Economic Modelling 127 (2023) 106466

Contents lists available at ScienceDirect

Economic Modelling

journal homepage: www.journals.elsevier.com/economic-modelling

Estimated monetary policy rules for the ECB with granular variations of forecast horizons for inflation and output[☆]

Jens Klose

THM Business School, Gießen, Germany

ARTICLE INFO

JEL classification:
E52
E58

Keywords:
Monetary policy rules
ECB
Forecasts

ABSTRACT

How does the European Central Bank (ECB) respond to inflation and output? To answer this question, we build a granular real-time database for inflation and output linked directly on the decision dates of the ECB. We develop daily forecasts for those two variables for a forecast horizon of up to fourteen months. We apply three different monetary policy rules, four different forecast data sources, three different ways of data computation and with respect to three different interest rates. The results indicate that the various data sources and computation approaches do not substantially change the findings. Those can be different for the monetary policy rule applied or the interest rate used. The results tend to be time-varying. In general, the forecast horizon for inflation is rather long-term, while the picture for output is less clear. Financial market participants can use the findings as it makes ECB monetary policy more predictable.

1. Introduction

The interest rate setting of central banks is always highly debated, i.e. on days where monetary policy decisions are taken. This is not different with respect to the decisions of the European Central Bank (ECB). Days before the Governing Council of the ECB meets to decide upon new monetary policy actions, the media and experts speculate what the ECB would or should do in order to deliver their objective of price stability. This was defined from 2003 onwards as being fulfilled when the inflation rate is close to, but below 2% in the medium term.[1] In the center of those decisions is always the policy interest rate the ECB can change on these meetings.

In the literature, the issue of interest rate setting by central banks is frequently evaluated via monetary policy rules. Possibly the most famous rules in this context are the Taylor rule (Taylor, 1993) and the first-difference rule (Orphanides, 2003). We will also use these two rules and additionally add a rule in between which is a Taylor rule with interest rate smoothing. All of these rules try to explain the interest rate setting policy of the central bank by looking at deviations of inflation from its target and of output from its potential.

The main innovation of this article is a real-time database built for the ECB decision days. This granular database builds daily forecasts for inflation rates and output based on three different forecast sources with three different methods of data computation. The structure of the underlying data allows for forecasts of up to 418 days (approximately one year and two months). Moreover, we use three different interest rates as explanatory variables: First, the main refinancing rate as the official policy rate of the ECB. Second, the short-term (daily) interbank rate the Euro Overnight Index Average (EONIA). Although this rate is, in principle, also subject to the zero-lower bound, it is less restrictive, since rates can be as low as the deposit rate, which is typically 0.5 percentage points below the main refinancing rate. Third, to abandon the zero lower bound and to specifically account for unconventional monetary policies carried out by the ECB since the beginning of the financial crisis, we use the shadow rate of Krippner (2013). This rate has the advantage over other shadow rates (like e.g. Wu and Xia, 2016) of being available on a daily basis and, thus, no further approximation is necessary.

The comprehensive assessment of different rules, data sources, computation methods and interest rates allows us to examine which specifications and forecast horizons deliver the best fit in the sense of explaining ECB interest rate setting best. This might also be an indication of how long the medium term orientation of the ECB really is.

The results indicate that the source of the data as well as the way the daily forecasts for inflation and output are computed tend to deliver relatively similar results. Thus, it can be concluded that all data

☆ I thank the participants of the European Economics and Finance Society Annual Conference 2021 and the seminar participants in Gießen for critical discussions. Moreover, I would like to thank the associate editor and two anonymous reviewers for helpful comments on an earlier version of this article.

E-mail address: jens.klose@w.thm.de.

[1] In its 2021 strategy review the ECB redefined its policy target to two percent. We stick to the "older" definition as it was mostly in place in the sample period under investigation.

https://doi.org/10.1016/j.econmod.2023.106466
Received 21 November 2022; Received in revised form 22 June 2023; Accepted 3 August 2023
Available online 9 August 2023

sources and computation methods consist of rather similar information, which is actually good news as each of those sources and computation methods could be used and the insights could be transferred to the other sources and computation methods. However, the results tend to differ concerning the monetary policy rule applied and the interest rate used in the rules. In the latter case, especially the use of shadow rules and thus unconventional monetary policy makes a difference. In general it has to be concluded that the inflation response of the ECB is rather long-term, meaning the best fit rules are frequently found at the maximum forecast horizon of 418 days. With respect to the output (-gap) response the picture is less clear but depends crucially on the specification chosen.

The results are of interest for financial market participants and central bank watchers alike as finding the best fit rules i.e. with respect to the forecast horizon makes ECB monetary policy more predictable and thus surprises which may cause disruption in the financial markets could be minimized. However, it has to be acknowledged that the best fit monetary policy rules may change over time, thus it has to be constantly monitored whether the ECB has possibly shifted its focus.

The paper is organized as follows. Section 2 presents the three monetary policy rules to be estimated and the literature with respect to the ECB. Section 3 describes the data sources used and the transformations performed to generate the daily data. Section 4 presents the results of the empirical estimations. Section 5 concludes the article.

2. Monetary policy rules

In this section we describe the similarities and differences of the three monetary policy rules we apply. We start with the most-famous monetary policy rule, the Taylor rule (Taylor, 1993). This rule tries to explain the level of the interest rate. It has the following form:

$$i_t = r^* + \pi_t + c_\pi \cdot (\pi_t - \bar{\pi}_t) + c_Y \cdot (Y_t - Y_t^*) \tag{1}$$

According to this rule the central bank interest rate (i_t) depends on the level of the natural real interest rate (r^*), the inflation rate (π_t), the deviation of inflation from its target ($\pi_t - \bar{\pi}_t$) and the deviation of output from its potential, the so-called output gap ($Y_t - Y_t^*$). The sum of the natural real interest rate and inflation represents the equilibrium level of the central bank interest rate when both deviations are zero, and thus if inflation equals its target and output equals its potential. The two deviations signal the direction of adjustment once they are nonzero. The strength of the adjustment is determined by the reaction coefficients (c_π) and (c_Y). Generally, positive reaction coefficients should be expected, since the central bank is due to increase its policy rate once inflation exceeds its target or output exceeds potential, and vice versa.

While Taylor (1993) originally derived the Taylor rule with respect to the interest rate setting of the US Federal Reserve, it was later on also applied to various other central banks, including the ECB (e.g., Gerdesmeier and Roffia, 2005; Gorter et al., 2008; Gross and Zahner, 2021).[2] Generally, the setting of policy rates by the ECB can also be described by a Taylor rule. However, to better fit with the actual data, the response coefficients should be estimated rather then set. To do so we operationalize Eq. (1) to the following estimation equation:

$$i_t = c(1) + \pi_{t+e} + c(2) \cdot (\pi_{t+e} - 1.75) + c(3) \cdot (Y_{t+f} - Y_{t+f}^*) + \varepsilon_t \tag{2}$$

Note that this Eq. (2) alters Eq. (1) in three dimensions: First, not only contemporaneous inflation and output data are used but also forecasts. Since we use daily data, the indices e and f denote the forecast horizons in terms of inflation and output, respectively, which need not be equal. Second, since the natural real interest rate is an unobservable variable, it needs to be estimated. We do so via the coefficient $c(1)$, which is not time varying, by construction. We will relax this constraint, when we come to time-varying parameter estimates in order to model a potential decrease in this variable over time, as found by other papers for the euro area (e.g. Mesonnier and Renne, 2007; Holsten et al., 2017; Beyer and Wieland, 2019; Brand and Mazelis, 2019). Third, the inflation target of the ECB is set to 1.75 in line with the "below but close to 2%" definition. The value 1.75 is chosen as the midpoint of the upper and lower bounds of the ECB inflation target of Orphanides and Wieland (2013), namely 2% and 1.5%, respectively. Even if we assume the inflation target to be 2% or 1.5%, that would only shift the estimate of the natural real interest rate 25 basis points downward or upward consistently throughout all specifications and forecast horizons, but would have no effect on the overall fit of the regression.

The first-difference rule applied was originally proposed by Orphanides (2003) for the Federal Reserve. It takes the following form:

$$i_t - i_{t-1} = c_\pi \cdot (\pi_t - \bar{\pi}_t) + c_{\Delta Y} \cdot (\Delta Y_t - \Delta Y_t^*) \tag{3}$$

According to this rule, the difference in policy rules between the current and the previous monetary policy meeting ($i_t - i_{t-1}$) is determined by the difference in the inflation rate and its target, thus similar to the Taylor rule, and the difference in the growth rates of output and its potential ($\Delta Y_t - \Delta Y_t^*$). So, the latter can be described as the output growth gap instead of the output gap, as in the Taylor rule. Using a forward-looking specification and reaction coefficients of 0.5 each, Orphanides and Wieland (2013), Bletzinger and Wieland (2017), and Hartmann and Smets (2018) showed that the first-difference rule describes the changes in the policy rates of the ECB quite well. We rearrange Eq. (3) and thus operationalized it for estimation purposes to, obtaining

$$i_t = i_{t-1} + c(4) \cdot (\pi_{t+e} - 1.75) + c(5) \cdot (\Delta Y_{t+f} - \Delta Y_{t+f}^*) + \varepsilon_t \tag{4}$$

Eq. (4) thus estimates the level of the interest rate as the Taylor rule does. Here, one major difference between the first-difference rule and the Taylor rule becomes obvious. While the prior obtains the level by the previous policy rate, which is normally close to the actual level – since central banks adjust their policy rates, if anything, gradually, by 25 basis points at a meeting, and only under extraordinary circumstances by larger increments – the latter level must be determined, that is, by the natural real interest rate, which is unobservable by nature.[3] When it comes to inflation and output growth responses, the adjustments are comparable to those of the Taylor rule, that is, we allow for varying forecasts of the inflation and output growth gaps, and the inflation target is again approximated as 1.75. The choice of the inflation target in this case is justified by Bletzinger and Wieland (2017) and Hartmann and Smets (2018), who estimated the inflation target to be in a range of 1.72 to 1.85.

Finally, we apply a rule in between the two rules explained above. This is a Taylor rule with interest rate smoothing. The rule is applied since it is well known that central banks adjust their interest rates rather inertially to changing fundamentals. The rule takes the following form:

$$i_t = c_i \cdot i_{t-1} + c_\pi \cdot (\pi_t - \bar{\pi}_t) + c_Y \cdot (Y_t - Y_t^*) \tag{5}$$

[2] Of course, the Taylor-rule has not only been applied with respect to the ECB. For applications to other countries see e.g. Hayat and Mishra (2010) or Eleftheriou and Kouretas (2023) for the US, Sznajderska (2014) for Poland and Caporale et al. (2018) for five emerging market economies.

[3] Orphanides (2006) points out that this is one advantage of first-difference rules, since they do not rely on unobservable variables such as the natural real interest rate.

This rule is in between the other two because on the one hand, the Taylor rule implies that their is no interest smoothing at all and thus $c_i = 0$ while substituting this by the natural real interest rate and the inflation rate. On the other hand, the first difference rule sets the interest rate smoothing parameter equal to unity ($c_i = 1$), thus implying perfect interest rate smoothing. The Taylor rule with interest rate smoothing does make neither of those assumptions but estimates the degree of interest rate smoothing via the parameter (c_i). We rearrange Eq. (5) along the very same lines as the previous two rules to operationalize it for estimation purposes. Thus, the rule takes the following form:

$$i_t = c(6) \cdot i_{t-1} + c(7) \cdot (\pi_{t+e} - 1.75) + c(8) \cdot (Y_{t+f} - Y^*_{t+f}) + \varepsilon_t \tag{6}$$

So, in this rule there are three parameters to estimate, which are the response to the lagged interest rate ($c(6)$), the reaction to the inflation gap ($c(7)$), where the inflation target is again set to 1.75, and the reaction to the output gap ($c(8)$). Please note, that even if the interest rate smoothing would be estimated as unity this would not directly lead to the first-difference rule as in the latter the output growth gap instead of the output gap is used.

3. Data

This section describes in detail the data sources and data transformations used for the variables in our estimation.

3.1. Data sources

Throughout the article we make use of real-time data, and therefore, the real-time critique of monetary policy rules (Orphanides, 2001) does not apply to our estimates.

Interest rates are generally not subject to the real-time critique. We use three different concepts: The daily money-market rate EONIA, the ECB's main refinancing rate, and the Krippner's (2013) shadow rate. The EONIA and the main refinancing rate are very similar to each other, while the shadow rate deviates from the other two rates with the introduction of unconventional monetary policy measures. That is, the shadow rate is found to be lower, since the zero lower bound is not binding. The data of the EONIA and main refinancing rate are obtained from the ECB Statistical Data Warehouse, while the shadow rate data are taken from Krippner's website.[4]

For all the other variables, contemporary as well as forecast data are needed. These are obtained from three different sources. First, we use the Eurosystem/ECB staff macroeconomic projections, which are always published in the last month of each quarter, together with the Governing Council meeting. These projections present i.e. data on inflation and real gross domestic product (GDP) growth (used as the output growth indicator). The first three publications in each year show both the outcomes of the previous year and forecasts for the current and following two years. Moreover, the final publication of each year in December, presents forecasts for three years ahead.[5] The first projection was published in December 2000, which is thus the beginning of the sample period when using those data, while all other estimations start with the introduction of the ECB, in the beginning of 1999. Before 2013, the projections published only range forecasts; therefore, we always use the midpoints of these ranges as point forecasts.

Second, we use the forecasts of the ECB Survey of Professional Forecasters (SPF). In this survey, the ECB asks financial and nonfinancial institutions (e.g., economic research institutions) about their expectations concerning important macroeconomic variables, such as inflation and real GDP growth. The survey is conducted each quarter. In recent years, participants' responses were due in January, April, July and October, and the averaged results were mainly also published in the respective months. In the first years of the survey, the publications were more irregular. Since it is unclear when the survey results are available to the members of the Governing Council and, thus, when they could influence monetary policy decisions, we introduce two approaches to the data. The first one is to use always the date the responses were due from the participating institutions. This approach assumes that the results become immediately available to policymakers once the questionnaires are received, such that the time to process the data is very short. The other approach uses the dates when the results of the survey are actually published. This approach therefore assumes that the Council members have no informational advantage over the other market participants, such that the time process the data is quite long. The survey publishes the average forecasts of the inflation rates and real GDP growth of the current and the next calendar year. In the third and fourth quarters, the values for the next calendar year are also presented[6]

Third, we use the forecasts for the euro area carried out by the European Commission. Although not generated by the ECB, it is the most detailed forecast for the euro area. In other words it is the only institutions presenting forecasts for the output gap and potential output growth, which we need to estimate the monetary policy rules. Therefore, when it comes to the output gap and potential output growth, we use these forecasts by the Commission in all the specifications, in line with Orphanides and Wieland (2013).[7] The disadvantage of using the Commission's forecasts is that the publication dates vary considerably over time and the forecasts are performed to different depths. Today the Commission performs four forecasts each year, in February, May, July, and November. The February and July forecasts are only interim forecasts, with data, for our purposes, on only inflation and real GDP growth. In contrast to this the May and November forecasts are fully-fledged forecasts, with data on the output gap and potential output growth as well. Unfortunately, the forecasts for potential output growth are only published since November 2012. However, based on the output gap ($Y - Y^*$) and real GDP growth forecasts (ΔY), we can calculate the implied potential output growth rates (ΔY^*) by using the following formula:

$$\Delta Y^*_{t+g} = \frac{\frac{\prod_{h=0}^{g}(1+\Delta Y_{t+h})}{1+(Y_{t+g}-Y^*_{t+g})}}{\frac{\prod_{h=0}^{g}(1+\Delta Y_{t+h-1})}{1+(Y_{t+g-1}-Y^*_{t+g-1})}} - 1 \tag{7}$$

Note, that the time-dimension denoted by the index g is now yearly, since the Commission provides yearly forecasts in the same way as the other databases. Specifically, in the first three quarters the forecasts for the current and next year are published, and forecasts for the year after next are added to the last forecasts of the year.

[4] https://www.ljkmfa.com/

[5] This is the current publication practice which started in December 2016. From March 2014 to October 2016, forecasts for only two calendar years were published, and, before that, forecasts for one calendar year in the first three quarters were published, with additional forecasts two calendar year ahead forecasts added in the December publication. This changing publication horizon does not, however, influence our results, since we need only forecasts for two calender years at the end of each year.

[6] The survey also publishes one-, two- and five-year-ahead forecasts. For comparability with the other data sources, we do not use this information.

