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Does the ECB Rely on a Taylor rule? Comparing ex-post with real time data

Abstract

In this paper it is assessed the differences that emerge in Taylor rule estimations for the European Central Bank (ECB) when using ex-post data instead of real-time forecasts and vice versa. The authors argue that previous comparative studies in this field risk mixing up two separate effects. First, the differences resulting from the use of ex-post and real-time data per se; and second, the differences emerging from the use of non-modified real-time data instead of real-time database forecasted values (and vice versa). Since both effects can influence the ECB reaction to inflation and the output gap in either way, it is used a more clear-cut approach to disentangle the partial effects. However, "good" forecasts have to be as close as possible to the forecasts the ECB governing council had at hand when taking its interest rate decision. Therefore, two approaches are used to generate the forecasts: first, forecasts generated relying on a pure AR process; and second, explicit ECB staff projections which are available only at a quarterly frequency. So, the authors found it indispensable to estimate all variants of the reaction function using also quarterly data. Our estimation results indicate that using real-time instead of ex-post data leads to higher estimated inflation coefficients while the opposite is true for the output gap coefficients. If real-time data forecasts based on AR processes for the current period are used (since actual data become available with a lag), this empirical pattern is even strengthened in the sense of even increasing the inflation response but lowering the reaction to the output gap while the reverse is true if "true" forecasts of real-time data for several periods are employed.

Keywords: European Central Bank, monetary policy, real-time data, Taylor rule.
JEL Classification: E43, E58.

Introduction

Ever since the founding of the European Central Bank (ECB) in 1999 the question whether it follows or should follow the famous Taylor rule was raised (Taylor, 1993). In fact many economists so far have investigated this issue with respect to the euro area using either data of a "fictitious" ECB prior to its establishment (see Peersman and Smets, 1999; Gerlach and Schnabel, 2000; Clausen and Hayo, 2002; Altavilla and Landolfo, 2005) or the limited data thereafter (see Surico, 2003; Fourçans and Vranceanu, 2003; Gerdesmeier and Roffia, 2003; Garcia-Iglesias, 2007; Belke and Polleit, 2007; and Fendel and Frenkel, 2009)[1]. By now we have seen more than ten years of ECB monetary policy and are now able to derive new estimates from a sufficiently broad euro area-specific database.

But the whole array of Taylor rule estimations enumerated above essentially rely on ex-post data. This comes as a surprise as the use of ex-post data "is based on unrealistic assumptions about the timeliness of data availability and ignores difficulties associated with the accuracy of initial data and subsequent revisions" (Orphanides, 2001, p. 964). Therefore, the analysis should be carried out using real-time data instead of ex-post data simply because the latter were not available to the central bank decision-making body at the time the interest rate decision was made. That is exactly why we focus on the extent of quantitative differences between the estimates occurring from using ex-post instead of real-time data.

To be more specific, these quantitative differences potentially stem from four sources. First, inflation and output gap data are available only with a lag. Second, data sets are revised as time goes by ("data uncertainty"). Third, the central bank governing council can construct the variables needed based only on past data and not with reference to the whole relevant sample period as is the case with ex-post data, since when the council constructs these variables it cannot "look back" at the whole sample ("statistical uncertainty"), and fourth (and less specific for the problem investigated here), the empirical model used to derive the estimates is not unique ("model uncertainty"). These sources of differences between real-time and ex-post data play a central role in the interpretation of our estimation results and we will come back to them when comparing the difference between the ex-post and real-time series of the inflation rate and the output gap.

However, in our paper we do not only focus on the changes in numerical values of estimation results arising from the use of ex-post instead of real-time data but also on those stemming from the use of forecasted variables instead of contemporaneous ones since central banks would react systematically too late when applying only contemporaneous variables because monetary impulses become effective with a lag (see Svensson, 2003, p. 449). In principle,

[1] In fact, also combinations of these two types can be found, mostly to expand the sample in order to generate more reliable estimates (see Gerlach-Kirsten, 2003; Siklos and Bohl, 2009). For a comparison between these two types of data at the early stage see Ullrich (2003).

there are two ways in which this comparison can be enacted: either by using ex-post data or by applying real-time data. However, we prefer to follow the latter approach because it appears to us more realistic that the ECB builds its forecast upon real-time data than on the (not available) ex-post data. Another advantage of this approach is that we are able to use a transparent procedure by comparing estimates based on ex-post with those employing real-time data and, later on, comparing real-time data estimates with estimates based on variable forecasts based on real-time data.

So far, estimations of ECB Taylor rules using real-time data are still quite scarce. In fact, there is only a couple of papers available dealing with this topic. Most of these papers focus on estimates on a monthly basis which is the natural frequency to choose because the ECB decides about its interest rate every month and not every quarter. However, we present estimations based on monthly and quarterly data which both rely exclusively on the EMU sample period.

We add quarterly data estimates because we want to distinguish the effects of using ex-post versus real-time data from the use of real-time forecasts instead of real-time data. This is because both effects can influence the monetary policy reaction coefficients either way. For the second above-mentioned comparison we need forecasts that correspond as close as possible to the unknown forecasts on which the ECB Governing Council bases its interest rate decisions. To find a database or derive forecasts that are as close to those of the ECB is the crucial task when assessing ECB policy.

We follow two approaches to cope with these requirements. First, we incorporate forecasts based on autoregressive (AR) processes because these forecasts are based on the available real-time data and, in principle, should also be easily available to the Governing council when taking its interest rate decisions. Second, we make explicit use of the ECB staff projections which appear to be highly appropriate to exploit in our case because these data are generated by the ECB itself. Unfortunately, they are available only at a quarterly frequency. Consequently, we have to add quarterly estimates in order to be able to detect potential differences in performance between these forecasts and real-time data.

The paper proceeds as follows. In Section 1, the Taylor rule and its extensions are described before we turn to the pattern of results gained in this field so far in Section 2. In Section 3, we explain our data choice and variable selection. In Section 4 we display our estimation results. The last section concludes.

1. The Taylor rule

It is well over a decade since John B. Taylor set out what has become a part of the current orthodoxy of monetary economics by now. In 1993 he proposed a new and simple monetary policy rule which suggests that the central bank should set interest rates according to deviations of the inflation rate from its target and the percentage deviations of the output from its potential (the so-called output gap). So, the rule can be derived in the following way:

$$i_t = r_t^* + \pi_t + \alpha_\pi\left(\pi_t - \pi^*\right) + a_y\left(y_t - y_t^*\right), \qquad (1)$$

where i_t is the interest rate set by the central bank, r_t^* stands for the equilibrium real interest rate, π_t is the inflation rate over the previous four quarters, π^* represents the constant inflation target, $\left(y_t - y_t^*\right)$ stands for the output gap and α_π, a_y are coefficients measuring the strength of the reaction to the inflation and output gap. Both coefficients are expected to be larger than zero. In fact, Taylor (1993) himself proposed that each coefficient should be equal to 0.5[1]. All variables with the exception of the inflation target are allowed to vary over time and are therefore indexed by *t*. However, in the literature this is the exception rather than the rule with respect to r_t^* when it comes to Taylor rule estimations[2]. For this purpose, we use the Fisher equation with adaptive expectations $\left(r_t = i_t - \pi_t\right)$ and apply the Hodrick-Prescott filter (HP-filter) (see Hodrick and Prescott, 1997) to the resulting real interest rate variable. In order to construct our variable measuring potential output y_t^*[3], we also apply the HP-filter. However, we check for the robustness of our estimation results by constructing this variable with the help of a linear and a quadratic trend because mis-measurement of the potential output has the potential to cause serious problems in Taylor rule estimations especially when the underlying output time series is based on real-time data[4].

