the ECB reacted later than it had done in the past. Beginning from 2021 Q2, the model proposed stricter conditions, while in reality monetary policy started to tighten from 2022 Q1, three quarters later. However, from 2022 H2, the ECB took strong measures to curb inflation, bringing the actual interest rate to a level consistent with the central bank's standard practice by the end of 2022. It can be concluded that the uncertainty of the forecasts, the adverse economic environment, the large inflation differences across euro area member states and, accordingly, the dissimilarities in inflation expectations, or the fact that each country managed the recovery from the downturn brought about by the coronavirus pandemic in a different way, could, among other factors, explain why it took the ECB longer to decide than before.

The research could be further improved in several ways. One such way is to use output gap forecasts in the estimation. Another option is to base the estimates solely on real-time data, which can produce more realistic results. A filtering method that tackles endpoint uncertainty and uses only real-time data could also be applied. Or, as another option, a time-varying rule could be estimated. Yet another possible way to improve this research is to use IV estimation in addition to OLS for the sake of robustness.

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Appendix

Table 3
VIF indicators measured in the models

	a1 equation (5)	a2 equation (6)	b1 equation (7)	b2 equation (8)	b2” equation (8)
	1999 Q2 – 2022 Q4				1999 Q2 – 2019 Q4
Output gap β_y	1.724	1.809	1.728	1.813	1.710
Equilibrium real interest rate β_r	1.575	1.622	9.679	9.187	7.383
Current inflation gap $\beta_{\pi 1}$	1.155	–	1.483	–	–
Forward-looking inflation gap $\beta_{\pi 2}$	–	1.214	–	1.445	1.583
Interest rate smoothing parameter λ	–	–	9.634	8.932	8.018

Note: The numbers indicate the factor by which the variance of a given explanatory variable is inflated because the explanatory variables within that regression all influence one another. For a VIF below 5, multicollinearity is not a problem in the model, between 5 and 10 it needs attention but the model remains stable, for a VIF above 10, multicollinearity needs to be addressed.

Figure 7
Differences between the shadow rate estimated by the b2 model using alternative t+4 forecasts and the actual shadow rate

Note: The residuals are taken from the second column of Table 4. The pseudo-forecast period starts from 2020 Q1 (grey band). If the value is positive (negative), the rate estimated by the model is higher (lower) than the actual value. Compare: Figure 4.

Table 4
Robustness check

	b2” with t+2 forecasts	**b2” with t+4 forecasts**
	1999 Q2 – 2019 Q4	**1999 Q2 – 2019 Q4**
Intercept α	–0.0695 (0.1382) *–0.3000*	–0.3589 (–0.2180) *–1.4391*
Output gap β_y	0.0859 *** (0.0298) *0.3709*	0.0883 *** (0.0312) *0.3540*
Equilibrium real interest rate β_r	0.1580 ** (0.0706) *0.6824*	0.1798 ** (0.0723) *0.7209*
Forward-looking inflation gap $\beta_{\pi 2}$	0.2429 ** (0.1023) *1.0490*	0.4601 *** (0.1682) *1.8448*
Interest rate smoothing parameter λ	0.7685 *** (0.0721) –	0.7506 *** (0.0800) –
Observations	83	83
Global F-test	613.11 ***	667.46 ***
Adjusted R^2	97.94%	97.86%
BIC	38.68	41.79
HQIC	31.45	34.55

Note: The table shows the regression results of the original models using t+2 forecasts and of the alternative models using t+4 forecasts. Both estimations were made using OLS, the outcome variable in both cases being the shadow rate calculated for the ECB in the study of De Rezende and Ristiniemi (2022). In all cases, the top value of the explanatory variables is the raw regression coefficient of the variable, with an asterisk next to it indicating the significance of the variable (significant at 10 per cent, ** significant at 5 per cent and *** significant at 1 per cent), the middle value in brackets shows the standard errors calculated with the HAC matrix, and the bottom value in italics is the regression coefficient adjusted for interest rate smoothing. The global F-test row shows the test statistic value and, using the markings mentioned above, the significance of the test.*