[7] The alternative would be to estimate the potential output via filtering techniques. However, Orphanides and van Norden (2002) have shown that this estimation has serious problems. Even if we leave this point aside, one cannot be sure whether the ECB Council members actually followed the same model to estimate potential output. However, we know that the forecasts of the Commission were available at a specific point in time.

3.2. Data transformation

We now describe how daily variables are computed from the yearly data. Since the daily rules are directly matched with the decisions days of the ECB Governing Council, our sample period starts on the January 7, 1999. Until 2015, the ECB Governing Council met monthly (on the first Thursday of the month) to discuss monetary policy changes. From 2015 onwards, these 12 meetings per year were reduced to eight meetings, now taking place every six to seven weeks, instead of every four to five weeks. The end of the sample is the meeting on October 29, 2020. In total, our sample, thus, includes 234 decisions. For those meeting dates, we collected the three different interest rates to model the possible changes in monetary policy associated with each Council meeting.

To transform yearly data into daily data, we follow the same procedure as Orphanides and Wieland (2013), Bletzinger and Wieland (2017), and Hartmann and Smets (2018) for their derivation of potential output growth. They transform yearly into quarterly data by setting the yearly values in the forecasts equal year-end values and then approximating the quarterly data as proportions of the last and current years' forecasts. In our case, year-end value is thus December 31 each year. We extend this procedure by applying it not only to potential output growth, but also to inflation, real GDP growth, and the output gap. We aim to generate forecasts that range, on the one hand, as far into the future as possible, by keeping, on the other hand a complete sample. Thus, the maximum forecast is set to 418 days, which is about one year and two months.[8]

We employ three different approaches to build the forecasts. First, we only use the data of the latest available (LA) forecasts, so the decisions of the Governing Council are driven purely by the last forecast known at a specific point in time. The variables thus constructed using the following formula:

$$
\begin{aligned}
x_{i+j}^{LA} &= \frac{n-(i+j)}{n} \cdot x_0^{LA} + \frac{(i+j)}{n} \cdot x_n^{LA} \qquad \forall (i+j) \le n \\
x_{i+j}^{LA} &= \frac{m-(i+j-n)}{m-n} \cdot x_n^{LA} + \frac{(i+j-n)}{m-n} \cdot x_m^{LA} \qquad \forall (i+j) > n
\end{aligned}
\tag{8}
$$

where the variable (x) is inflation, real GDP growth, the output gap, or potential GDP growth; n stands for the number of days in the current year, so either 365 or 366, and m for those in the current and the next year, being thus 730 or 731; i represents the day of the ECB decision within a year, where, for example, if the Council meeting takes place on January 31, the value would be 31; j is the forecast horizon, ranging from zero (contemporaneous value) to 418 (maximum forecast horizon). This equation is split into two parts, representing the daily forecasts of the current year (if $(i+j) \le n$) and for the next year (if $(i+j) > n$). The current year daily forecasts depend on the previous years' (x_0) and the current years outcome (x_n) and is closer to the latter the later the forecast day is in the year. The same holds with respect to the next year's daily forecasts, where the boundaries are, the current years outcome (x_n) and the next years outcome (x_m).[9]

As an example for the calculation, we take the first Governing Council meeting on January 7, 1999. At that time the latest available forecast e.g. from the European Commission were published on October 21, 1998 which are thus the latest available data. The year 1999 had 365 days (which is n) and the January 7 is the 7th day of the year, thus i is equal to 7. E.g. for the contemporaneous forecast (j=0) the computation would result in taking 358/365 times the variable (inflation or output) value of the year 1998 plus 7/365 times the value of the year 1999. Accordingly, the fractions would change the longer the forecast horizon j is chosen. This computation is applied until a forecast horizon of 358 days is reached since this would mean that the forecast is applied for the last day of the year December 31. For longer forecast horizons, the lower part of Eq. (8) is applied. E.g. for a forecast horizon of 359 which corresponds in our example to the January 1, 2000, we build the forecast value as 365/366[10] times the value of 1999 plus 1/366 times the value of 2000.

While Eq. (8) is purely backward looking in the underlying forecasts and does thus not capture new information between two forecasts, we employ rational approximation (RA) as a second strategy. Here, the forecast day is weighted if it is closer to the last available or to the next available (NA) forecast publication. The variables therefore take into account not only information that is currently available, but also information that is rationally expected, with the latter becoming more important the closer the decision is to the next forecast. This specification can be written as follows:

$$
\begin{aligned}
x_{i+j}^{RA} &= \frac{k-l}{k} \cdot x_{i+j}^{LA} + \frac{l}{k} \cdot \left[\frac{n-(i+j)}{n} \cdot x_0^{NA} + \frac{(i+j)}{n} \cdot x_n^{NA} \right] \qquad \forall (i+j) \le n \\
x_{i+j}^{RA} &= \frac{k-l}{k} \cdot x_{i+j}^{LA} + \frac{l}{k} \cdot \left[\frac{m-(i+j-n)}{m-n} \cdot x_n^{NA} + \frac{(i+j-n)}{m-n} \cdot x_{m-n}^{NA} \right] \qquad \forall (i+j) > n
\end{aligned}
\tag{9}
$$

The next available forecasts are calculated in the same way as the latest available forecasts presented above. The weighting of the influence of both forecasts types is given by k and l, where k denotes the days between the latest and the next available forecasts, while l signals the days between the latest forecast and the ECB decision.

In order to illustrate the computation, we expand the example given for the latest available data for the first Governing Council meeting on January 7, 1999. As mentioned above for European Commission forecasts the latest available data rely on the forecasts of October 21, 1998. Thus, we compute the forecasts here in the very same fashion as for the latest available forecasts. In order to compute rational expectations also the next available forecast are used. Those were published on March 30, 1999. For those forecasts, we do the very same calculations as described for the latest available data with only changing the forecast values. Finally, a weighting is given to the forecasts from October 21, 1998 and March 30, 1999. Between both publications there are 160 days which is equal to k. The day of the decision (January 7, 1999) is 78 days after the first publication date, thus l equals 78. Therefore, the forecast based on the publication from October 21, 1998 enter with a fraction of 82/160 and those of the March 30, 1999 with 78/160.

As a third strategy, we use information on current inflation (CI), since inflation rates are published every month and thus more frequently than the forecasts.[11] We therefore use the information of the latest inflation rate instead of the previous year's inflation. This approach can be formalized as follows:

$$
\begin{aligned}
x_{i+j}^{LA\_CI} &= \frac{n-(i+j+d)}{n-d} \cdot x_d^{LA\_CI} + \frac{(i+j-d)}{n-d} \cdot x_n^{LA\_CI} \qquad \forall (i+j) \le n \\
x_{i+j}^{LA\_CI} &= \frac{m-(i+j-n)}{m-n} \cdot x_n^{LA\_CI} + \frac{(i+j-n)}{m-n} \cdot x_m^{LA\_CI} \qquad \forall (i+j) > n
\end{aligned}
\tag{10}
$$

Compared to Eq. (8), the difference is that we introduce d to represent the number of days elapsed until the currently known inflation rate. Therefore, for example, if the inflation rate of January is known,

[8] The limiting factor for all the estimations is the decision on November 8, 2001, since no two-year-ahead forecasts of the output gap or potential output growth were available at that time, as the Commission published its new forecast only on November 21, 2001.

[9] For December meetings, this equation would need to be expanded by forecasts for the next year and the year after next forecasts, since the daily forecasts range into the calendar year after the next.

[10] 366 is used here as the year 2000 was a leap year.

[11] In fact, inflation rates are even published twice a month by Eurostat. The first (preliminary) publication is typically at the end of the respective month, while the second (about two to three weeks later) is the official publication. However, inflation rates are hardly ever corrected, even between those two publications.

d would be equal to 31. Note that this changes only the shorter end of our forecasts, that is, only those for the current calendar year, while the forecasts for the next calendar year remain unchanged.

As an example, take again the first Governing Council meeting on January 7, 1999. At that time, already the yearly inflation rate of November 1998 was known. So the year is prolonged by 31 days as the December 1998 inflation rate was missing. Thus, the contemporaneous forecast for January 7, 1999 is now computed as 358/396 times the known realized inflation rate in November 1998 plus 38/396 times the latest available forecast of inflation for the year 1999.

4. Results

In this section we present the results of our empirical specification. We have three different policy rules, three different computation methods, three different interest rates, and four different data sources. In total, we therefore test 108 different specifications. We follow the same ordering when interpreting the results, starting by differentiation between rules, followed by the data computations, interest rates, and data sources.

Moreover, we estimate the rules for varying inflation and output forecasts, ranging from zero to 418 days each.[12] By allowing for all possible forecast combinations between the two variables, 175.561 different policy rules are estimated for each specification and we are able to determine the forecast horizon that fits the interest rate best. We show some of those results in the next subsection. Please note however, that those policy rules describe the policy actions of the ECB rather than its preferences. In order to interpret the response coefficients and forecast horizons as ECB's (medium term) preference you would have to assume that those are revealed preferences as the ECB can determine its actions freely. However, the forecast combination that best fits the actual interest rate setting behavior of the ECB can be assumed to vary in time. Therefore, we present in the following subsection time-varying coefficient results, to demonstrate whether this is actually true.

Since we use real-time data, thus the data the members of the ECB Governing Council had at hand when making their decisions, instrumental variable methods, such as the generalized method of moments (Clarida et al., 1998, 2000), are not necessary in our estimation. Instead the regressions are estimated in a straightforward manner by using ordinary least squares (OLS).

4.1. Baseline results

This section presents the results of the different rules for the whole sample period. First, we present the results of all 175.561 different estimates of the various rule specifications in one figure. Second, of the various rules, we pick the one that best describes the ECB's interest rate setting, which can thus be called the "best fit" rule when describing ECB policy. This rule is determined as having the highest R-squared value of all 175.561 rules in one specification.

4.1.1. Taylor rules

With respect to Taylor rules for every specification three coefficients are estimated: the natural real interest rate, the response coefficient for the inflation gap and the response coefficient for the output gap. Moreover, the goodness of fit is shown by the R-squared.

Latest Available Data

Fig. 1 shows the results when using the latest available data and the EONIA as the interest rate. Several conclusions can be drawn from this:

First, the results look rather similar, irrespectively of the data source. This holds i.e. for the Commission and SPF data, while rules with ECB data appear to be a bit different.

Second, the coefficient estimates are generally in line with expectations, meaning that all the coefficients are always found to be positive. The estimates of the natural real interest rate range from zero to 0.5, while this rate tends to be lowest for contemporaneous data and highest for either contemporaneous inflation and long-term output forecasts or for long-term inflation forecasts. The estimates of the output response coefficient are between 0.15 and 0.4. The point estimates gradually rise with rising output gap forecast horizon. This pattern of higher estimates for longer-term forecasts with respect to the ECB is also found by Sauer and Sturm (2007) or Gorter et al. (2008). Orphanides (2001), however, finds the opposite with respect to the Federal Reserve. But this result may be driven by the simultaneous variation in inflation and output gap forecast horizon. Our results also indicate that the output coefficient decreases with higher inflation forecast, so possibly offsetting the effect of output gap forecast horizon. The highest coefficients are found when the rule is estimated with contemporaneous inflation, and the highest number of days is determined for output forecasts. The response coefficients with respect to inflation differ more widely, and this difference is almost exclusively due to differences in inflation forecasts. While the estimates are almost 0 when contemporaneous inflation forecasts are used, they peak at about 1.4 if the rule is estimated with the maximum of 418 forecast days. It is obvious that the inflation response increases considerably with the inflation forecast horizon. This is evidence that the ECB is tackling inflation expectations rather than the currently observed inflation rate. This result of rising inflation coefficients the longer the forecast horizon is frequently found in literature either for the Federal Reserve (Orphanides, 2001) or the ECB (Gerdesmeier and Roffia, 2005; Sauer and Sturm, 2007; Gorter et al., 2008 or Belke and Klose, 2011). However, the inflation coefficient is not the only element that rises with the inflation forecast horizon. The very same pattern also holds with respect to R-squared. While this measure is quite low, at levels of about 0.3 for contemporaneous inflation forecasts, it rises to 0.55 with rising inflation forecast horizon. In contrast to the inflation coefficient estimates, however, with the exception of the Commission forecast, the best fit to the data is found not at the maximum number of forecasting days with, 418, but shortly before.

From the results in Fig. 1 no conclusions about the significance of the coefficients can be drawn. To do so we use Fig. 2 showing a two-dimensional graph of the inflation and output-gap coefficients for its varying forecast horizons. In order to be able to build these graph, we use the following restrictions: First, the analysis is done for the Taylor rules with latest available data, EONIA and EU-Commission data which corresponds to the data used in the upper-left chart in Fig. 1. However, for the other data sources the figure would be quite similar, as the data sources do not change the results considerably. Second, since we always employ estimates of two forecast horizons (one for inflation and one for the output-gap), we have to restrict one dimension in order to be able to draw two-dimensional graphs of the coefficients. We do so by restricting always the other forecast horizon at its best fit level, meaning at the level where the highest R-squared can be found. This means e.g. that for the inflation graph on the left side of Fig. 2 the output-gap forecast horizon is held constant at 10 days because this is the best fit forecast level. For the output-gap graph, the inflation forecast horizon is held constant at 418 days. From the results, it becomes obvious that the inflation coefficient rises in with the inflation forecast horizon. While the coefficients are even insignificant for a forecast horizon of up to 120 days, in the end they are clearly significant. For the output-gap coefficients, there is not much variation. The coefficients are significant throughout.

In Fig. 3, the analysis is executed with the ECB main refinancing rate instead of the EONIA. The changes are marginal for this interest rate, so the conclusions drawn are still valid in this specification.

[12] It may be assumed that the ECB itself does not perform its monetary policy analysis in such a detailed way, meaning on a daily basis. Nevertheless, the approach is useful to give in indication in which range the best-fit forecast horizons lie and how large the differences for various forecast horizons and specifications are.

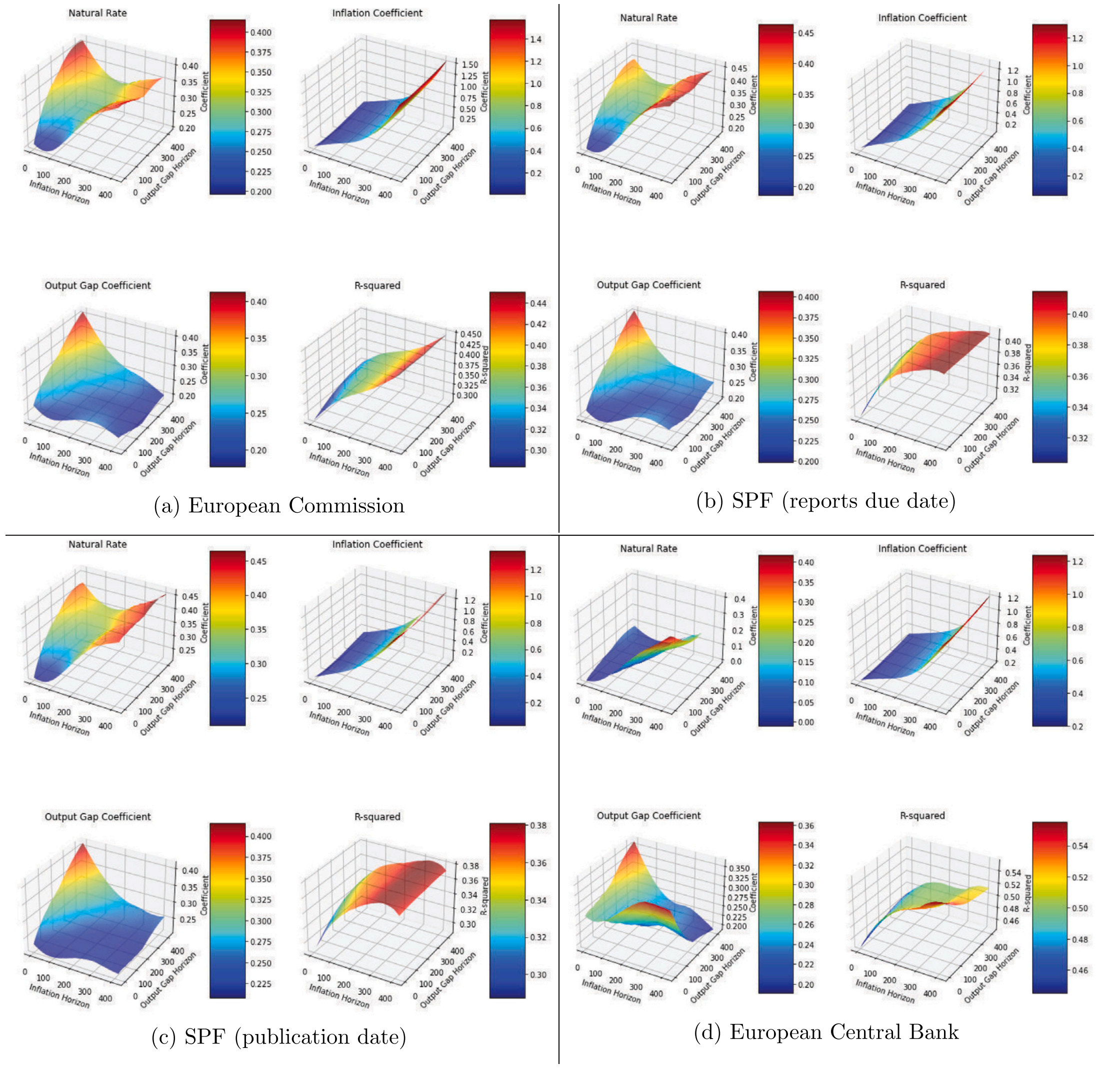


Fig. 1. Taylor rules with latest available data and EONIA. Notes: Taylor rule using latest available data, dependent variable = EONIA, SPF=survey of professional forecasters.