[1] However, Ball (1999) argues that the coefficients need to be adjusted in order to display an optimal policy reaction. Accordingly, also Belke and Polleit (2009, pp. 714ff. and 765ff.) conclude that central bank's orientation and the structure of the economy have to be taken into consideration when determining the coefficients.

[2] Our results clearly indicate that using a time varying equilibrium real interest rate improves the fit of Taylor rule signaled by the adjusted R^2 as compared to reaction functions assuming a constant rate. The results for the latter are available from the authors upon request.

[3] The choice of the correct potential output measure is of course one possible source of measurement problems of the Taylor rule.

[4] See Orphanides and van Norden (2002) for a detailed discussion on the unreliability of output gap estimates in real time. See Gros, Mayer and Ubide (2005, p. 10) for the same discussion in the context of EMU as a special case.

For estimation purposes equation (1) can be rearranged as follows:

$$i_t = r_t^* - (a_\pi - 1)\pi^* + a_\pi \pi_t + a_y (y_t - y_t^*), \qquad (2)$$

with $a_\pi = 1 + \alpha_\pi$. In the notation of equation (2), the Taylor principle implies that the coefficient a_π needs to be larger than unity in order to raise the nominal interest rate by more than the inflation rate and, by this, to increase the real interest rate which is the decisive variable for investment or consumption decisions. If $a_\pi < 1$, the real interest rate would decrease if inflation is rising, leading to even more inflationary pressure in the future. Since Taylor proposed $\alpha_\pi = 0.5$ it immediately follows that $a_\pi = 1.5$.

The first commonly used extension of the Taylor rule is the inclusion of an interest rate smoothing term to account for the fact that central banks typically adjust the key interest rate in rather small steps without hardly ever revising the direction thereafter. In this case, equation (2) turns into:

$$i_t = \rho \times i_{t-1} + (1-\rho) \times$$
$$\times \left[r_t^* - (a_\pi - 1)\pi^* + a_\pi \pi_t + a_y (y_t - y_t^*) \right], \qquad (3)$$

where ρ represents the smoothing parameter. If $\rho = 1$ the interest rate is solely influenced by the past interest rate and for $\rho = 0$ equation (3) reduces to equation (2). However, as experience shows, reasonable results should lie somewhere in $(0 < \rho < 1)$.

A second extension is the forward-looking perspective. Clarida and Gertler (1996), for instance, argued in favor of using a forward-looking specification of the Taylor rule because any other specifications would imply that the central bank would respond systematically too late as monetary impulses become effective only with a lag. Therefore, they proposed to use expected future values of the inflation rate based on the information available at the point in time, where the decision is made. Later on this concept was expanded to the use of forecasts for the output gap as well. Hence, a forward-looking Taylor reaction function would look like:

$$i_t = \bar{r}_t^* - (a_\pi - 1)\pi^* + a_\pi \times$$
$$\times E(\pi_{(t+j|t)}) + a_y \times \left[E(y_{(t+k|t)}) - \bar{y}_t^* \right], \qquad (4)$$

where E is the expectations operator and j, k are some positive values indicating the forecast horizon. Note that j and k need not be equal so that different forecasts horizons for the inflation rate and the output are possible. With forecasts used in the Taylor rule also the variables $\bar{r}_t^*$ and $\bar{y}_t^*$ are adjusted because in the former case the expected inflation measure alters and in the latter case the trend changes because of more data.

It is of course possible to complement forward-looking Taylor rules with an interest rate smoothing term and this is in fact done in most of the cases. However, imposing forward-looking elements onto the Taylor reaction function only makes sense in the context of real-time data because these were the data the central bank has based its forecasts on. In contrast, extracting forecasts from ex-post data means forming forward-looking expectations based on data which were de facto not available at the time of decision-making which is quite unrealistic.

Therefore, the approach, carried out here, is a three-step one. First, we estimate Taylor reaction functions with ex-post data. Second, we compare the resulting estimates with those gained for estimates of the Taylor rule based on unmodified pure real time (which are available to the decision-making body "contemporarily") data. Third, we assess the differences between real-time database estimated Taylor rules and the ones which rely on forecasted variables based on real-time data.

2. Survey of the literature

As mentioned above, up to now the available empirical work providing Taylor rule estimates in real time for the euro area is by far not exhaustive. Nevertheless, their findings are worth mentioning here because they are natural candidates for comparisons to the results derived from the analysis carried out in our paper. We pick up five of them in the following.

In Adema (2004), Taylor rule estimates using ex-post and "quasi" real-time data are compared. The difference between real-time and "quasi" real-time data is simply that data revisions are supposed to be fairly small and can thus be neglected. Making this assumption, Adema ends up with coefficients ρ = 0.75, α_π = 1.80, a_y = 1.72 for ex-post and ρ = 0.64, α_π = 1.89, a_y = 0.46 for "quasi" real-time data covering the sample period of 1994Q1 to 2000Q4, thus mostly the pre-ECB era.

In the same vein as Adema is the paper by Carstensen and Colavecchio (2004). The authors limit themselves to an estimation of Taylor rules with "quasi" real-time data but do not compare their results to Taylor rules using ex-post estimates. Thus, they do not only neglect the data revisions but also abstract from any time lag problem. This is exactly why their results are, in the quantitative dimension, somewhere between Taylor rules estimated with ex-

post and those based on real-time data. For the sample period of 1999M1-2004M2 they come up with coefficients $\rho = 0.95$, $a_\pi = 1.01$, $a_y = 1.36$.

Gerdesmeier and Roffia (2005) are among the first authors using real-time data instead of "quasi" real time data. They estimate Taylor rule coefficients for the period of 1999M1-2003M6. For *ex-post* data they find $\rho = 0.84$, $a_\pi = 1.08$, and $a_y = 0.70$. When using *contemporaneous* realizations of *real-time* data, the picture changes as in this case the estimated output gap coefficient increases (2.05) while the estimated inflation parameter falls far below unity (0.39). The degree of interest rate smoothing decreases to 0.63. However, conducting their analysis with twelve month *forecasts* of the independent macro variables based on *survey* data collected in real time, they arrive at much higher values for the estimated coefficient of inflation (1.31) while ρ and a_y remain more or less unchanged ($\rho = 0.71$ and $a_y = 1.95$). The already rather high estimated inflation coefficient gets even larger when applying a two year instead of a one year forecast based on real-time survey data ($a_\pi = 2.91$, $\rho = 0.67$, and $a_y = 2.02$).

Working with *ex-post* data, Sauer and Sturm (2007) come up with estimated coefficients $\rho = 0.94$, $a_\pi = -0.84$, $a_y = 1.45$ for the period ranging from January 1999 to October 2003. Employing *real-time* data instead, the estimated coefficients turn out to be $\rho = 0.98$, $a_\pi = -0.27$ and $a_y = 3.01$. When they implement forecasts of the independent macro variables based on real-time data, the estimated inflation coefficient becomes positive and larger than unity (6.62) and the estimated interest rate smoothing parameter and the estimated coefficient of the output gap become $\rho = 0.98$ and $a_y = 9.24$, respectively. However, in all cases, the Taylor rule coefficients are insignificant which is probably due to the overly large estimated interest smoothing parameter.

Finally, Gorter, Jacobs and de Haan (2008) compare estimates of the ECB Taylor rule using ex-post data with estimates based on independent macro variables which are forecasted based on real-time data[1]. For the period of 1997M1-2006M12, they find estimated coefficients for the former equal to $\rho = 0.95$, $a_\pi = 0.09$, and $a_y = 0.37$ and $\rho = 0.86$, $a_\pi = 1.39$, $a_y = 1.52$ for the latter. However, we would like to argue that the next issue for further research beyond this study is to really distinguish between the effect of using real time instead of ex-post data and the one induced by the use of forecasts.