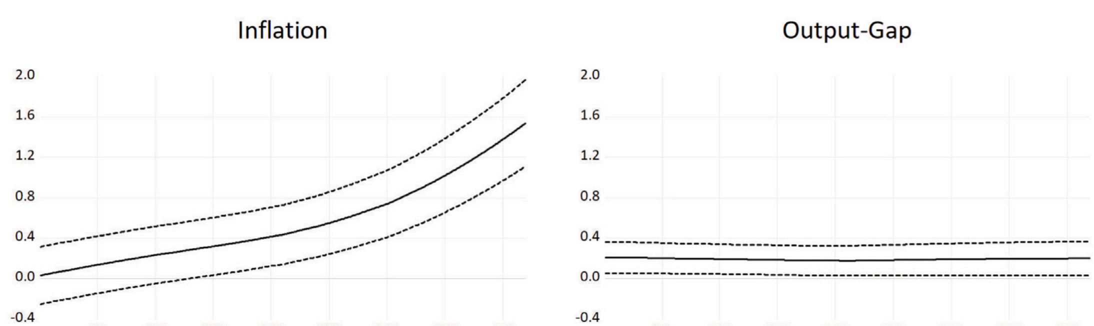
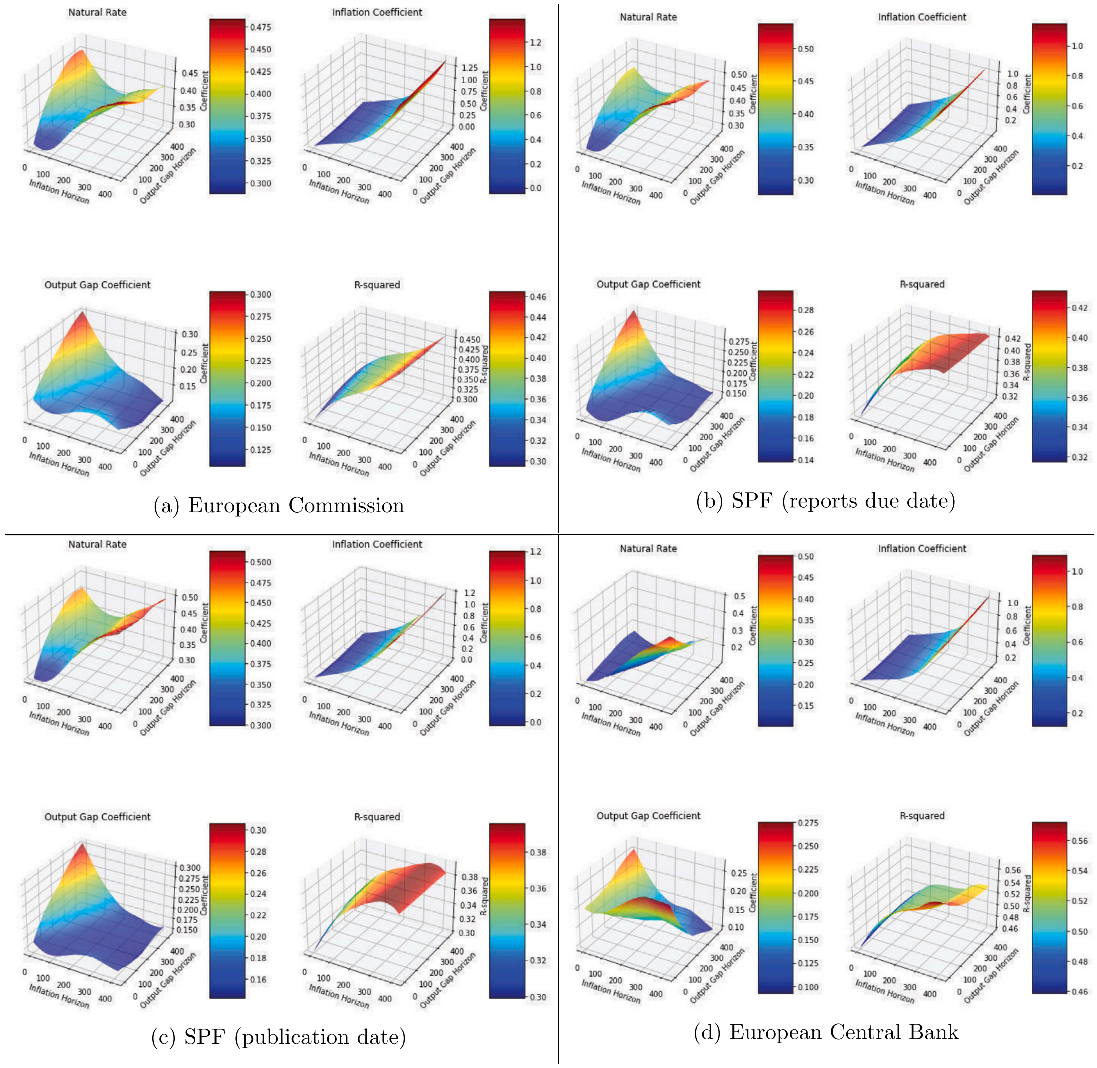


Fig. 2. Inflation and output-gap coefficients for Taylor rule with latest available data, EONIA and EU-Commission data.
Notes: Taylor rule coefficients for inflation (left panel) and output-gap (right panel) for estimates with latest available data, EONIA and EU-Commission data. In each graph the coefficients for varying forecast horizons (horizontal axis) are shown given that the other forecast horizon is at its best fit level. The solid lines show the coefficient estimates while dashed lines represent the 95% confidence interval.

When the analysis is conducted using the shadow rate as the interest rate to be explained (Fig. 4), the illustration stays almost the same as in the previous two figures, but the magnitude of the coefficients changes considerably, i.e. with respect to the natural real interest rate and the inflation response coefficient. Since the shadow rate is not subject to the zero lower bound, the natural real interest rate now tends to be lower, dropping to its lowest level at about −0.9 when ECB forecasts are used. Contrary to this drop, the influence of inflation increases, ranging now from its lowest level of about 0.5 to its maximum of about three for the longest inflation forecast specifications.

Table 1 plots the Taylor rules with the highest explanatory power, in the sense of those rules having the best fit with the actual interest rate, that is, the highest R-squared value. Generally, the fit is best in the specifications for ECB data. This result could indicate this dataset's



(a) European Commission (b) SPF (reports due date) (c) SPF (publication date) (d) European Central Bank

Fig. 3. Taylor rules with latest available data and main refinancing rate.
Notes: Taylor rule using latest available data, dependent variable = main refinancing rate, SPF=survey of professional forecasters.

Table 1
Taylor rules with latest available data.

Dependent variable	EONIA				MRR				Shadow-Rate			
Forecast Database	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB
Natural Rate	0.40***	0.46***	0.43***	0.41***	0.48***	0.53***	0.49***	0.49***	−0.26	−0.18	−0.24	−0.23
	(0.13)	(0.14)	(0.12)	(0.13)	(0.12)	(0.12)	(0.12)	(0.10)	(0.18)	(0.19)	(0.20)	(0.16)
Inflation	1.54***	1.13***	1.01***	1.11***	1.33***	0.98***	0.88***	0.91***	2.80***	2.24***	2.08***	2.21***
	(0.22)	(0.20)	(0.21)	(0.16)	(0.19)	(0.17)	(0.18)	(0.14)	(0.30)	(0.28)	(0.30)	(0.22)
Output-Gap	0.21***	0.24***	0.25***	0.35***	0.15**	0.18***	0.17**	0.27***	0.12	0.17	0.15	0.32***
	(0.08)	(0.08)	(0.09)	(0.07)	(0.07)	(0.07)	(0.07)	(0.06)	(0.11)	(0.11)	(0.12)	(0.09)
R^2	0.45	0.41	0.38	0.56	0.46	0.43	0.40	0.57	0.46	0.42	0.38	0.57
Best Fit Inflation Forecast	418	392	350	413	418	392	350	402	418	395	361	413
Best Fit Output Forecast	10	25	332	0	0	0	0	0	0	0	0	0

Notes: Dependent variable: EONIA-rate, MRR (main refinancing rate) and shadow-rate according to Krippner (2013). Forecast Database: EC = European Commission, SPF-DR = Survey of Professional Forecasters date at which reports are due, SPF-DP = Survey of Professional Forecasters date at which publication in published, ECB = European Central Bank. Standard errors in parentheses. A significance level of 1%, 5% and 10% is denoted by ***, ** and *.

information advantage, since the forecasts and the (unobserved) policy rule are implemented by the same institution.

In almost all cases, the best fit is achieved for the contemporaneous output gap data, while, for inflation rates, the best fit forecast is long-term, that is, more than one year in most specifications. Since the best fit forecast horizons are comparable among specifications, the influence of the coefficients is also rather similar, at least for the EONIA and the main refinancing rate as interest rates to be explained. Here the natural rate is about 0.5 in all specifications and thus considerably lower than the 2% originally proposed by Taylor (1993) for the US. This difference should be due to the downward trend in real interest rates since the beginning of the 1990s (e.g., Holsten et al., 2017).

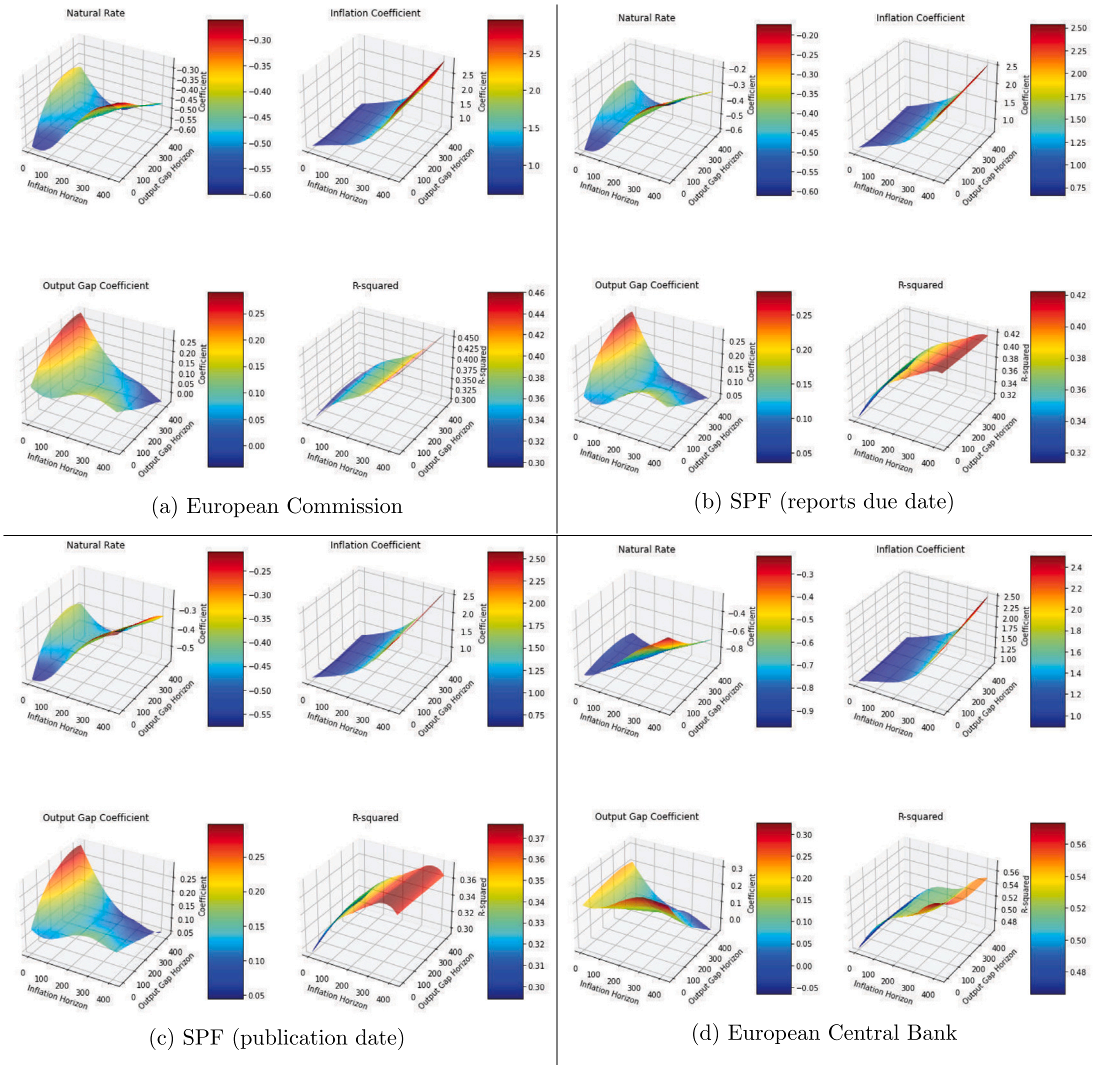


Fig. 4. Taylor rules with latest available data and shadow rate.
Notes: Taylor rule using latest available data, dependent variable = shadow rate, SPF=survey of professional forecasters.

Moreover, the response coefficient with respect to the inflation gap is with about one considerably higher than the 0.5 in the originally proposed rule. Thus, the ECB tends to tackle inflation deviations even more aggressively, even more so when using the European Commission data, where the response coefficient exceeds 1.5. In contrast, the response coefficients with respect to the output gap tend to be a bit lower than the originally proposed 0.5, even if all the estimates remain significant positive.

When the shadow rate is used as the dependent variable, the estimates change in all cases. First, the natural rate estimates are now even (insignificantly) negative. This is what would be expected, given that the zero lower bound is not binding here and the rates are thus lower than the other two since the beginning of quantitative easing. Second, the response to the inflation rate is now even higher, with levels exceeding two in all specifications. Third, the response coefficients with respect to the output gap are now even lower and become insignificant in most specifications.

Data with Rational Approximation

Since use of the latest available forecasts necessarily neglects any new information arriving between the latest forecast and the Council's decision, we use our rational approximation approach to also account for information becoming available afterward, that is, information from those of the next forecast. All in all the results using the rational approximation are broadly the same for the EONIA, the main refinancing rate, and the shadow rate, respectively.[13]

Therefore, the best fit forecast horizons (see Table 2) are also comparable when the rational approximation data instead of the latest available data are used; that is, the best-fitted estimate is found for (almost) contemporaneous output data and inflation forecasts with (close to) the maximum of 418 days. It does not come as a surprise, therefore, that the response coefficients are also broadly comparable to those using the latest available data.

But why are the estimates that also take into account the information of the subsequent forecasts not substantially different from those using only latest available data? One explanation is that the forecasts by the institutions change only gradually from one forecast to the other, with the exception of crisis periods. This being said, rational approximation and latest available data are not that different from each other.

[13] The corresponding figures are available upon request.

Table 2
Taylor rules with rational approximation.

Dependent variable	EONIA				MRR				Shadow-Rate			
Forecast Database	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB
Natural Rate	0.40***	0.56***	0.56***	0.48***	0.56***	0.64***	0.63***	0.56***	−0.20	−0.06	−0.07	−0.16
	(0.12)	(0.07)	(0.12)	(0.10)	(0.10)	(0.10)	(0.11)	(0.09)	(0.16)	(0.16)	(0.17)	(0.14)
Inflation	1.12***	1.04***	1.07***	0.94***	0.98***	0.91***	0.94***	0.80***	2.36***	2.22***	2.30***	2.06***
	(0.18)	(0.19)	(0.21)	(0.15)	(0.16)	(0.16)	(0.18)	(0.13)	(0.25)	(0.26)	(0.28)	(0.20)
Output-Gap	0.33***	0.36***	0.35***	0.45***	0.26***	0.29***	0.28***	0.37***	0.24**	0.29***	0.27**	0.42***
	(0.07)	(0.07)	(0.08)	(0.06)	(0.06)	(0.06)	(0.07)	(0.05)	(0.10)	(0.10)	(0.10)	(0.08)
R^2	0.49	0.47	0.45	0.60	0.52	0.49	0.47	0.62	0.51	0.48	0.46	0.61
Best Fit Inflation Forecast	418	418	418	418	418	418	415	418	418	418	418	418
Best Fit Output Forecast	12	0	13	0	0	0	0	0	0	0	0	0

Notes: Dependent variable: EONIA-rate, MRR (main refinancing rate) and shadow-rate according to Krippner (2013). Forecast Database: EC = European Commission, SPF-DR = Survey of Professional Forecasters date at which reports are due, SPF-DP = Survey of Professional Forecasters date at which publication in published, ECB = European Central Bank. Standard errors in parentheses. A significance level of 1%, 5% and 10% is denoted by ***, ** and *.

Table 3
Taylor rules with latest available data and current inflation.

Dependent variable	EONIA				MRR				Shadow-Rate			
Forecast Database	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB
Natural Rate	0.40***	0.46***	0.30**	0.41***	0.48***	0.53***	0.37***	0.49***	−0.26	−0.18	−0.44**	−0.23
	(0.13)	(0.14)	(0.08)	(0.13)	(0.12)	(0.12)	(0.12)	(0.12)	(0.18)	(0.19)	(0.20)	(0.16)
Inflation	1.54***	1.13***	0.14	1.11***	1.33***	0.98***	−0.08	0.91***	2.80***	2.24***	0.47***	2.21***
	(0.22)	(0.20)	(0.12)	(0.16)	(0.19)	(0.17)	(0.09)	(0.14)	(0.30)	(0.28)	(0.14)	(0.22)
Output-Gap	0.21***	0.24***	0.25***	0.35***	0.15**	0.18***	0.21**	0.27***	0.12	0.17	0.22*	0.32***
	(0.08)	(0.08)	(0.08)	(0.07)	(0.07)	(0.07)	(0.07)	(0.06)	(0.11)	(0.11)	(0.11)	(0.09)
R^2	0.45	0.41	0.38	0.56	0.46	0.43	0.40	0.57	0.46	0.42	0.38	0.57
Best Fit Inflation Forecast	418	392	87	413	418	392	4	402	418	395	0	413
Best Fit Output Forecast	10	25	88	0	0	0	0	0	0	0	0	0

Notes: Dependent variable: EONIA-rate, MRR (main refinancing rate) and shadow-rate according to Krippner (2013). Forecast Database: EC = European Commission, SPF-DR = Survey of Professional Forecasters date at which reports are due, SPF-DP = Survey of Professional Forecasters date at which publication in published, ECB = European Central Bank. Standard errors in parentheses. A significance level of 1%, 5% and 10% is denoted by ***, ** and *.

Latest Available Data with Current Inflation

When using the inflation information published between the last forecast and the decision of the Governing Council, the results, especially for short-term inflation forecasts, change considerably. This does not come as a surprise, since the new official inflation information published influences contemporaneous data the most, whereas it has no influence on the long-term forecasts, such as those for 418 days, since they are always in the next calendar year. This being said, the differences from the estimates with the latest available data are highest for contemporaneous inflation data and converge to those with an increasing inflation forecast horizon.

Surprisingly, the inflation coefficient estimates are the ones that are the least affected by the use of current inflation data. Still the response coefficients are close to zero when using contemporaneous inflation data and rise with the inflation forecast horizon for the estimates using the EONIA or main refinancing rate as dependent variable.[14] When the shadow rate is used instead, the coefficients are again higher, at about 0.5 at the short end.

With respect to the output response, there now tend to be two maxima for short-term inflation forecasts: one also for contemporaneous output data and one for a maximum of 418 output forecasts. This result holds at least for estimating the model with the EONIA. For the other two interest rates, both contemporaneous inflation and output data tend to generate the highest output response coefficients.

Contrary to this, the natural real interest rate is now always at a low level for contemporaneous inflation data and rises with its forecast horizon. In addition, R-squared remains the lowest for short-term inflation forecasts, at least for three of the four data sources. With respect to data using the SPF publication date, now the maximum is even found for short-term inflation forecasts or even contemporaneous inflation data.

This finding translates also to the best fit rules in Table 3. With respect to the estimates using Commission, ECB, or SPF reports due data, the results are unchanged from those of Table 1, since the best fit inflation forecast is long-term and thus not influenced by current inflation data. Only with respect to the estimates with SPF publication data are the best fit inflation forecasts considerably reduced. Therefore, the natural real interest rate and the inflation response are lower in the specifications with the best fit.

4.1.2. First-difference rules

As an alternative, the results for the first-difference rule are presented here. Only the two responses with respect to the inflation gap and the output growth gap need to be estimated in this rule. We use the same ordering as in the previous section, presenting first the results with the latest available data, followed by those with rational approximation and current inflation.

Latest Available Data

Fig. 5 presents the results of the first-difference rule with the EONIA as dependent variable. It is generally striking that the fit, as represented by the R-squared, is considerably higher than for the Taylor rule estimates, and even close to unity overall. There is thus less variation in the fit for various forecast horizons. This pattern is simply due to the fact that the lagged interest rate (i.e., the interest rate after the last decision of the Governing Council) already explains much of the current interest rate (thus the one prevailing after the current Governing Council meeting). This being said, the response coefficients of inflation and output growth gaps signal only the direction and strength of the adjustment based on those fundamentals. Even though the differences in R-squared are not that large, they still exist. In other words, the best fit for all the data sources is found for longer-term output growth

[14] The corresponding figures are again available upon request.

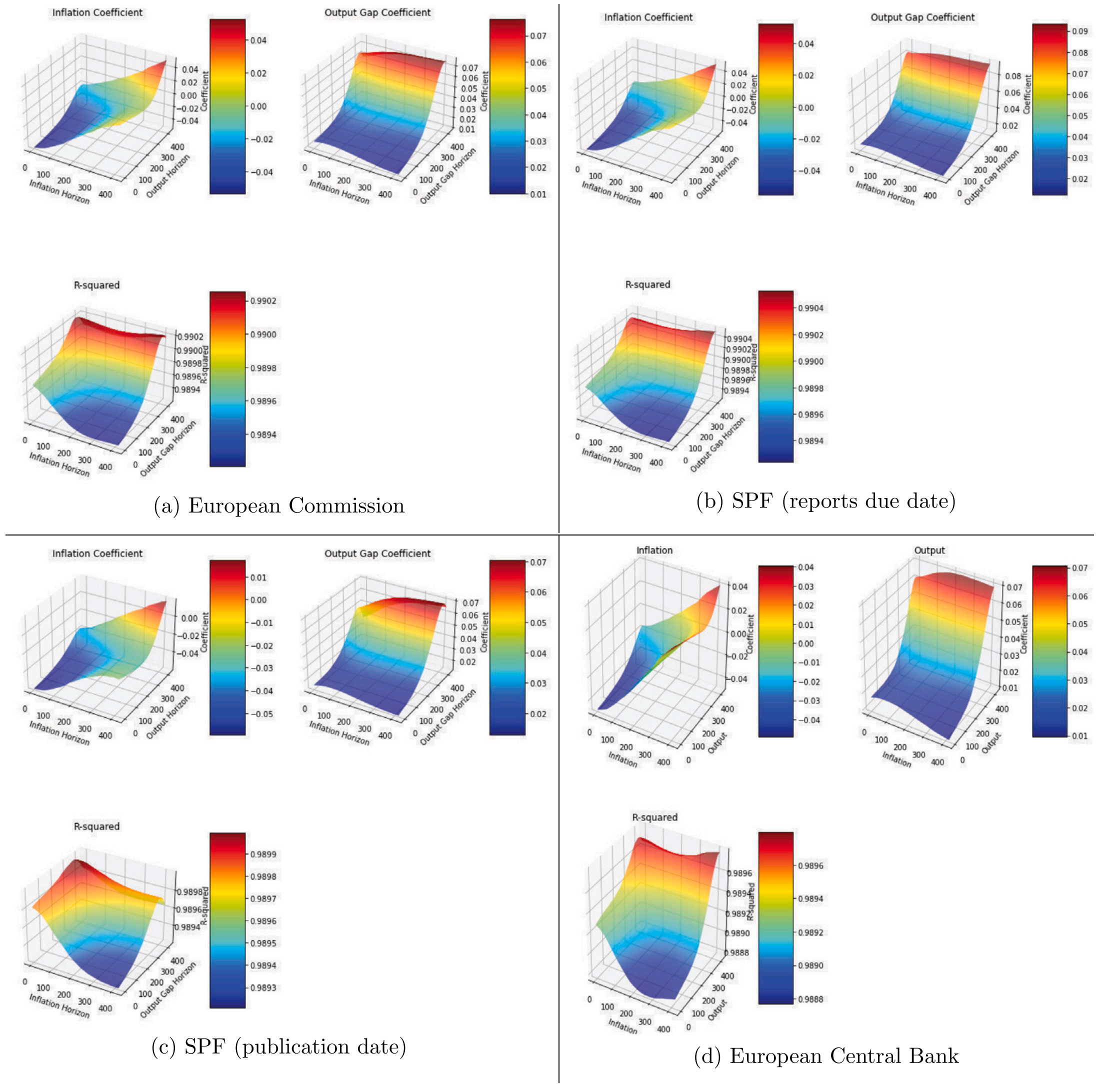


Fig. 5. First-difference rules with latest available data and EONIA.
Notes: First-difference rule using latest available data, dependent variable = EONIA, SPF = survey of professional forecasters.

forecasts. Inflation forecasts play less of a role here. This result is the opposite of what we found for the Taylor rule estimates.

Quite the same picture emerges when looking at the output growth coefficients. These are close to zero for contemporaneous output growth data and rise to about 0.07 for longer-term forecasts of the variable.

The evolution of the inflation response coefficients is comparable to that of the Taylor rules, meaning that the coefficients tend to rise with increasing inflation forecast horizons. This pattern is also found by Wieland and Wolters (2013) with respect to the Federal Reserve and ECB. Moreover, though, the coefficients are now also rising with increasing output growth forecasts. Note, however, that the response coefficients are considerably smaller than for the Taylor rules, with a maximum of about 0.04. Moreover, for short-term forecast horizons, the coefficients even become negative. Therefore, in those cases, the ECB follows a destabilizing policy with respect to inflation.

Estimating the first-difference rules with the main refinancing rate instead of the EONIA (Fig. 6) leaves the results broadly unchanged, as was also the case for the Taylor rule estimates. If, however, the first-difference rule is estimated with the shadow rate as the dependent variable (Fig. 7), the results change considerably. First, the best fit is now generated for rather short-term inflation and output growth forecasts. Second, the maximum output growth response now varies among the different data sources, and no clear picture thus emerges for these. Third, the inflation response is now found to be mainly negative across the different data sources.

Table 4 presents the best fit forecast horizon based on the highest R-squared values for the different specifications. It shows that the best fit output forecast horizon is rather long term when the rules are estimated with the EONIA or the main refinancing rate, and rather short term for shadow rate specifications. The best fit inflation forecast horizons differs considerably, however, among the different data sources.

Concerning the inflation coefficients in the specifications with the highest explanatory power, no clear picture emerges for the EONIA and main refinancing rate specifications, since the coefficients are found to be (in-)significantly positive or negative. However, it can be said that the lower the best fit inflation forecast, the more likely a negative inflation coefficient becomes. Since, for the shadow rate specifications, the best fit inflation forecasts are rather short term, the best fit inflation coefficients are found to be significantly negative throughout. In contrast, the output growth coefficient is found to be significantly positive for the EONIA and main refinancing rate specifications, while the coefficients are reduced and mainly insignificant if the shadow rule is the dependent variable.

Data with Rational Approximation

When using rational approximation instead of latest available data, we find almost the same pattern as for the Taylor rule estimates,

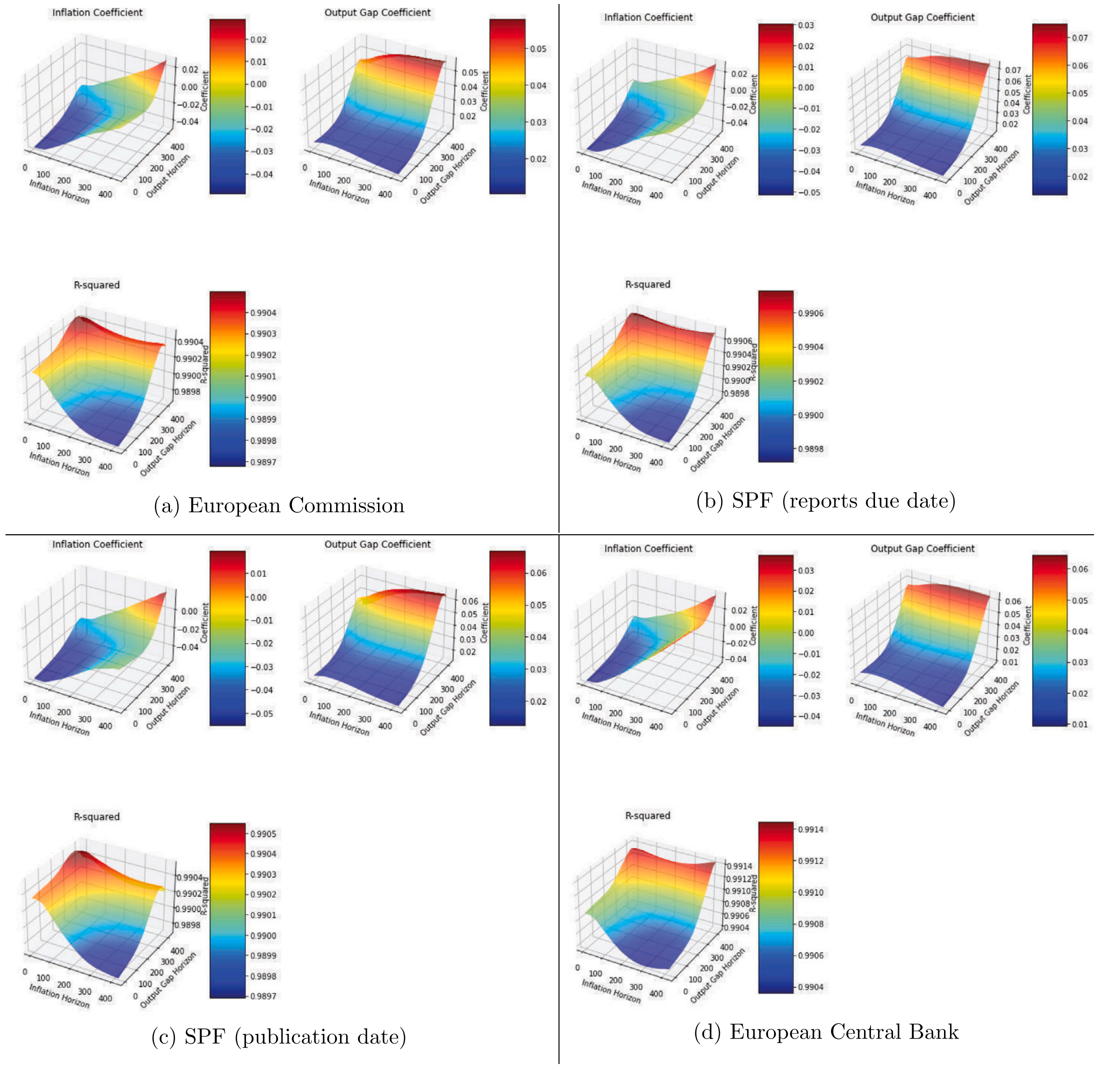


Fig. 6. First-difference rules with latest available data and main refinancing rate.
Notes: First-difference rule using latest available data, dependent variable = main refinancing rate, SPF = survey of professional forecasters.

Table 4
First-difference rules with latest available data.