3. The data issue

Our Taylor rule estimations for the EMU period are based both on quarterly and monthly data. Hence, a side-effect is that in our paper we are able to check whether the estimation results closely correspond with the results other studies come up with (as is coincidentally corroborated later on by our analysis). All data are taken from the Euro Area Business Cycle Network (EABCN) real-time database[2]. The output variable is captured as usual by real GDP (for quarterly data) and industrial production (for monthly data).

The price level is proxied by the harmonized index of consumer prices (HICP) and the interest rate variable by the three-month Euribor. Unfortunately, these data are only available from 2001 onwards in the EABCN database so that the data before (1999 and 2000) have been collected from the ECB monthly bulletins.

All data are seasonally adjusted and cover the euro area consisting of its first twelve members[3] for the sample period from 1999Q1 (1999M1) to 2007Q2 (2007M6). We choose the specific end of the sample period with an eye on the fact that the data provided by the EABCN are cut off in March 2008. To account for ex-post data adjustments even at the end of the sample period which have the potential to lead to differences of estimation results, dependent on the use of ex-post versus real-time data, we decided to leave ample room of three quarters for revisions. With this, we are in line with the findings and recommendations by Coenen, Levin and Wieland (2005). Hence, in our case the ex-post variables are those available in 2008M3 for the whole estimation period (1999M1 to 2007M6). In the case of the interest rate this is also the (forecasted) real-time series because the interest rate is not subject to the real-time critique. In contrast to that, the other real-time data are known by the ECB governing council at the time the decision was made and, hence, represent exactly the information that could explain interest rate rises/cuts. Unfortunately, the last values known to the ECB are never the contemporaneous ones as information about them becomes

[1] This study relies on survey data of real-time forecasts made by major banks in the EMU.

[2] This database relies on the data gathered for the ECB monthly bulletin. The cut-off date for the statistics is normally more than one week before the bulletin is published and thus corresponds almost one to one to the data the ECB governing council had at hand when taking its interest rate decision because the first meeting of the month (where interest decisions are made) takes place one week before the publication of the bulletin.

[3] Thus, we include Greece which joined the EMU in 2001 and omit Slovenia which became a member not earlier than 2007.

available only with a lag. Therefore, when using real-time data, the ECB would react systematically too late in the sense that it reacts to values which are not up to date.

That is why *forecasts* of the variables included in the Taylor reaction function need to be implementted. It appears straightforward to construct forecasts covering exactly that "time lag deficit" because in this case a comparison between ex-post and real-time data would rely exactly on the same time periods. So, this type of forecast is applied by us as a first strategy.

But as the ECB monetary strategy is medium term oriented, it also appears reasonable to incorporate a really forward-looking forecast. We use this as our second empirical strategy. Here, we strictly follow Sauer and Sturm (2007) who implement forecasts of 6 months for inflation and 3 months for the output gap. Using these forecast horizons, we address the ECB's medium term orientation. What is more, we take into account that the primary goal of the ECB is to maintain price stability since the smaller forecast horizon of the output gap takes the future inflationary pressures associated with this variable into account.

A second problem which emerges along with forecasts is the choice of the forecasting method /database to mimic forward-looking behavior of the monetary authority since there are no reliable monthly ECB internal data available to the researcher. So, the resulting Taylor rule estimates using calculated forecasts or survey data are just as good to the extent to which they coincide with the ECB forecasts[1]. So, what forecast technique is the most preferable in our context? As our first strategy, we decided to strictly follow Sauer and Sturm (2007) by employing an AR(3) process to model monthly forecasts. For the purpose of quarterly forecasting we decided to use an AR(2) process[2]. These forecasts are based on the real-time data which are in principle also available to the Governing council when making its interest rate decision.

In addition, we estimate the forward looking equations using the ECB staff projections. These projections are supposed to be the best proxy for the forecasts of the ECB governing council when making its interest rate decision. From December 2000 onwards these projections were published bi-annually (in June and December) as "Eurosystem staff economic projections." Since September 2004 the latter are complemented by "ECB staff projections" which are included in the respective March and September issue of the ECB monthly bulletin. Thus, we are capable of generating a time series on a quarterly basis for which in the third month of each quarter a new projection becomes available. In order to take these forecasts into account, our sample has to start in 2000Q4 and to be adjusted for the absence of any projections in the first and third quarter before 2004Q3 by taking the respective values of the prior projections. Since both projections come up with a corridor for the inflation rate and real GDP growth, we decided to simply use the mean of it as our empirical realization of the projection variable.

Coming back to the Taylor rule, there are in fact five variables that are needed. First, the interest rate (i_t), second, the equilibrium real interest rate (r_t^*), third, the inflation target (π^*), fourth, the inflation rate (π_t) and fifth, the output gap $\left(y_t - y_t^*\right)$ which consists of an output measure and the potential output.

Turning from the least to the most complex variable, we start with the inflation target which is simply set equal to two percent in line with the ECB announcement to define price stability with a increase of HICP of close to but less than two percent over the medium term. The interest rate can be taken directly from the database without any adjustment. As a measure of the inflation rate, the year-on-year increase in the HICP is taken. Hence, the formula constructing the inflation rate looks like this:

$$\pi_t = 100\left[\log\left(HICP_t\right) - \log\left(HICP_{t-12}\right)\right]$$

(for monthly data), (5)

$$\pi_t = 100\left[\log\left(HICP_t\right) - \log\left(HICP_{t-4}\right)\right]$$

(for quarterly data). (5a)

Applying these transformations to ex-post data is a trivial task but when it comes to real time data it gets slightly more complicated because in every period the last available value has to be diminished by its value one year ago. However, due to the existence of the time lag, the last value available is never the actual value. For monthly data, the lag is normally two months and thus for quarterly data one quarter[3]. When employing forecasts, we simply use

[1] Obviously, the respective forecasts have to be as close as possible to the (unknown) ECB predictions to be good forecasts in the sense of modeling the Taylor rule correctly and not close to the true values emerging several periods thereafter. If the ECB does not make any forecast errors at all (perfect foresight) then the ECB forecasts and "true" values would be the same. However, this is quite unrealistic.

[2] We also experimented with different AR processes but the results did not change significantly. The results are available on request.

[3] In fact the ECB publishes since November 2001 a flash estimate of the HICP which would reduce the time lag to one month. We did not use those estimates for our analysis because it is not available for the whole sample period. However, we checked for robustness of our results by adding the flash estimates and the interpretation is not altered by this.

the forecasted HICP value at the corresponding point in time and subtract its value one year before from it.

To get a clearer picture of how we constructed our data, consider the scenario prevailing in January 1999. The last empirical realization of the HICP available to the ECB is the one relating to 1998M11. The HICP variable lagged by one year (1997M11) is subtracted from this value using equation (5). This difference yields the data point of the inflation rate in real time in January 1999. For the forecasts the procedure is the same. Let us again consider as an example the construction of the data point for January 1999. Since we have decided to use the monthly frequency we construct forecasts up to July 1999 (six month forecast) using an AR(3) process for the original series available in January 1999. This means that we have generated eight additional data points to the original series (1998M12-1999M7). From this expanded series we take the value of 1999M1 and subtract it by the value of 1998M1 again using equation (5) for our contemporaneous forecasts and the values 1999M7 subtracted by its 1998M7 counterpart for the forward-looking forecasts. The results of the calculations are taken as the data points for January 1999 in the contemporaneous forecast series and the forward-looking forecast series, respectively. In case of quarterly data generated with an AR(2) process our procedure is the same except for the fact that the forecast horizon changes from six months to two quarters and we use equation (5a) to calculate the inflation rate.