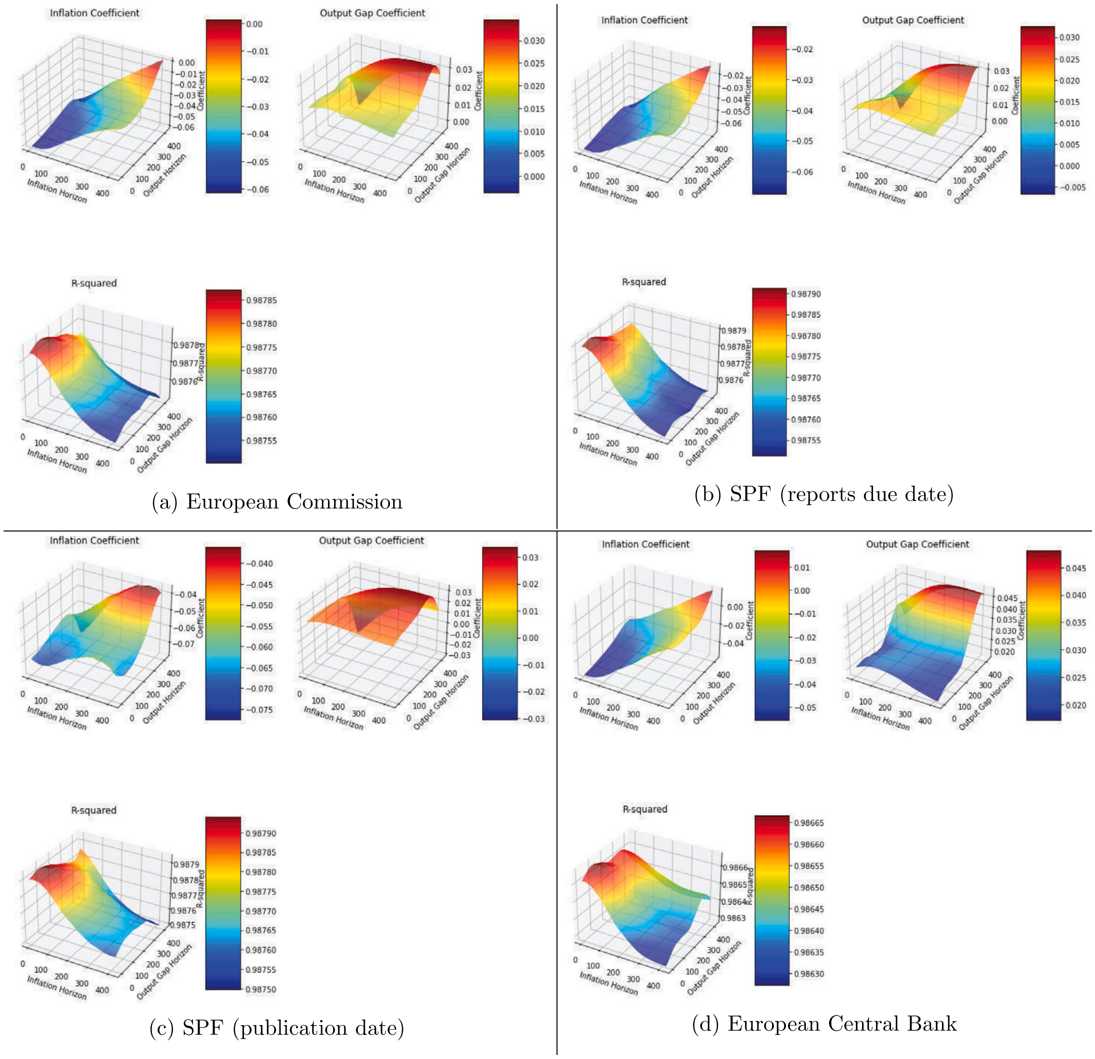
Dependent variable	EONIA				MRR				Shadow-Rate			
Forecast Database	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB
	0.040	0.046*	−0.039**	0.039*	−0.028*	−0.020	−0.037***	0.037**	−0.060**	−0.067***	−0.069***	−0.054**
Inflation	(0.026)	(0.025)	(0.016)	(0.023)	(0.014)	(0.014)	(0.014)	(0.018)	(0.024)	(0.024)	(0.024)	(0.024)
Output-Growth-Gap	0.076***	0.092***	0.048***	0.069***	0.043***	0.061***	0.045**	0.064***	0.019	0.018	0.020	0.023*
	(0.015)	(0.016)	(0.017)	(0.015)	(0.013)	(0.015)	(0.014)	(0.012)	(0.012)	(0.012)	(0.13)	(0.012)
R^2	0.990	0.991	0.990	0.990	0.990	0.991	0.991	0.991	0.988	0.988	0.988	0.987
Best Fit Inflation Forecast	418	418	27	418	27	53	53	418	19	19	23	23
Best Fit Output Forecast	386	406	329	412	350	383	323	417	82	63	63	81

Notes: Dependent variable: EONIA-rate, MRR (main refinancing rate) and shadow-rate according to Krippner (2013). Forecast Database: EC = European Commission, SPF-DR = Survey of Professional Forecasters date at which reports are due, SPF-DP = Survey of Professional Forecasters date at which publication in published, ECB = European Central Bank. Standard errors in parentheses. A significance level of 1%, 5% and 10% is denoted by ***, ** and *.

namely, that the results do not differ much from each other.[15] There are only some changes, such as those concerning the maximum R-squared value with respect to the inflation forecast horizon or with respect to the output growth response coefficients for the shadow rate specifications. This pattern is now more clear-cut, in the sense that the maximum is reached throughout all specifications for rather long-term output growth forecasts.

Table 5 summarizes the best fit first-difference rules with rational approximation data. While the figures of the rational approximation estimates seem quite similar to those using latest available data, the results of looking only at the best fit rule are now more clear-cut for the EONIA and main refinancing rate specifications. This finding holds, for example, for the best fit inflation forecast horizon, which is now 418 throughout. Since the inflation coefficient increases with the inflation

[15] The corresponding figures for the first-difference rules are also available upon request.



(a) European Commission (b) SPF (reports due date) (c) SPF (publication date) (d) European Central Bank

Fig. 7. First-difference rules with latest available data and shadow rate.
Notes: First-difference rule using latest available data, dependent variable = shadow rate, SPF = survey of professional forecasters.

Table 5
First-difference rules with rational approximation.

Dependent variable	EONIA				MRR				Shadow-Rate			
Forecast Database	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB
Inflation	0.064***	0.079***	0.062***	0.063***	0.044**	0.057***	0.039*	0.050***	−0.037	0.048	−0.061***	−0.051**
	(0.022)	(0.022)	(0.024)	(0.021)	(0.020)	(0.019)	(0.021)	(0.017)	(0.025)	(0.036)	(0.023)	(0.024)
Output-Growth-Gap	0.095***	0.096***	0.089***	0.081***	0.080***	0.080***	0.072***	0.067***	0.039*	0.067***	0.019	0.018
	(0.014)	(0.014)	(0.016)	(0.014)	(0.012)	(0.013)	(0.014)	(0.012)	(0.022)	(0.023)	(0.12)	(0.012)
R^2	0.991	0.991	0.991	0.991	0.991	0.991	0.991	0.992	0.988	0.988	0.988	0.987
Best Fit Inflation Forecast	418	418	418	418	418	418	418	418	17	418	15	3
Best Fit Output Forecast	418	418	407	418	418	418	405	418	366	413	81	78

Notes: Dependent variable: EONIA-rate, MRR (main refinancing rate) and shadow-rate according to Krippner (2013). Forecast Database: EC = European Commission, SPF-DR = Survey of Professional Forecasters date at which reports are due, SPF-DP = Survey of Professional Forecasters date at which publication in published, ECB = European Central Bank. Standard errors in parentheses. A significance level of 1%, 5% and 10% is denoted by ***, ** and *.

horizon, it does not come as a surprise that the inflation response is now found to be significantly positive for all of these specifications.

On the other hand, the inflation response in the shadow rate specifications is now less clear, since the best fit forecast horizon in output growth and inflation tends to rise in two specifications, making the inflation coefficient insignificant, while the output growth coefficient becomes significantly positive.

Overall, one can conclude that the use of rational approximation data increases the best fit inflation forecast horizon, leading to higher inflation response coefficients.

Latest Available Data with Current Inflation

When re-estimating first-difference rules using current inflation data, i.e., the short-term inflation estimates change. Over all three interest rate specifications, two things stand out especially.[16] First, inflation coefficients tend to rise i.e. when applying short-term inflation and long term output growth forecasts and become mainly positive now. Second,

[16] The detailed figures are for these first-difference rules available also upon request.

Table 6
First-difference rules with latest available data and current inflation.

Dependent variable	EONIA				MRR				Shadow-Rate			
Forecast Database	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB
	0.040	0.046*	0.007	0.039***	0.020	0.025	−0.011	0.037**	−0.027	−0.044	−0.051*	−0.022
Inflation	(0.026)	(0.025)	(0.012)	(0.023)	(0.023)	(0.022)	(0.012)	(0.014)	(0.022)	(0.027)	(0.029)	(0.021)
Output-Growth-Gap	0.076***	0.092***	0.069***	0.069***	0.058***	0.074***	0.062***	0.064***	0.029*	0.020	0.025*	0.043**
	(0.015)	(0.016)	(0.018)	(0.015)	(0.013)	(0.014)	(0.015)	(0.012)	(0.017)	(0.013)	(0.14)	(0.019)
R^2	0.990	0.991	0.990	0.990	0.990	0.991	0.990	0.991	0.988	0.988	0.988	0.987
Best Fit Inflation Forecast	418	418	0	418	418	418	55	418	90	211	211	81
Best Fit Output Forecast	386	406	365	412	387	405	352	417	267	85	149	327

Notes: Dependent variable: EONIA-rate, MRR (main refinancing rate) and shadow-rate according to Krippner (2013). Forecast Database: EC = European Commission, SPF-DR = Survey of Professional Forecasters date at which reports are due, SPF-DP = Survey of Professional Forecasters date at which publication in published, ECB = European Central Bank. Standard errors in parentheses. A significance level of 1%, 5% and 10% is denoted by ***, ** and *.

the maximum of R-squared in the shadow rate specifications tends to shift. While the optimum was found to be at rather short-term inflation and output growth forecast horizons, the best fit rules are now found to have considerably longer forecast horizons in both dimensions.

This pattern can also be seen in Table 6, where, in all the shadow rate specifications, the best fit forecast horizon has shifted to the longer end. This results in less negative and mainly insignificant inflation coefficients and higher output growth coefficients. For the specifications using the EONIA or the main refinancing rate as the dependent variable, only some best fit rules change compared to Table 4. It is, however, noteworthy that these rules are the ones with (significantly) negative inflation coefficients beforehand. Thus, when using current inflation rates, we no longer find any specification for which the inflation coefficient is significantly negative, and the ECB thus followed mainly an inflation-stabilizing policy.

4.1.3. Taylor rules with interest rate smoothing

Finally, Taylor rules including an interest rate smoothing parameter are applied. These rules can be interpreted of being in between the two rules estimate above. In this kind of rules, three parameters are estimated. Those are: First, the interest rate smoothing parameter, second, the response to the inflation gap and third, the response to the output gap.

Latest Available Data

When using latest available data the coefficient estimates presented in Fig. 8 emerge. Generally, all coefficient estimates of the lagged interest rate are found to be close to unity. They range in between 0.97 and 1. This being said, interest rate smoothing is quite high and thus the estimates are more comparable to those of the first-difference rules. However, they are not identical for two reasons: First, the coefficient estimates of the lagged interest rate are close to but not exactly one as it is assumed in the first-difference rules. Second, the rules estimated here are Taylor rules and thus the output gap enters the equation and not the output growth gap as in the case of the first-difference rules.

But since interest rate smoothing is close to unity the results show similarities to the first-difference rules. These similarities are: First, high R-squared values are obtained. Those range from 0.9898 to 0.9890. This being said, there is not much variation in the goodness-of-fit for the different time horizons. However, the fit of the rules seems to be best for short-term inflation and long-term output forecasts, thus a pattern which is broadly comparable to the findings in the first-difference rules. This holds for three of the four used data forecasts. If, however, ECB forecasts are used the reverse tends to be true.

Second, the coefficient of the lagged interest rate tends to be highest for short-term inflation and long-term output forecasts and thus, the same as for the R-squared. This being said, it can be concluded that a higher interest rate smoothing parameter increases the goodness of fit.

Third, concerning the inflation reaction the coefficients tend to rise the longer the inflation forecast horizon. This is a pattern, which is also found in the Taylor and first-difference rules. Like in the first-difference rules the short-term inflation coefficients tend to be even negative, thus, pointing to a destabilizing policy of the ECB in these cases.

Fourth, almost the opposite conclusion has to be drawn when it comes to the output reaction. Here, the short-term reaction coefficients are found to be positive. In contrast, output coefficients with long term inflation and output horizons tend to turn negative.

The results are, in fact, quite similar if the main refinancing rate or the shadow rate is used instead of the EONIA (Figs. 9 and 10).

In Table 7 the results of the best fit rules for each specification are presented. Two things stand out: First, when using the EONIA or main refinancing rate as interest rate, the forecasts of the European Commission and the two from the Survey of Professional Forecasters lead to very similar results, which is a low forecast horizon for inflation and a long one for output. This leads to an interest rate smoothing parameters of unity, negative inflation reactions and positive (although not always significant) output reactions. However, the reverse is true when ECB forecasts are used. Here the best fit inflation horizon is 0 and the output horizon is 418. Accordingly also the best fit parameter estimates change with an interest rate smoothing coefficient which is with only 0.97 considerably lower, an inflation coefficient turning significantly positive and an output coefficient now being significantly negative.

Second, the results when using the shadow rate as the interest rate are different from those of the other two interest rates. Here all four data sources appear to lead to similar results, which is i.e. a best fit inflation horizon being short-term and a output horizon of about 70 days. This leads to estimates of the lagged interest rate of unity, negative inflation reactions and positive output responses over all four specifications.

Data with Rational Approximation

The coefficient estimates when rational approximation data are used are remarkable similar to those when using the latest available data.[17] However, the goodness of fit, as measured by the R-squared, is altered considerably compared to the previous estimates. I.e. when the EONIA is used as interest rate the best fit rules are now found at a low forecast horizon for output and a high one for inflation.

This results also in some changes in the best fit rules (Table 8). Since there are now more specifications with a rather short forecast horizon for inflation and a long one for output, the interest rate smoothing parameters tend to be lower, inflation coefficients tend to be more positive and output coefficients appear to be more negative. But this change is almost solely due to the altered best fit forecasts horizons and not to changes in the parameter estimates for the very same forecast horizons.

Latest Available Data with Current Inflation

When applying latest available data with currently known inflation rates, the evolution of the coefficient estimates over the various time horizons stays broadly unchanged.[18] I.e. the interest rate smoothing and output parameter tends to decrease with rising forecast horizon in

[17] Detailed figures and estimates are available from the authors upon request.

[18] Again, detailed results are available upon request.

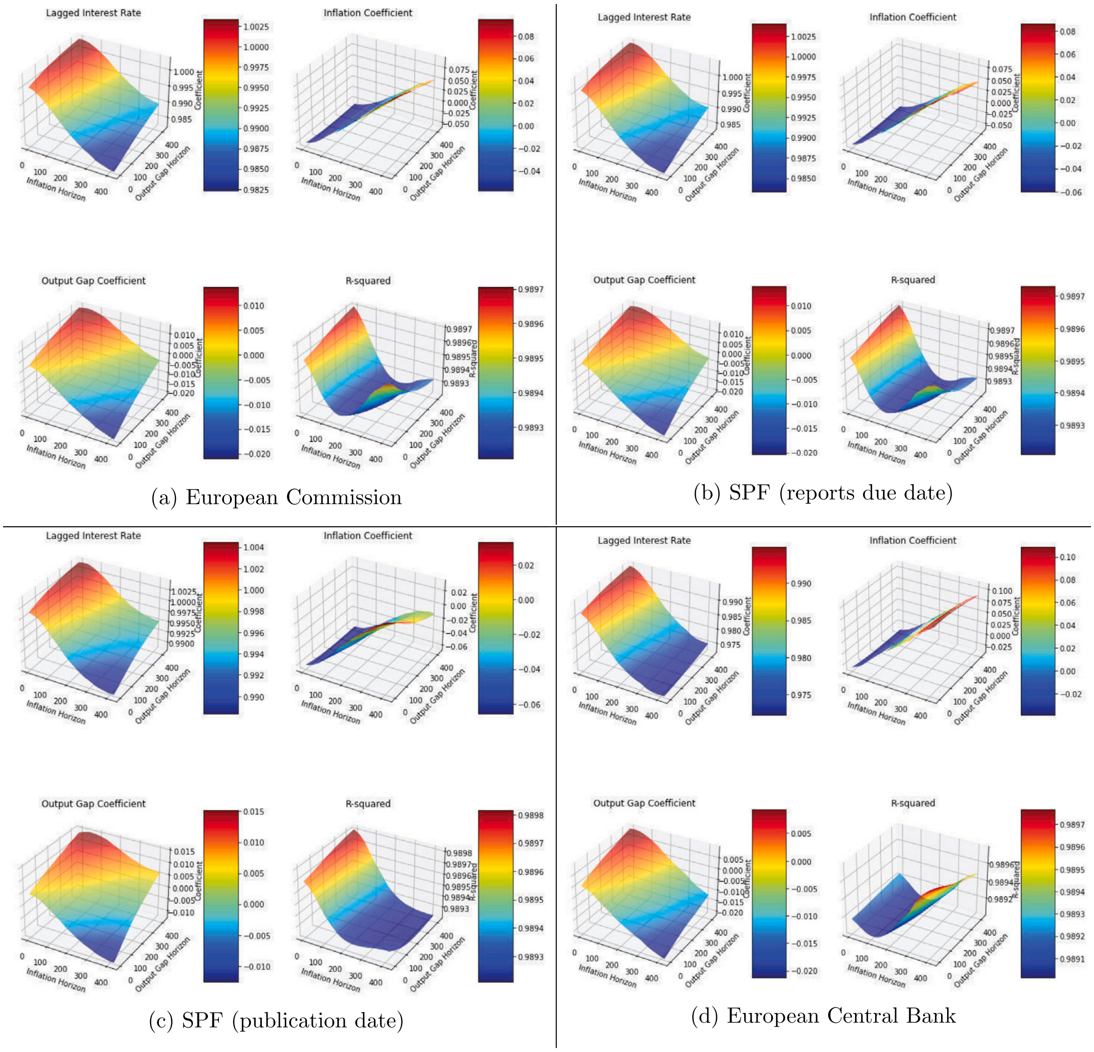


Fig. 8. Taylor rules with interest rate smoothing, latest available data and EONIA.
Notes: Taylor rule with interest rate smoothing using latest available data, dependent variable = EONIA, SPF = survey of professional forecasters.

Table 7
Taylor rules with interest rate smoothing and latest available data.

Dependent variable	EONIA				MRR				Shadow-Rate			
Forecast Database	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB
	1.003***	1.004***	1.004***	0.972***	1.004***	1.005***	1.005***	0.975***	1.008***	1.011***	1.010***	1.000***
Lagged Interest Rate	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)	(0.008)	(0.008)	(0.008)	(0.011)
Inflation	−0.058***	−0.060***	−0.065***	0.108***	−0.054***	−0.057***	−0.061***	0.091***	−0.084***	−0.097***	−0.097***	−0.060*
	(0.006)	(0.018)	(0.018)	(0.028)	(0.015)	(0.015)	(0.015)	(0.023)	(0.030)	(0.030)	(0.030)	(0.034)
Output-Gap	0.013	0.013*	0.014*	−0.021***	0.013*	0.014*	0.015**	−0.020***	0.017*	0.019*	0.019*	0.017*
	(0.008)	(0.008)	(0.008)	(0.008)	(0.007)	(0.007)	(0.007)	(0.007)	(0.010)	(0.010)	(0.010)	(0.010)
R^2	0.990	0.990	0.990	0.990	0.990	0.990	0.990	0.991	0.988	0.988	0.988	0.987
Best Fit Inflation Forecast	0	0	0	418	0	0	8	418	0	15	19	0
Best Fit Output Forecast	418	418	418	0	418	418	418	0	70	70	70	63

Notes: Dependent variable: EONIA-rate, MRR (main refinancing rate) and shadow-rate according to Krippner (2013). Forecast Database: EC = European Commission, SPF-DR = Survey of Professional Forecasters date at which reports are due, SPF-DP = Survey of Professional Forecasters date at which publication in published, ECB = European Central Bank. Standard errors in parentheses. A significance level of 1%, 5% and 10% is denoted by ***, ** and *.

both inflation and output, while the inflation coefficient is rising with increasing inflation forecast horizon. However, the goodness of fit is rather in line with the findings of the rational approximation, namely, that best fit rules appear to have rather long term inflation forecasts and short term output forecast.

This leads to the result that the best fit rules tend to have a quite low interest rate smoothing parameter, a positive inflation coefficient and a negative output coefficient (Table 9)

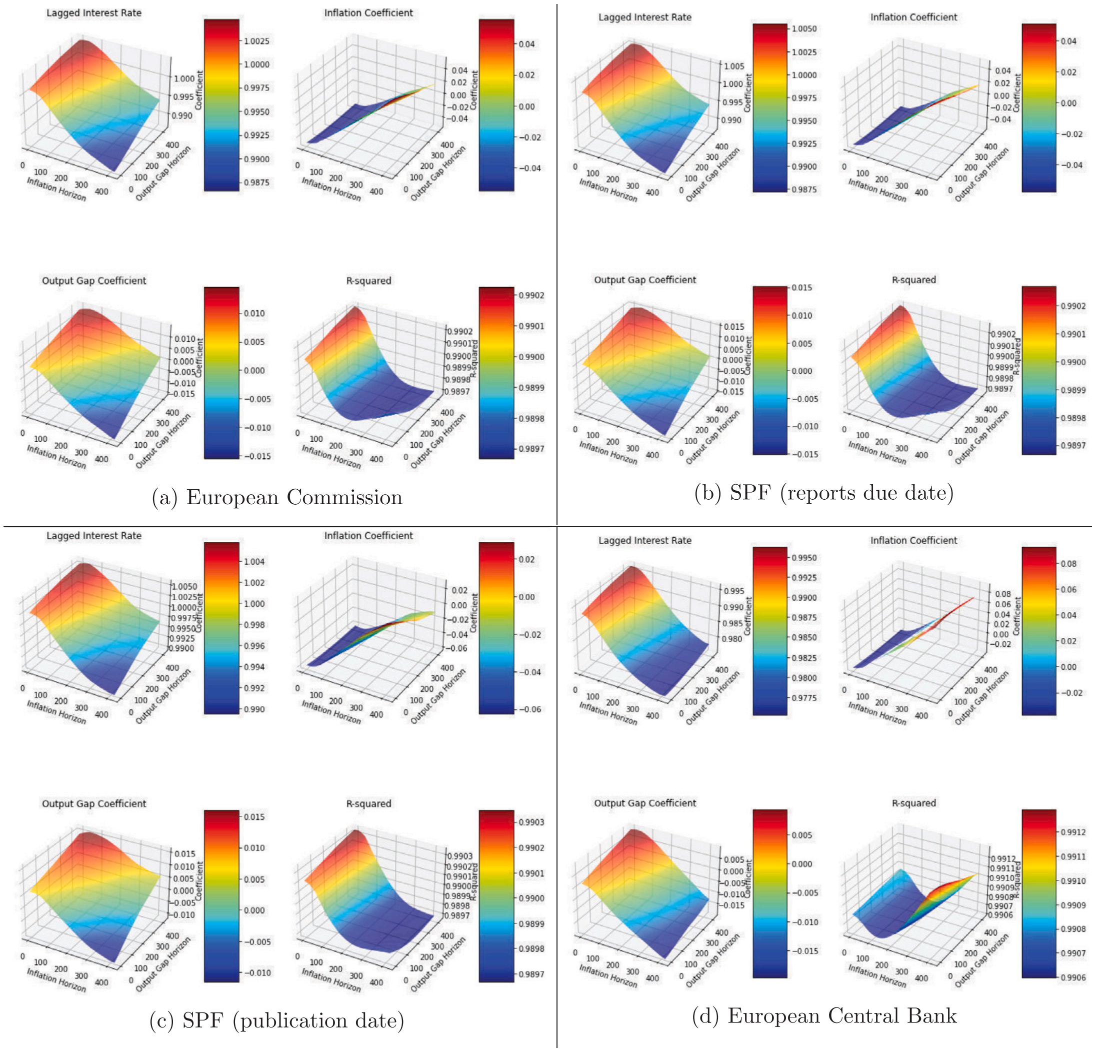


Fig. 9. Taylor rules with interest rate smoothing, latest available data and main refinancing rate.
Notes: Taylor rule with interest rate smoothing using latest available data, dependent variable = main refinancing rate, SPF = survey of professional forecasters.

Table 8
Taylor rules with interest rate smoothing and rational approximation.

Dependent variable	EONIA				MRR				Shadow-Rate			
Forecast Database	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB
	0.978***	0.978***	0.981***	0.969***	1.007***	0.982***	1.007***	0.974***	1.008***	1.008***	1.008***	0.965***
Lagged Interest Rate	(0.006)	(0.05)	(0.006)	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)	(0.008)	(0.008)	(0.008)	(0.010)
Inflation	0.134***	0.146***	0.125***	0.146***	−0.058***	0.107***	−0.058***	0.115***	−0.074***	−0.073**	−0.077***	0.169***
	(0.029)	(0.028)	(0.031)	(0.025)	(0.015)	(0.025)	(0.015)	(0.021)	(0.028)	(0.028)	(0.028)	(0.052)
Output-Gap	−0.030***	−0.031***	−0.029***	−0.029***	0.018***	−0.026***	0.018***	−0.025***	0.016	0.016	0.017	−0.011
	(0.008)	(0.008)	(0.008)	(0.007)	(0.007)	(0.007)	(0.007)	(0.006)	(0.010)	(0.010)	(0.010)	(0.011)
R^2	0.990	0.990	0.990	0.991	0.990	0.991	0.990	0.992	0.988	0.988	0.988	0.987
Best Fit Inflation Forecast	418	418	418	418	0	418	0	418	0	0	2	418
Best Fit Output Forecast	0	0	0	0	418	0	418	0	418	418	418	210

Notes: Dependent variable: EONIA-rate, MRR (main refinancing rate) and shadow-rate according to Krippner (2013). Forecast Database: EC = European Commission, SPF-DR = Survey of Professional Forecasters date at which reports are due, SPF-DP = Survey of Professional Forecasters date at which publication in published, ECB = European Central Bank. Standard errors in parentheses. A significance level of 1%, 5% and 10% is denoted by ***, ** and *.

4.2. Time-varying regression results

We now want to determine whether the results found in the previous section are due to our sample period or whether they can be generalized for the ECB. We therefore adopt a time-varying regression approach. We start with a minimum of 30 observations, and, thus, with the first 30 ECB Governing Council decisions. The first regression includes the sample period from January 7, 1999 (first decision) to June 21, 2001 (30th decision).[19] We then add one decision to the 30 first observations and re-estimate the estimation. This procedure is reiterated until all the observations are included, and the last sample period

[19] For the regressions using ECB data, the sample period shifts to December 14, 2000, to July 10, 2003, since the ECB forecast data are only available from December 2000 onward.

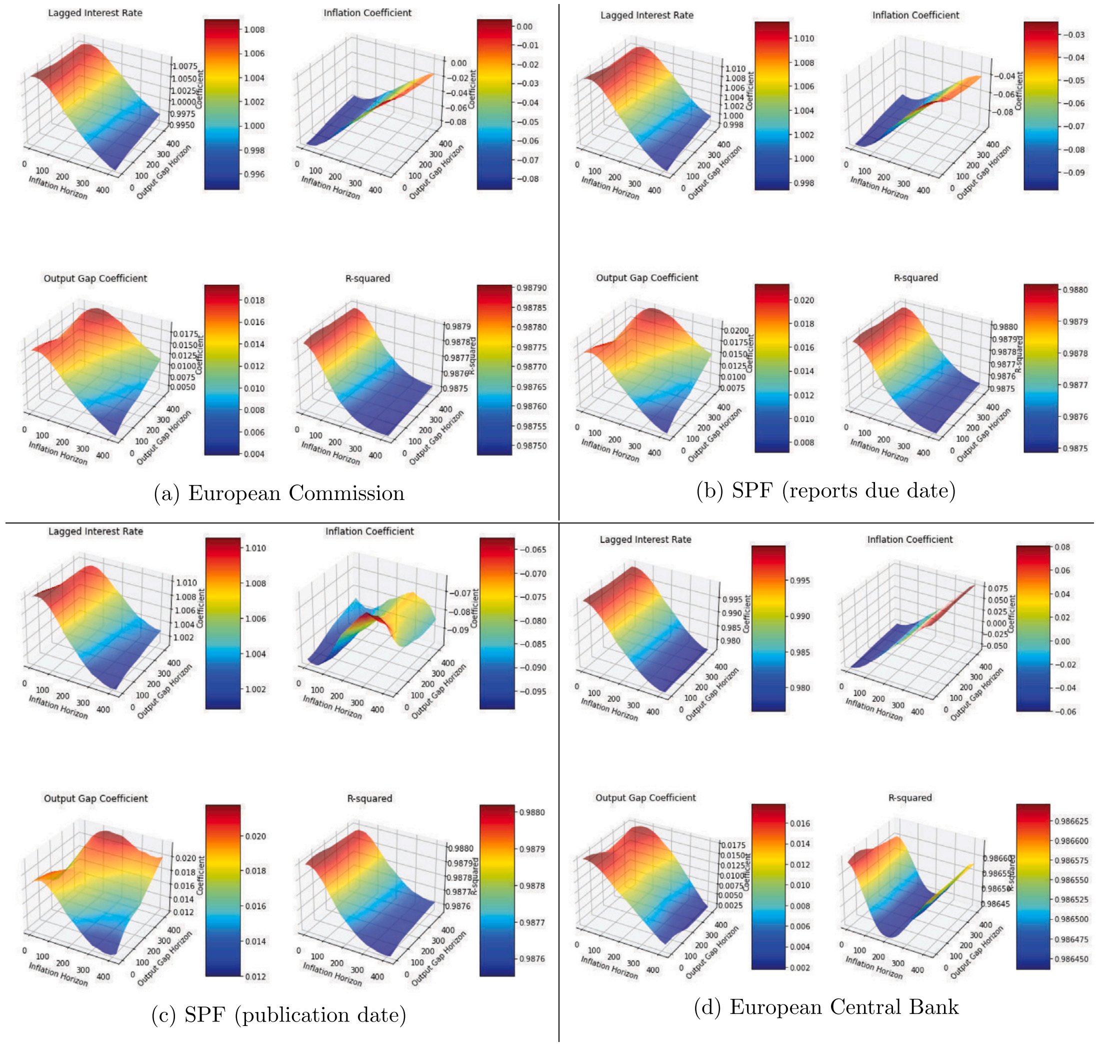


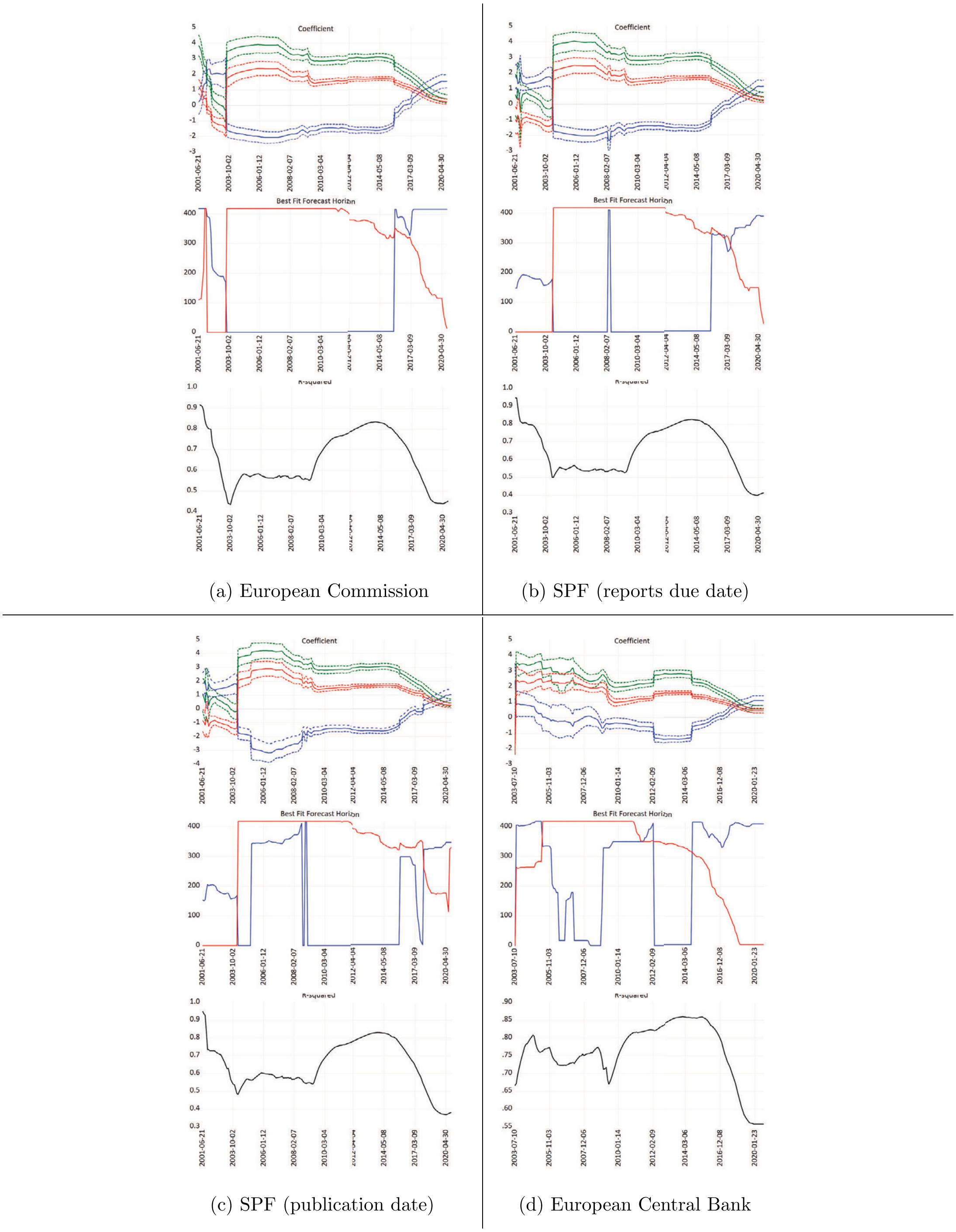
Fig. 10. Taylor rules with interest rate smoothing, latest available data and shadow rate.
Notes: Taylor rule with interest rate smoothing using latest available data, dependent variable = shadow rate, SPF = survey of professional forecasters.