When using ECB staff projections we always used the projections to expand the forecasted HICP series since the ECB publishes forecasts for each year. So, for 2000Q4 the mean projection of the inflation rate of the year 2000 is taken as the contemporaneous forecast and for the forward-looking forecast the mean inflation rate of the year 2001 available in 2000Q4 is chosen. Since the forecast horizon amounts to two quarters, thus, the forecasted inflation rate is that for 2001Q2. Again, both results are considered as the data points for 2000Q4 in the respective series.

To construct the output gap variable, a measure of the potential output is needed. In the literature the HP-filter is commonly used. However, the HP-filter is as a detrending method not necessarily displaying the correct path of the output potential[1]. Therefore, we also use potential output measures based on a linear and, alternatively, a quadratic trend[2]. When the HP-filter is employed the smoothing parameter is set to 14.400 for monthly and 1.600 for quarterly data. With these potential output measures it becomes possible to calculate the output gap which is done using the following transformation:

$$Y_t = 100\left[\log\left(y_t\right) - \log\left(y_t^*\right)\right]. \tag{6}$$

In case of ex-post data it is again straightforward to calculate the output gap because here the potential output can be built over the whole sample period. To get the output gap in real time is, however, much harder because initially after the start of EMU there were only data of the pre-ECB era available to construct the potential output. The question is now how far this data set needs to reach into the past to generate reliable estimates of the potential. In the following, we use the data of the ten preceding years, thus, the output gap in 1999M1 was built on the data going back to 1989M1. However, it is clearly at odds with the experience of any observer that the ECB is deriving its potential output estimates still today from data of 1989. Hence, every real time estimate relies on the preceding ten years of data. For instance, in order to construct the output gap in real time for every month/ quarter, the output gap is calculated with the data of the preceding ten years and the last value of this 10-year period is taken as the data point of the respective period in real time.

As an example, in 1999M1 the output gap is estimated based on the data ranging from 1989M1 to 1999M1 and value of the time series in the last month is taken as the data point of the output gap for 1999M1 in real time[3]. We apply the same procedure for all other periods as well in order to generate the output gap in real time[4]. In order to generate the AR forecasted estimates we simply add the values using the same AR processes as for the inflation rate construction explained above, assuming a forecast horizon of three months/one

[1] See for an extensive comparison between various types of potential output gap measures and their relevance for output gap estimates Chagny and Döpke (2001).

[2] The linear detrended potential output is generated by the expression $y^*_{t_{lin}} = y^*_{0_{lin}} + \alpha \times t$, while the potential output computed imposing a quadratic trend is derived from the transformation $y^*_{t_{qua}} = y^*_{0_{qua}} + \beta \times t^2$, with α and β, respectively, being the slope coefficients.

[3] In this example, we neglect the time lag problem for reasons of simplicity but we account for the lag of 3 months and 2 quarters respectively when constructing the time series.

[4] In order to account for the well-known end-of-sample bias induced by the HP-filter, we also used forecasts of the output series to expand the sample and avoid this problem. Therefore, we used corresponding (lagged) values of the forecasts generated by the AR processes explained above. However, the results are not altered by this.

quarter. For each output time series we then construct the realization of potential output which is used to construct the output gap. As a next step, we take the respective values of each time series and include them in the two forecasted output gap time series.

For the ECB staff projection forecasts we first take the output growth factor for every year and multiply it by its value lagged one year to get a measure of real GDP for the respective quarter. The following procedure corresponds to the forecasts generated with AR processes. Consider again the period 2000Q4 as an example. So, in the original GDP series we have data up to 2000Q2 and need to add data up to 2001Q1. For the periods of 2000Q3 and Q4, we use the mean growth factor of the year 2000 as it was available in 2000Q4 and multiply it by the values of GDP as of 1999Q3 and Q4. We adopted the same procedure to our forecast of 2001Q1, where we take the mean growth factor of 2001 as it was available in 2000Q4 and multiply it by the value of GDP in 2000Q1. With this expanded series we again calculate the realization of potential output which is used to construct our output gap variable for 2000Q4. The respective data points are then included in the forecasted output gap series.

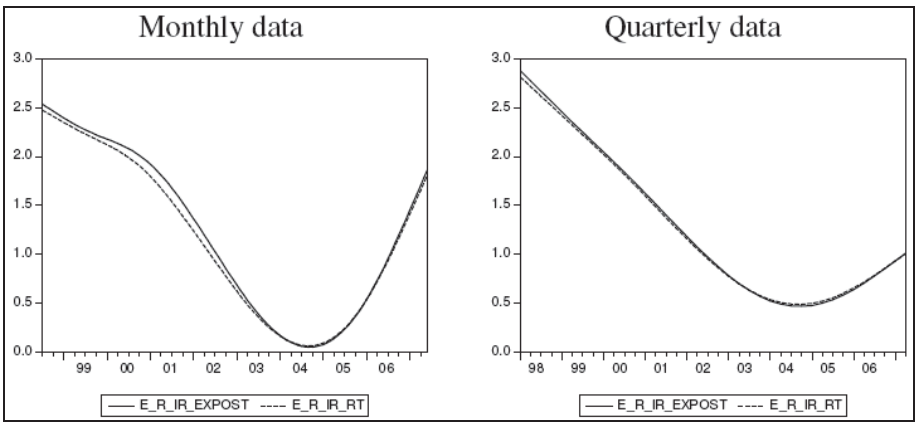
The last independent macro variable that needs to be specified is the equilibrium real interest rate. In fact, the equilibrium real interest rate has in the context of Taylor rules almost never played the role it should have because it was mainly just held constant over time by making it a part of the constant in econometric analysis[1].

However, there is considerable uncertainty about how to calculate the non-observable equilibrium real interest rate. It may be approximated by a multi-year average of the difference between the actual nominal interest rate and inflation. However, such a measure would depend on the period used for forming the average. Alternatively, assuming a constant equilibrium real interest rate over long periods may not be appropriate either. Besides the expected rate of return on tangible fixed assets and the general propensity to save, the equilibrium real interest rate may also depend on the general assessment of the uncertainty in the economy and the degree of credibility of the central bank. If these aspects are not taken into account, the resulting Taylor rate may be of questionable informative value.

Seen on the whole, thus, it is widely agreed upon by economists that the equilibrium real interest rate is by no mean constant over time[2] and should be allowed to fluctuate just like other variables. Hence, we insert an explicit measure of the equilibrium real interest rate into the Taylor rule specification by using the Fisher equation with adaptive expectations to construct the real interest rate

$$r_t = i_t - \pi_t , \tag{7}$$

and finally employ the HP-filter to the resulting time series. Applying detrending methods is probably the easiest and less precise way to calculate the equilibrium level but as Wu (2005) puts it: this is "reasonable over periods where inflation and output growth are stable" which is the case for the sample period investigated by us. This leads to the time series of the equilibrium rate as shown in Figure 1.



Notes: The solid lines E_R_IR_EXPOST show the equilibrium real interest rate calculated with ex-post data while the dashed line (E_R_IR_RT) covers the same variable if real-time data are used.
Source: EABCN and own calculations.

Fig. 1. Real equilibrium interest rates

[1] A notable exception from this rule is Plantier and Scrimgeour (2002).
[2] For the case of the euro area see Cuaresma, Gnan and Ritzberger-Gruenwald (2004), Mésonnier and Renne (2007), Garnier and Wilhelmsen (2009).