Table 9
Taylor rules with interest rate smoothing, latest available data and current inflation.

Dependent variable	EONIA				MRR				Shadow-Rate			
Forecast Database	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB	EC	SPF-DR	SPF-DP	ECB
Lagged Interest Rate	0.983***	0.983***	0.985***	0.972***	0.986***	0.987***	0.989***	0.975***	1.001***	1.004	1.004***	0.977***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)	(0.006)	(0.005)	(0.009)	(0.009)	(0.009)	(0.010)
Inflation	0.095***	0.087***	0.028*	0.108***	0.056*	0.051*	0.013	0.091***	−0.031	−0.050	−0.070*	0.077
	(0.035)	(0.032)	(0.015)	(0.028)	(0.030)	(0.028)	(0.013)	(0.023)	(0.029)	(0.035)	(0.041)	(0.053)
Output-Gap	−0.021**	−0.020**	−0.014*	−0.021***	−0.016**	−0.015**	−0.011	−0.020***	0.015	0.018	0.020	0.003
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.007)	(0.007)	(0.012)	(0.012)	(0.012)	(0.011)
R^2	0.990	0.990	0.989	0.990	0.990	0.990	0.990	0.991	0.988	0.988	0.988	0.987
Best Fit Inflation Forecast	418	418	0	418	418	418	0	418	108	211	268	418
Best Fit Output Forecast	0	0	0	0	0	0	0	0	418	418	418	63

Notes: Dependent variable: EONIA-rate, MRR (main refinancing rate) and shadow-rate according to Krippner (2013). Forecast Database: EC = European Commission, SPF-DR = Survey of Professional Forecasters date at which reports are due, SPF-DP = Survey of Professional Forecasters date at which publication in published, ECB = European Central Bank. Standard errors in parentheses. A significance level of 1%, 5% and 10% is denoted by ***, ** and *.

thus corresponds to the full sample of the previous section. A total of 205 different sample periods with, again, 175.561 different rules are estimated. Therefore, for each specification, 35.990.005 different estimations are carried out. Because of this large number of rules, only rules with the highest explanatory power, in the sense of those with the best fit in each specification and sample period, are presented in the following. Moreover, we restrict our analysis to the specifications using the latest available data and the Taylor rule as well as the first-difference rule as we have seen the previous section that the Taylor rule with interest rate smoothing leads to rather similar results as the



(a) European Commission (b) SPF (reports due date)

(c) SPF (publication date) (d) European Central Bank

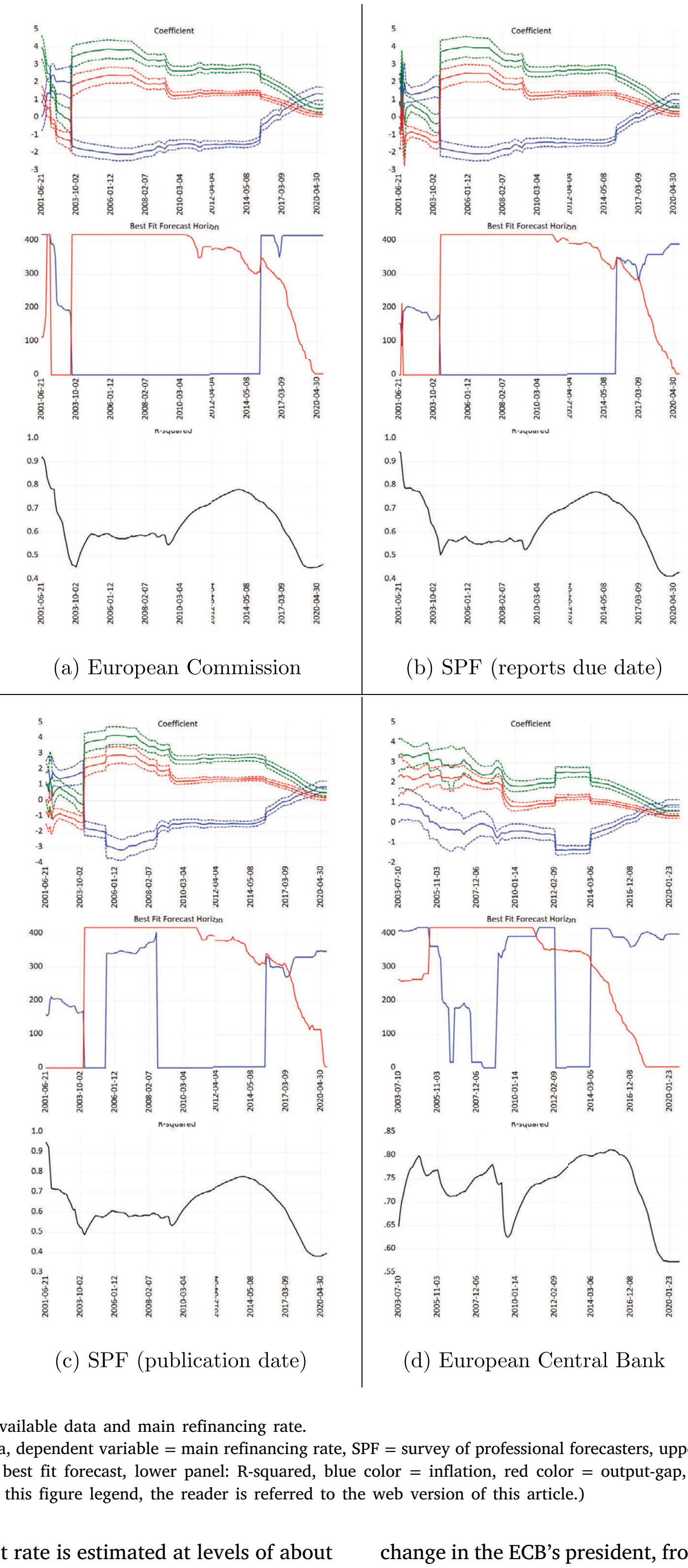
Fig. 11. Rolling Taylor rules with latest available data and EONIA.
Notes: Taylor rule using latest available data, dependent variable = EONIA, SPF = survey of professional forecasters, upper panel: solid-lines = coefficients, dashed-lines = 95% confidence interval, middle panel: best fit forecast, lower panel: R-squared, blue color = inflation, red color = output-gap, green color = natural real interest rate. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

first-difference rule. For rational approximation and current inflation data, we provide the results in an appendix. Generally, the results are similar to those using latest available data.

4.2.1. Taylor rules

Applying this time-varying coefficient approach to the Taylor rules with latest available data and the EONIA as the dependent variable leads to the results presented in Fig. 11. Generally, the results are very similar, independent of the data sources used. We identify four different phases. The first period, from the beginning of the European Monetary Union until mid-2003 to the beginning of 2004 is characterized by a high but steadily decreasing fit of the Taylor rules.[20] Moreover, the best fit inflation forecast is medium term, at mainly about 200 days into the future, while the best fit output gap forecast is the contemporaneous one. The inflation response coefficient in this period is about two, while the output coefficient tends to decrease and even becomes negative in

[20] Note that the first period cannot be identified with ECB data, since those estimates only start in mid-2003.



(a) European Commission (b) SPF (reports due date)

(c) SPF (publication date) (d) European Central Bank

Fig. 12. Rolling Taylor rules with latest available data and main refinancing rate.
Notes: Taylor rule using latest available data, dependent variable = main refinancing rate, SPF = survey of professional forecasters, upper panel: solid-lines = coefficients, dashed-lines = 95% confidence interval, middle panel: best fit forecast, lower panel: R-squared, blue color = inflation, red color = output-gap, green color = natural real interest rate. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

most cases. The natural real interest rate is estimated at levels of about zero in this period.

The second period runs from mid-2003 to the beginning of 2004 and thus corresponds remarkably to two fundamental changes within the ECB. The first is the change in the ECB's inflation target, from an inflation rate below 2% to an inflation rate of below but close to 2% in May 2003. Thus, strictly speaking, only from this time onward is the applied inflation target of 1.75 reasonable, while it could have been lower beforehand. The second event during this period is the first change in the ECB's president, from Duisenberg to Trichet, in November 2003. At the beginning of this second period, the best fit inflation and output forecast horizons are changing dramatically. Now the best output forecast is long term, that is, 418 days into the future, while the best inflation rate is the contemporaneous one. This result also has large effects on the estimated coefficients: the natural real interest rate rises to levels of about 4%, a good one to two percentage points higher than the other estimates of this variable at that time (e.g., Holsten et al., 2017). Moreover, the response coefficient on output increases significantly to levels of about two. Surprisingly, the inflation response coefficient falls into negative territory and is highly significant, with the exception of the ECB data estimates. We can thus conclude that the ECB has not followed a stabilizing policy with respect to this variable during this period.

The beginning of the third period is associated with the financial crisis. It starts after the ECB coped with the first deteriorations in economic performance via rapid interest rate cuts until mid-2009. This period is characterized by a rising fit of the Taylor rule, while inflation, the output response coefficients, and the natural real interest rate are at about −1.5, 1.5, and 3%, respectively.

The fourth period starts around the time the ECB announced its large-scale asset purchase program in January 2015. This period is characterized, on the one hand, by rising inflation response coefficients becoming even significantly positive toward the end of our sample period. Thus, during this period the ECB returned to an inflation-stabilizing policy, possibly to fight deflation in this period. On the other hand, the natural real interest rates as well as output response coefficients are steadily decreasing in this period toward the levels described in Section 4.1. This change in coefficients is also associated with another shift in the best fit forecast horizon. While the best fit output forecast horizon is steadily decreasing, the best fit inflation forecast horizon becomes rather long term around the introduction of the quantitative easing program. Even though the estimated coefficients are now more in line with the proposed Taylor rule coefficients, the fit of the Taylor rule actually deteriorates in this period.

The results remain broadly unchanged when the main refinancing rate instead of the EONIA is used as the dependent variable (Fig. 12); that is, the four different periods can also be identified here.

In addition, somehow surprisingly, the results using the shadow rate as the dependent variable are almost the same as for the other two variables (Fig. 13). While this result is clear for the first two periods, since no unconventional monetary measures were introduced and the shadow rate is thus quite close to the other rates, more differences could have been expected in the third and fourth periods. However, this is not the case. In fact, the only difference we observe is that, in the fourth period, the rise in the inflation coefficient and the drop in the natural real interest rate are now steeper compared to the specifications with the EONIA or the main refinancing rate as the dependent variable. We also observed this pattern in Section 4.1.

4.2.2. *First-difference rules*

When turning to the first-difference rules, we find the estimated coefficients to be considerably smaller, as also seen in Section 4.1. Using the EONIA as the dependent variable leads to the results presented in Fig. 14. The best fit output forecast horizon is found to be rather long term throughout all the periods and data sources. Moreover, the estimated response coefficients turn out to be mainly significant at the 95% level and are positive in a range of about 0.1 to 0.2, although the response coefficient decreases with a longer sample size. The best fit inflation forecast horizon, however, shifts several times. It is rather short term at the beginning of the sample, resulting in negative response coefficients; in 2006, the forecast horizon becomes long term and the response coefficients also increase into the positive territory. However, this result is reversed in the wake of the financial crisis in 2009, when the forecast horizon becomes short term again and, with it, the response coefficients become significantly negative. A last shift is noted between 2015 and 2016, when the forecast horizon becomes long term again and, with it, the response coefficient becomes positive.

In sum, the four periods identified for the Taylor rules can also be identified in terms of first-difference rules. However, some things are different. First, although, in the Taylor rule specifications, all the coefficients and the natural real interest were changing, this is now mainly the case for the inflation response coefficient. Second, the timing of the periods is somewhat different. While the first shift in the first-difference rules only appears in 2006, it was observed earlier in the Taylor rule estimations. The same holds with respect to the last shift, for the first-difference rules in 2015 and 2016.

Despite these differences, the main results from the Taylor rule estimations also prevail in the first-difference rule estimations. These are, i.e., the positive but decreasing response coefficient of output and the mainly negative response coefficient of inflation, which only becomes positive in the last years of the sample period.

The results are mainly robust to the choice of the interest rate. If the main refinancing rate is used instead of the EONIA, the picture remains almost the same (Fig. 15).

When we use the shadow rate as a dependent variable instead (Fig. 16), the results change insofar that the periods in which the best fit inflation forecast horizon is long term vanish, and the best fit horizon is thus rather short term throughout. This result also leads to lower and mainly negative inflation response coefficients.

5. Conclusions

In this article, we present data on contemporaneous and forward-looking daily inflation rates and output, based on different official European data sources, namely, the European Commission, the ECB, and the ECB's SPF. Moreover, we apply three different methods for the data computation: one using the latest available, purely backward-looking data; a partly forward-looking rational approximation approach; and a backward-looking approach using actual inflation publications instead of forecasts. We thus provide the first granular database of daily-frequency inflation and output for the ECB.

We use the data to evaluate monetary policy, that is, we estimate two different monetary policy rules, namely, the Taylor rule and a first-difference rule, with respect to three different interest rates. We thus provide a detailed comparison of the different specifications. The results indicate that the best fit rules differ little with respect to the data sources or the data computation, and more with the choice of the policy rule or the interest rate tackled. In the latter case, the difference is mainly driven by the inclusion of unconventional monetary policy measures in the interest rate, as in the use of shadow rates instead of short-term or official key interest rates.

The results presented here can be used by financial market participants, because they give an indication of the ECB's policy rule, that is, the forecast horizon and the response coefficients, with respect to inflation and output. Monetary policy thus becomes more predictable when these rules are used. While the implications with respect to the output response differ considerably among the various specifications, we can conclude that the best fit inflation forecast horizon is currently rather long term, that is, the longest forecast horizon possible in our approach, 418 days. This being said, the medium-term orientation of the ECB seems to be between 1 and 1.5 years into the future, if not longer, in the current environment.

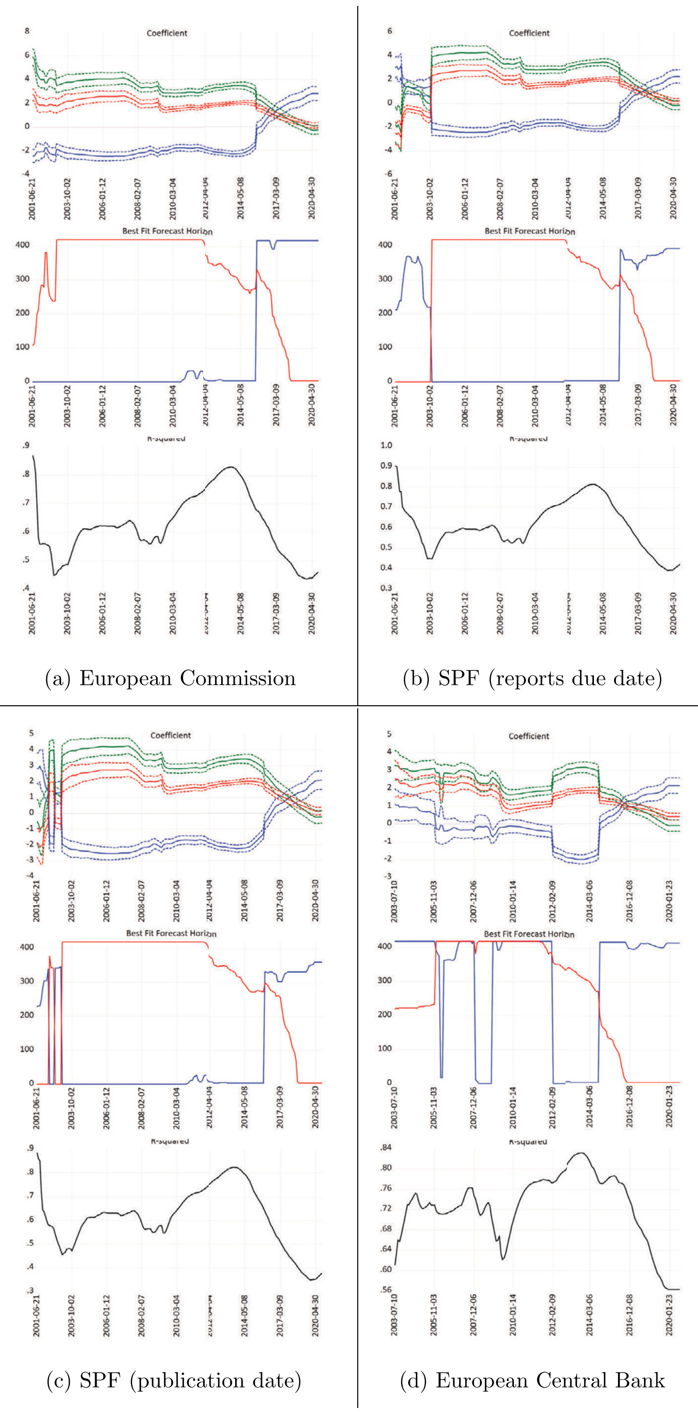
We have also shown, however, that the forecast horizons of the policy rules can rapidly shift. Although we have identified only a few such shifts in the ECB policy rules from 1999 to 2020, besides large economic crises, these shifts have the potential to cause substantial turbulence in financial markets. Therefore, ideally, they need to be explained by the ECB beforehand, such as in the form of changing forward guidance, so the markets can adjust to the new rules and turbulence is held to a minimum.

Declaration of competing interest

The corresponding author states that there is no conflict of interest for the paper.

Data availability

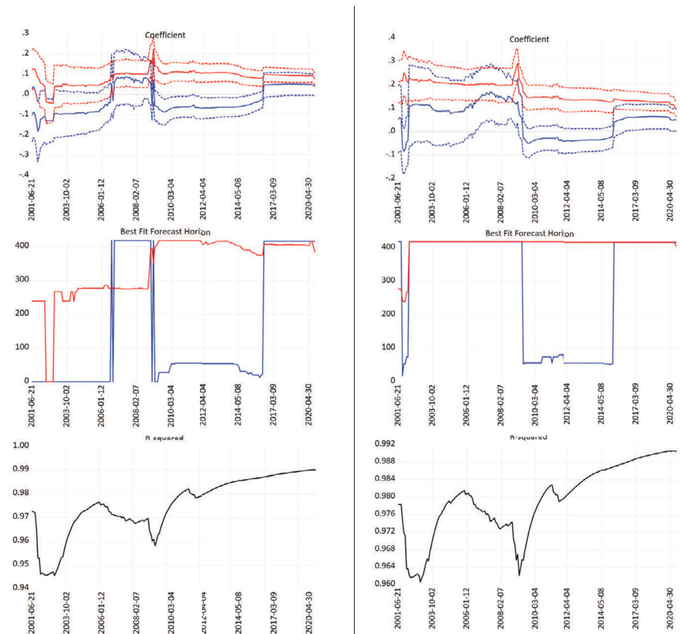
Data will be made available on request.



(a) European Commission (b) SPF (reports due date)

(c) SPF (publication date) (d) European Central Bank

Fig. 13. Rolling Taylor rules with latest available data and shadow rate.
Notes: Taylor rule using latest available data, dependent variable = shadow rate, SPF = survey of professional forecasters, upper panel: solid-lines = coefficients, dashed-lines = 95% confidence interval, middle panel: best fit forecast, lower panel: R-squared, blue color = inflation, red color = output-gap, green color = natural real interest rate. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



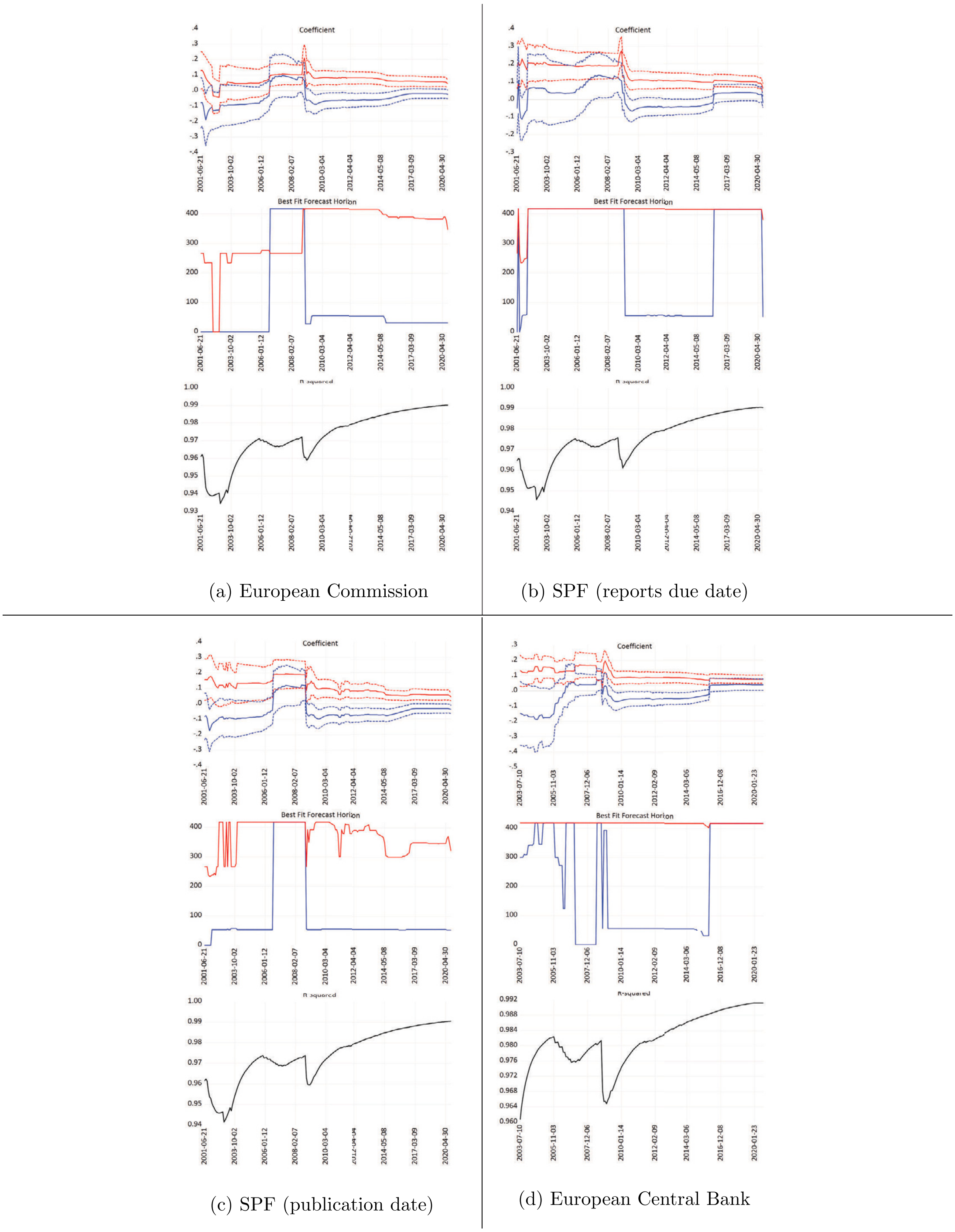
(a) European Commission

(b) SPF (reports due date)

(c) SPF (publication date)

(d) European Central Bank

Fig. 14. Rolling first-difference rules with latest available data and EONIA.
Notes: First-difference rule using latest available data, dependent variable = EONIA, SPF = survey of professional forecasters, upper panel: solid-lines = coefficients, dashed-lines = 95% confidence interval, middle panel: best fit forecast, lower panel: R-squared, blue color = inflation, red color = output-gap. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



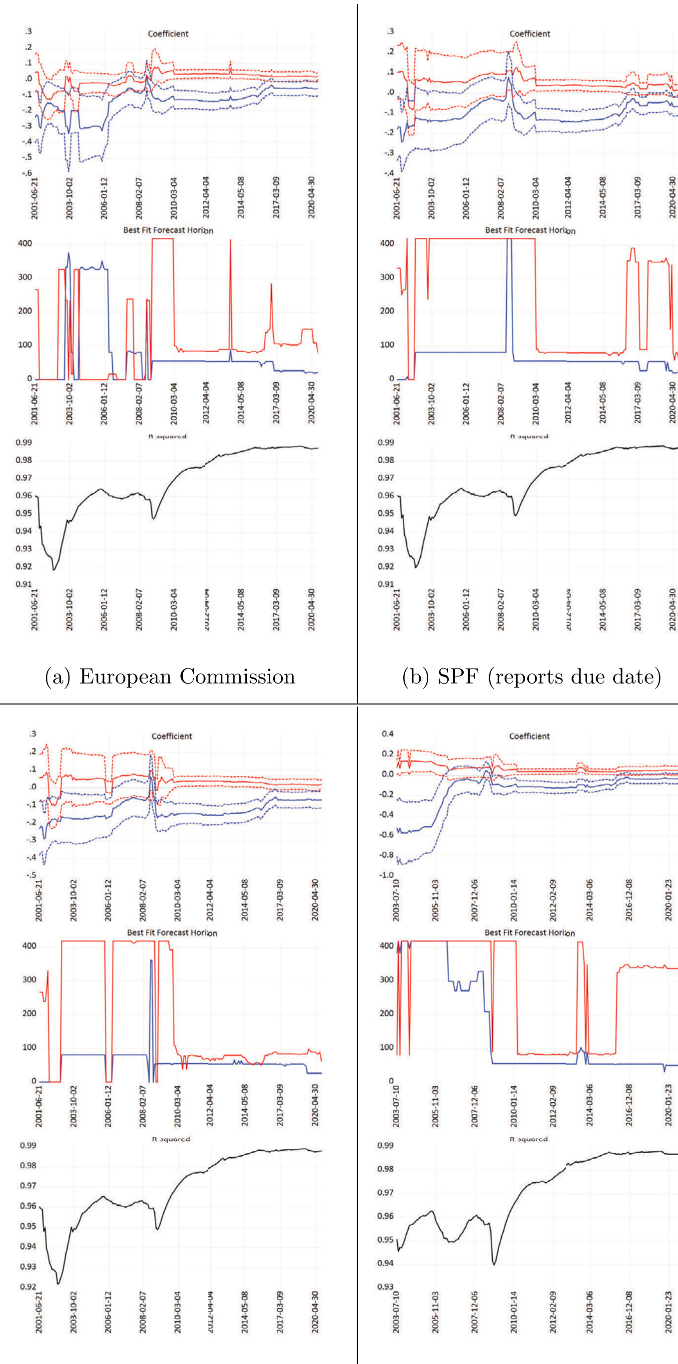
(a) European Commission

(b) SPF (reports due date)

(c) SPF (publication date)

(d) European Central Bank

Fig. 15. Rolling first-difference rules with latest available data and main refinancing rate.
Notes: First-difference rule using latest available data, dependent variable = main refinancing rate, SPF = survey of professional forecasters, upper panel: solid-lines = coefficients, dashed-lines = 95% confidence interval, middle panel: best fit forecast, lower panel: R-squared, blue color = inflation, red color = output-gap. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



(a) European Commission (b) SPF (reports due date)

(c) SPF (publication date) (d) European Central Bank

Fig. 16. Rolling first-difference rules with latest available data and shadow rate.
Notes: First-difference rule using latest available data, dependent variable = shadow rate, SPF = survey of professional forecasters, upper panel: solid-lines = coefficients, dashed-lines = 95% confidence interval, middle panel: best fit forecast, lower panel: R-squared, blue color = inflation, red color = output-gap. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.econmod.2023.106466.

References

Belke, A., Klose, J., 2011. Does the ECB rely on a Taylor rule during the financial crisis? Comparing ex-post and real time data with real time forecasts. Econ. Anal. Policy 41 (2), 147–171.

Beyer, R., Wieland, V., 2019. Instability, imprecision and inconsistent use of equilibrium real interest rate estimates. J. Int. Money Finance 94, 1–14.

Bletzinger, T., Wieland, V., 2017. Lower for longer: The case of the ECB. Econom. Lett. 159, 123–127.

Brand, C., Mazelis, F., 2019. Taylor-Rule Consistent Estimates of the Natural Rate of Interest. ECB Working Paper Series 2257, Frankfurt.

Caporale, G.M., Helmi, A.N., Catik, F.M., Ali, C., Akdeniz, M.H., 2018. Monetary policy rules in emerging countries: Is there an augmented nonlinear Taylor rule? Econ. Model. 72, 306–319.

Clarida, R., Gali, M., Gertler, J., 1998. Monetary policy rules in practice - Some international evidence. Eur. Econ. Rev. 42, 1033–1067.

Clarida, R., Gali, M., Gertler, J., 2000. Monetary policy rules an macroeconomic stability: Evidence and some theory. Q. J. Econ. 115 (1), 147–180.

Eleftheriou, M., Kouretas, G.P., 2023. Monetary policy rules and inflation control in the US. Econ. Model. 119, 106137.

Gerdesmeier, D., Roffia, B., 2005. The relevance of real-time data in estimating reaction functions for the Euro area. North Am. J. Econ. Finance 16 (3), 293–307.

Gorter, J., Jacobs, J., de Haan, J., 2008. Taylor rules using expectations data. Scand. J. Econ. 110 (3), 473–488.

Gross, J., Zahner, J., 2021. What's on the ECB's mind? Monetary policy before and after the Global financial crisis. J. Macroecon. 68, 103292.

Hartmann, P., Smets, F., 2018. The First Twenty Years of the European Central Bank: Monetary Policy. ECB Working Paper Series 2219, Frankfurt.

Hayat, A., Mishra, S., 2010. Federal reserve monetary policy and the non-linearity of the Taylor rule. Econ. Model. 27 (5), 1292–1301.

Holsten, K., Laubach, J., Williams, T., 2017. Measuring the natural rate of interest: International trends and determinants. J. Int. Econ. 108 (S1), S59–S75.

Krippner, L., 2013. Measuring the stance of monetary policy in zero lower bound environments. Econom. Lett. 118, 135–138.

Mesonnier, J., Renne, J., 2007. A time-varying natural rate of interest for the euro area. Eur. Econ. Rev. 51, 1768–1784.

Orphanides, A., 2001. Monetary policy rules based on real-time-data. Amer. Econ. Rev. 91, 964–985.

Orphanides, A., 2003. Historical monetary policy analysis and the Taylor rule. J. Monetary Econ. 50 (5), 983–1022.

Orphanides, A., 2006. The road to price stability. Amer. Econ. Rev. 96 (2), 178–181.

Orphanides, A., van Norden, S., 2002. The unreliability of output-gap estimates in real time. Rev. Econ. Stat. 84 (4), 569–583.

Orphanides, A., Wieland, V., 2013. Complexity and monetary policy. Int. J. Central Bank. 9 (1), 167–204.

Sauer, S., Sturm, J.E., 2007. Using Taylor rules to understand ECB monetary policy. Ger. Econ. Rev. 8 (8), 375–398.

Sznajderska, A., 2014. Asymmetric effects in the Polish monetary policy rule. Econ. Model. 36, 547–556.

Taylor, J., 1993. Discretion versus policy rules in practice. In: Carnegie-Rochester Conference Series on Public Policy, Vol. 39. pp. 195–214.

Wieland, V., Wolters, M., 2013. Chapter 5 - forecasting and policy making. Handb. Econ. Forecast. 2 (A), 239–325.

Wu, J., Xia, F., 2016. Measuring the macroeconomic impact of monetary policy at the zero lower bound. J. Money Credit Bank 48 (2–3), 253–291.