In this figure, the calculated paths of the equilibrium real interest rate for monthly and quarterly, ex-post and real-time data are displayed. It is obvious that the rate is by no means constant over time. In fact, its absolute deviation over time amounts to about 2.5 percent. For an "equilibrium" interest rate, the gyrations appear to be rather strong. However, the scale of our calculations is in line with the real equilibrium interest rates calculated by other authors such as, for instance, Cuaresma, Gnan and Ritzberger-Gruen-Wald (2004, p. 194), Mésonnier and Renne (2007, p. 1776), Garnier and Wilhelmsen (2009, p. 310), who all come up with a similar variance. The graphs in Figure 1 suggest anyway that the original real interest rate constructed from the Fischer equation is stationary, which we would expect. A second striking observation is that the shapes of the curves turn out to be rather similar – independent on whether they are based on ex-post or on real-time data. Hence, differences in the Taylor rule coefficients cannot be explained by differences in this measure.

4. Estimation results

We now estimate Taylor reaction functions using Generalized method of moments (GMM). As instruments we employ only lagged values of the right hand side variables. In the case of monthly data, our set of instruments comprises up to the last six months of inflation and the output gap and whenever implemented two to six lags of the interest rate. When we use quarterly data, the maximum number of lags is reduced from six to four[1]. Whenever it is necessary according to the usual diagnostics, up to six lags of the equilibrium real interest rate are included. As the relevant weighting matrix we choose the heteroskedasticity and autocorrelation consistent HAC matrix by Newey and West (1987).

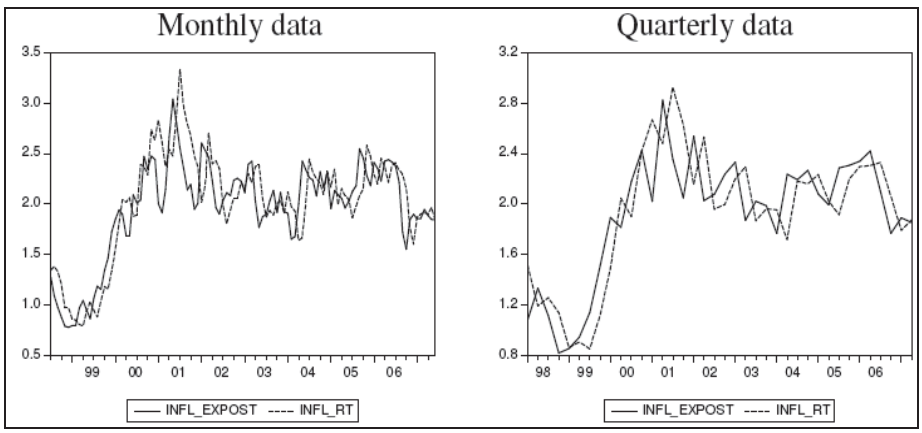
Our regression equations are directly derived from equations (2) to (4) which were explained in Section 1. For estimation purposes they can be written as follows when taking an inflation target of 2% into account:

$$i_t = a_0 + r_t^* - (a_\pi - 1)\times 2 + a_\pi \pi_t + a_y Y_y + \varepsilon_t, \quad (2a)$$

$$i_t = \rho \times i_{t-1} + (1-\rho)\times \times \left[a_0 + r_t^* - (a_\pi - 1)\times 2 + a_\pi \pi_t + a_y Y_y\right] + \varepsilon_t, \quad (3a)$$

$$i_t = a_0 + \overline{r_t^*} - (a_\pi - 1)\times 2 + a_\pi \times E\left(\pi_{(t+j|t)}\right) + + a_y \times \left[E\left(y_{(t+j|t)}\right) - \overline{y_t^*}\right] + \varepsilon_t. \quad (4a)$$

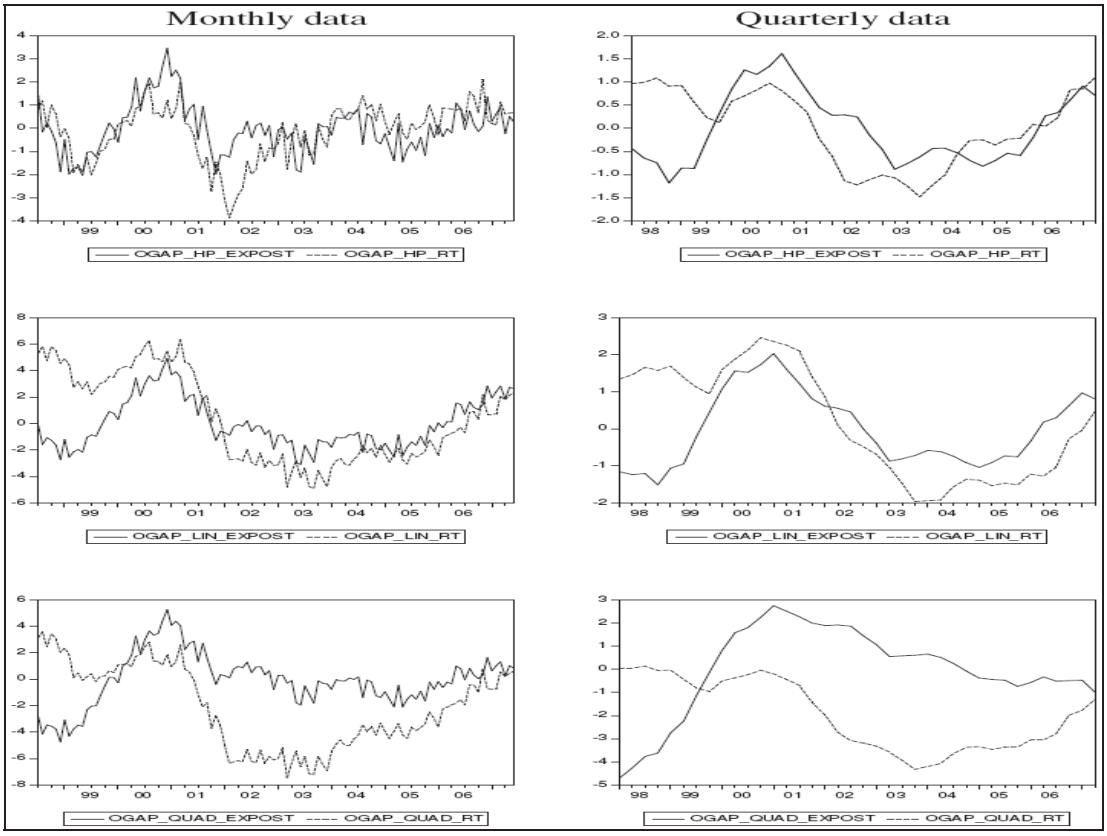
Here, the constant a_0 is expected to be equal to zero because all variables typically included in the constant (namely the equilibrium real interest rate and the inflation target) are now explicitly appearing in the Taylor rule specification. In fact, we even go beyond these three specifications by adding forecasts to the interest rate-smoothed Taylor rule and, by this, in a way merging equations (3a) and (4a). We display first eyeball evidence of potential numerical differences in the realization of ex-post and real-time database variables in Figures 2 and 3.



Notes: The solid line (INFL_EXPOST) shows the inflation rate calculated with ex-post data and the dashed line (INFL_RT) covers the inflation rate variable available to policy decision makers in real time.
Source: EABCN and own calculations.

Fig. 2. Inflation rates ex-post and in real time

[1] The choice of the instruments was made in line with the empirical literature in this field so far. For monthly data this is Sauer and Sturm (2007) and for quarterly data Belke and Polleit (2007). Although using GMM is strictly speaking not needed when estimating real-time and forward-looking Taylor rules, we decided to use it also in these specifications because otherwise we would induce model uncertainty within our estimates which we want to avoid. We also considered using information criteria in order to extract the "best" specification but this would mean employing a different set of instruments to each estimate. As this different choice of instruments is an additional source of differences between the estimates, we feel legitimized to rely on a constant set of instruments.



Notes: The solid lines cover the output gaps estimated using ex-post data while the dashed lines show those if real-time data are used, the abbreviations HP, LIN, QUA signal that potential output for this output gap is estimated using the HP-filter, linear trend or quadratic trend.
Source: EABCN and own calculations.

Fig. 3. Output gaps ex-post and in real time

Figure 2 gives an overview of the respective inflation rates. It becomes obvious that the differences mainly occur because of the imposed time lag of two months and one quarter respectively (see Section 3). This does not come as a surprise as inflation data are not affected by statistical uncertainty (inflation rates get calculated instead of estimated) and are typically hardly ever revised later on.

In contrast to that, the output gap time series displayed in Figure 3 differ quite considerably in many cases. Especially at the start of our sample period the empirical realizations of the output gap deviate significantly from each other, indicating large statistical uncertainty and data revisions. With the exception of the lower two graphs which cover output gaps calculated using a potential output constructed with a quadratic trend, it becomes evident that both lines move closer together after the first years. Thus, we feel legitimized to conclude that there was less statistical uncertainty and data revisions thereafter.

4.1. Estimations of original Taylor rules – ex-post versus real-time data. We now make use of this array of variables to estimate the coefficients of differently specified Taylor reaction functions. Table 1 displays the respective estimations of the *original* Taylor rule without any interest rate-smoothing and any forward-looking components.

Table 1. Original Taylor rule estimates (equation (2a))

	Ex-post data						Real-time data					
	(1.1)	(1.2)	(1.3)	(1.4)	(1.5)	(1.6)	(1.7)	(1.8)	(1.9)	(1.10)	(1.11)	(1.12)
	Y^M_{HP}	Y^M_{LIN}	Y^M_{QUA}	Y^Q_{HP}	Y^Q_{LIN}	Y^Q_{QUA}	Y^M_{HP}	Y^M_{LIN}	Y^M_{QUA}	Y^Q_{HP}	Y^Q_{LIN}	Y^Q_{QUA}
a_0	0.04 (0.04)	0.15*** (0.04)	0.06** (0.03)	0.06 (0.05)	-0.04 (0.04)	-0.40*** (0.05)	-0.05 (0.05)	-0.07 (0.04)	0.09* (0.05)	-0.03 (0.08)	-0.04 (0.07)	0.47*** (0.14)
a_π	0.75*** (0.08)	0.23* (0.12)	0.17 (0.12)	0.80*** (0.15)	0.94*** (0.12)	0.68** (0.26)	0.96*** (0.08)	1.36*** (0.08)	1.38*** (0.08)	1.34*** (0.11)	1.45*** (0.18)	1.52*** (0.17)
a_y	0.32*** (0.02)	0.15*** (0.02)	0.20*** (0.02)	0.80*** (0.10)	0.53*** (0.04)	0.22** (0.10)	0.24*** (0.06)	0.07*** (0.01)	0.07*** (0.01)	0.44*** (0.10)	0.23*** (0.04)	0.24*** (0.04)
Adj R^2	0.87	0.73	0.84	0.81	0.83	0.53	0.80	0.81	0.81	0.75	0.70	0.72
J-stat	0.12 (0.67)	0.06 (0.68)	0.06 (0.75)	0.11 (0.58)	0.10 (0.62)	0.12 (0.56)	0.07 (0.66)	0.13 (0.60)	0.13 (0.58)	0.13 (0.51)	0.11 (0.58)	0.12 (0.54)

Notes: GMM estimates, *, **, *** denote significance at the 10%, 5%, 1% level, standard errors are in parenthesis, for J-statistic p-values are in parenthesis; M – monthly estimate, Q – quarterly estimate, HP – HP-filter, LIN – linear trend, QUA – quadratic trend used.

Looking at the results displayed in Table 1, the first stylized fact is that ex-post and in real time the coefficients of the inflation rate and the output gap are almost always significantly different from zero while this is hardly ever the case for the constant term (a_0). This clear empirical pattern provides evidence in favor of the hypothesis that the inflation target and the equilibrium real interest rate are indeed the only terms influencing the constant and by modeling them explicitly, the constant becomes zero.

If we base our estimations on ex-post data (columns 1.1 to 1.6), the Taylor principle ($a_\pi > 1$) is always violated. According to this interpretation, the ECB has followed a destabilizing policy, thus accommodating inflationary or deflationary deviations from the macroeconomic equilibrium in the economy. However, this picture clearly flips to the better side when we use real-time data (columns 1.7 to 1.12). In this case, the $a_\pi > 1$ condition is fulfilled throughout our estimations with the only exception of column 1.7. What is more, the estimated coefficients in fact approach the value of 1.5 as proposed by Taylor. Hence, in real-time the ECB has clearly followed a policy of fighting inflation quite aggressively.

However, regarding the output gap coefficient the opposite holds true. Here, the reaction is larger if we use ex-post data (columns 1.1 to 1.6), thus indicating a more active response to this variable. In contrast to that, the output gap variable seems to be less important in real time (columns 1.7 to 1.12) even though it remains significant with the expected positive sign.

These findings contradict those gained by Gerdesmeier and Roffia (2005) who estimate a stronger reaction of the ECB to the output gap in real time compared to the ex-post data scenario while inflation gets less important. Both the longer sample period we have used[1] and our specific choice of instruments might be potential explanations for these differing results. However, our results closely correspond with those found by Sauer and Sturm (2007) for the Taylor rules without interest rate smoothing even though their inflation coefficient estimated in real time does not exceed unity.

It is worthwhile to note that our empirical findings are independent of the frequency used. In both cases – monthly and quarterly data – we are able to identify a stronger reaction of ECB monetary policy to inflation and a weaker reaction to the output gap in real time. Thus, our results are not affected by the frequency used.

4.2. Taylor rule estimations with interest rate smoothing – ex-post versus real-time data. Summarizing, for the Taylor rule without interest rate smoothing the differences of results are quite substantial. Whether this remains true for Taylor rules including interest smoothing can be judged based on the entries in Table 2.

Table 2. Taylor rule estimates with interest rate smoothing (equation (3a))

	Ex-post data						Real-time data					
	(2.1)	(2.2)	(2.3)	(2.4)	(2.5)	(2.6)	(2.7)	(2.8)	(2.9)	(2.10)	(2.11)	(2.12)
	Y^M_{HP}	Y^M_{LIN}	Y^M_{QUA}	Y^Q_{HP}	Y^Q_{LIN}	Y^Q_{QUA}	Y^M_{HP}	Y^M_{LIN}	Y^M_{QUA}	Y^Q_{HP}	Y^Q_{LIN}	Y^Q_{QUA}
ρ	0.88*** (0.04)	0.79*** (0.04)	0.72*** (0.02)	0.43*** (0.08)	0.55*** (0.09)	0.77*** (0.09)	0.97*** (0.04)	0.92*** (0.03)	0.96*** (0.03)	0.95*** (0.10)	0.48** (0.19)	0.72*** (0.10)
a_0	0.24 (0.16)	0.09* (0.05)	-0.02 (0.03)	-0.06 (0.03)	-0.01 (0.07)	-0.71*** (0.16)	-0.58 (0.84)	0.87*** (0.30)	3.25 (2.52)	2.16 (4.72)	0.21* (0.10)	1.81*** (0.48)
a_π	0.89*** (0.26)	1.24*** (0.11)	0.87*** (0.09)	1.19*** (0.07)	1.29*** (0.12)	1.89* (0.99)	4.59 (5.55)	1.52*** (0.50)	2.21 (1.34)	16.01 (37.16)	2.16*** (0.37)	1.00* (0.54)
a_y	0.70*** (0.24)	0.26*** (0.04)	0.25*** (0.02)	0.73*** (0.07)	0.68*** (0.10)	0.04 (0.27)	0.93 (1.65)	0.37*** (0.12)	0.76 (0.59)	5.11 (11.71)	0.40*** (0.08)	0.62*** (0.14)
Adj R^2	0.98	0.98	0.98	0.92	0.91	0.82	0.97	0.96	0.97	0.70	0.68	0.81
J-stat	0.11 (0.60)	0.11 (0.63)	0.12 (0.86)	0.09 (0.89)	0.14 (0.71)	0.16 (0.71)	0.12 (0.76)	0.09 (0.96)	0.12 (0.91)	0.12 (0.84)	0.11 (0.81)	0.17 (0.78)

Notes: GMM estimates, *, **, *** denote significance at the 10%, 5%, 1% level, standard errors are in parenthesis, for J-statistic p-values are in parenthesis; M – monthly estimate, Q – quarterly estimate, HP – HP-filter, LIN – linear trend, QUA – quadratic trend used.

The inclusion of the interest rate smoothing term changes the results quite considerably. In case of monthly data (columns 2.1-2.3 and 2.7-2.9), the lagged interest rate always comes out to be highly significant and amounts to values of above 0.7 in all specifications. If quarterly data are used (columns 2.4-2.6 and 2.10-2.12), the degree of interest rate smoothing is less clear since its variance is higher: the empirical realization of the estimated ρ ranges from 0.43 to 0.95.

However, at least for monthly data a clear empirical pattern emerges from Table 2. If we use ex-post data (columns 2.1-2.3), the interest smoothing parameter, although still relatively high, turns out to be always lower than in the real-time data case (columns 2.7-

[1] Our estimates cover the period up to mid-2007, thus our sample includes almost four additional years in contrast to the study by Gerdesmeier and Roffia (2005).

2.9), where the coefficient is close to unity in all specifications. For quarterly estimates such a conclusion is only valid for cases in which we use the HP-filtered output gap (column 2.10). This finding is in line with the recommendation raised by Orphanides (2003) that central bankers should avoid overreactions, given that the available real-time data may be subject to substantial mis-measurement.

Unfortunately, the Taylor rule coefficients get estimated very poorly in the case of real time data. This might be mainly due to the high empirical realizations of the smoothing parameter. In fact, there are only three out of six specifications, where the Taylor rule coefficients are significantly different from zero (columns 2.8, 2.11 and 2.12). Here, the Taylor principle is again fulfilled but now also a larger estimated coefficient emerges for the output gap compared to the findings in Table 1. However, in the three other cases (columns 2.7, 2.9 and 2.10) in which the Taylor rule coefficients are insignificant the present realization of the interest rate is the best predictor of the future, i.e., one period-ahead, interest rate.

Overall, it turns out that the Taylor rule coefficients are estimated more precisely with *ex-post data*. In fact, with only one exception (column 2.6) the estimated coefficients are highly significant. In contrast to the estimates conducted using ex-post data without a smoothing parameter (columns 1.1 to 1.6), the coefficient of inflation now satisfies the Taylor principle in the majority of the cases. What is more, the output gap coefficient tends to increase slightly.

A systematic comparison of the performance of the Taylor rule estimations in the "ex-post data" and "real-time data" scenarios does only make sense, if we arrive at significant estimates for both types of data. A closer look at Table 2 reveals that this is only the case for linear trend estimates (columns 2.2 and 2.5 for ex-post data, 2.8 and 2.11 for real-time data, respectively). The coefficient of inflation increases, if we employ real-time data like it was the case in Table 1. However, for the output gap a slightly more ambiguous pattern emerges since its estimated coefficient increases in one case and decreases in the other. But as the increase in the case of monthly data may be traced back to the higher smoothing parameter, we feel legitimized to emphasize the explanation that the output gap reduces as soon as real-time data are used.

4.3. Estimations of Taylor rules based on real-time data – current period forecasts and „true" forecasts generated by AR processes versus original real-time data. So far we compared the relative performance of Taylor rule estimations dependent on the use of ex-post data or of real-time data, the data set available to the ECB at the time it has to make their decision. In the following, we check whether our estimations based on real-time data change if we implement real time forecasts. If we find significant numerical estimation differences between both types of Taylor rules we are able to distinguish the effects which the use of real-time data has from the ones that are essentially induced by the application of a forecast based on real-time data.

We, thus, strive to go beyond those comparative studies which consider those two effects simultaneously and, hence, risk mixing up both effects. What is more, we feel legitimized to argue that we are – as an innovation to the literature – able to identify whether both effects played a role or (even more important) whether the results are driven by only one source whereas the other actually does not have any influence. In order to clarify issues, we display our Taylor rule estimations based on forecasted macro variables without interest rate smoothing and two different forecasts in Table 3.

Table 3. Taylor rule estimates based on AR forecasted macro variables – real-time data (equation (4a))

	Forecast for current period						Forecast inflation 6M/output gap 3M					
	(3.1)	(3.2)	(3.3)	(3.4)	(3.5)	(3.6)	(3.7)	(3.8)	(3.9)	(3.10)	(3.11)	(3.12)
	Y^{M}_{HP}	Y^{M}_{LIN}	Y^{M}_{QUA}	Y^{Q}_{HP}	Y^{Q}_{LIN}	Y^{Q}_{QUA}	Y^{M}_{HP}	Y^{M}_{LIN}	Y^{M}_{QUA}	Y^{Q}_{HP}	Y^{Q}_{LIN}	Y^{Q}_{QUA}
a_0	0.00 (0.06)	-0.05 (0.04)	0.03 (0.06)	0.13* (0.07)	0.01 (0.05)	0.39*** (0.13)	-0.03 (0.08)	0.12*** (0.03)	-0.09 (0.13)	-0.04 (0.09)	0.13*** (0.05)	1.61*** (0.07)
a_π	1.22*** (0.10)	1.62*** (0.08)	1.61*** (0.08)	1.52*** (0.14)	1.54*** (0.18)	1.55*** (0.19)	0.19 (0.18)	0.54*** (0.09)	0.12 (0.18)	2.67*** (0.27)	0.26 (0.17)	0.33* (0.17)
a_y	0.19*** (0.07)	0.03** (0.02)	0.04** (0.02)	0.37*** (0.14)	0.20*** (0.05)	0.21*** (0.06)	-0.13 (0.12)	0.12*** (0.01)	-0.00 (0.03)	0.92*** (0.29)	0.44*** (0.05)	0.63*** (0.03)
Adj R^2	0.85	0.80	0.80	0.50	0.52	0.52	0.72	0.76	0.70	0.34	0.58	0.28
J-stat	0.08 (0.51)	0.11 (0.71)	0.11 (0.71)	0.13 (0.50)	0.12 (0.52)	0.12 (0.54)	0.05 (0.82)	0.11 (0.73)	0.05 (0.82)	0.13 (0.47)	0.07 (0.87)	0.12 (0.64)

Notes: GMM estimates, *, **, *** denote significance at the 10%, 5%, 1% level, standard errors are in parenthesis, for J-statistic p-values are in parenthesis; M – monthly estimate, Q – quarterly estimate, HP – HP-filter, LIN – linear trend, QUA – quadratic trend used.

Using the forecast for the current period (which becomes necessary as monetary policy operates with a lag) delivers almost the same results as the real-time data in Table 1 (columns 3.1-3.6 and 1.7-1.12). In fact, it even strengthens the pattern detected by increasing the inflation parameter even more and by

simultaneously decreasing the output response. However, it has to be mentioned that by introducing these forecast the adjusted R^2 drops sharply for quarterly data (columns 3.4-3.6).

If we use "true" forecasts (columns 3.7-3.12), with a horizon of six months for inflation and of three months for the output gap, the overall picture changes dramatically. As displayed in Table 3, columns 3.7 to 3.9, in two of the three monthly specifications (columns 3.7 and 3.9) the Taylor rule explains virtually nothing since all coefficients are insignificant. In the remaining specification (3.8), the estimated coefficients turn out to be significant but the Taylor principle is clearly violated while the output gap parameter stays more or less unchanged.

When we use quarterly data, the goodness-of-fit of the regression equation is rather low as measured by the adjusted R^2. A closer inspection of the results in columns 3.10 to 3.12 reveals that the importance of the output gap is going to rise when forecasts based on real-time data are used as input variables. In all three specifications the estimated output gap coefficients are larger than their real time counterparts which were displayed in columns from 1.10 to 1.12 in Table 1. However, the inflation parameter in the "truly" forecasted Taylor rules in most cases turns out to take values far below unity (columns 3.11 and 3.12). But when applying the HP-filter as a measure of potential output the inflation parameter is even increasing[1]. Nevertheless, it is by no means granted that results generated with the help of the HP-filter are superior to others. Hence, except for the one outlier (column 3.10) it can again be concluded that the estimation results are rather independent of the frequency chosen.

4.4. Estimations of Taylor rules with interest rate smoothing based on real-time data – current period forecasts and "true" forecasts generated by AR processes versus original real-time variables. In this part of our comparative investigation exercise, we check for the relative performances of Taylor reaction functions based on time series of macro variables generated by current period forecasts and "true" forecasts. Our estimation results are shown in Table 4.

Table 4. Taylor rule estimates with interest rate smoothing based on AR forecasted variables (equations (3a) and (4a))

	Forecast for current period						Forecast inflation 6M / output gap 3M					
	(4.1)	(4.2)	(4.3)	(4.4)	(4.5)	(4.6)	(4.7)	(4.8)	(4.9)	(4.10)	(4.11)	(4.12)
	Y^M_{HP}	Y^M_{LIN}	Y^M_{QUA}	Y^Q_{HP}	Y^Q_{LIN}	Y^Q_{QUA}	Y^M_{HP}	Y^M_{LIN}	Y^M_{QUA}	Y^Q_{HP}	Y^Q_{LIN}	Y^Q_{QUA}
ρ	0.83*** (0.05)	0.94*** (0.03)	0.95*** (0.02)	0.69*** (0.09)	0.38*** (0.11)	0.54*** (0.08)	0.93*** (0.02)	0.86*** (0.03)	0.92*** (0.03)	0.86*** (0.04)	0.39*** (0.10)	0.62*** (0.06)
a_0	-0.25*** (0.06)	1.16** (0.49)	2.29** (1.04)	0.32** (0.14)	0.12** (0.06)	1.64*** (0.20)	-0.14 (0.14)	0.48*** (0.13)	1.87** (0.73)	0.51* (0.27)	0.13** (0.05)	2.04*** (0.30)
a_π	1.67*** (0.19)	1.80* (0.98)	2.45** (1.09)	2.06*** (0.43)	0.42 (0.46)	-0.19 (0.25)	1.25*** (0.37)	0.26 (0.18)	1.09*** (0.37)	0.97 (0.68)	0.20 (0.21)	0.41 (0.29)
a_y	0.23 (0.17)	0.54** (0.24)	0.70** (0.32)	1.58*** (0.50)	0.44*** (0.07)	0.68*** (0.08)	-0.07 (0.15)	0.26*** (0.05)	0.51*** (0.18)	1.79** (0.71)	0.51*** (0.05)	0.72*** (0.10)
Adj R^2	0.97	0.97	0.97	0.84	0.76	0.66	0.98	0.97	0.98	0.89	0.76	0.79
J-stat	0.11 (0.83)	0.09 (0.98)	0.10 (0.95)	0.14 (0.86)	0.15 (0.66)	0.13 (0.74)	0.13 (0.74)	0.09 (0.91)	0.11 (0.87)	0.16 (0.61)	0.14 (0.77)	0.12 (0.86)

Notes: GMM estimates, *, **, *** denote significance at the 10%, 5%, 1% level, standard errors are in parenthesis, for J-statistic p-values are in parenthesis; M – monthly estimate, Q – quarterly estimate, HP – HP-filter, LIN – linear trend, QUA – quadratic trend used.

The high degree of interest rate smoothing at a monthly frequency (columns 4.1 to 4.3 and 4.7 to 4.9) already identified by us in Section 4.2 can also be supported by the forecasts even though the smoothing parameters on average turn out to be slightly lower here compared to our estimates which used real-time data (columns 2.7 to 2.9), in turn leading to more significant inflation and output gap coefficients. With respect to the inflation coefficient our result from Section 4.3 that reactions are even stronger when current forecasts are used is reinforced while for truly forward looking Taylor rules this is not the case as it was also found in Section 4.3.[2] However, the estimated output gap coefficient amounts to 0.54 for current forecasts (column 4.2) and 0.26 (column 4.8) for truly forward-looking forecasts and, hence, remains quite close to its real time counterpart (0.37 in column 2.8).

[1] The impression also conveyed by the results depicted in Table 4 is that the use of quarterly HP estimates has the potential to alter the estimation results significantly.

[2] However this comparison has to rely on our estimates using the linear detrended output gap because these were the only significant Taylor rule estimates when applying interest rate smoothing in real time.

If quarterly instead of monthly data are used (columns 4.4 to 4.6 and 4.10 to 4.12), the empirical pattern looks a bit different. Again, in the same way as for quarterly data in Table 2, the smoothing parameter differs quite considerably over the specifications, independent on what kind of forecast is applied. Moreover, for both types of forecasting the importance of the output gap parameter increases slightly and remains highly significant (row 4, columns 4.5 to 4.6 and 4.11 to 4.12, respectively) while the inflation coefficient decreases sharply taking even values lower than unity, thus violating the Taylor principle (columns 4.5 to 4.6 and 4.11 to 4.12, respectively)[1]. In fact, all but one (column 4.4) coefficients of the inflation rate become insignificant and in one case the sign of the estimated coefficients gets even negative (column 4.6).

4.5. Estimations of Taylor rules based on real-time data – current period forecasts and „true" forecasts estimated using staff projections versus original real-time variables. The final part of our analysis uses staff projections to generate the forecasts. As argued above, these forecasts should be quite close to those the ECB governing council had at hand when making its interest rate decision. Since these projections are only available at a quarterly frequency, we just rely on quarterly estimates of Taylor rules with and without interest rate smoothing. However, as we have shown in Sections 4.1 and 4.3, our results should be rather independent of the frequency used by construction, at least as far as Taylor reaction functions without interest rate smoothing are concerned. We display our Taylor rule estimates with and without interest rate smoothing based on staff projections forecasted variables in Table 5.

Table 5. Taylor rule estimates with and without interest rate smoothing based on staff projections forecasted variables (equations (3a) and (4a))

	Forecast for current period						Forecast inflation 6M/output gap 3M					
	(5.1)	(5.2)	(5.3)	(5.4)	(5.5)	(5.6)	(5.7)	(5.8)	(5.9)	(5.10)	(5.11)	(5.12)
	Y^{M}_{HP}	Y^{M}_{LIN}	Y^{M}_{QUA}	Y^{Q}_{HP}	Y^{Q}_{LIN}	Y^{Q}_{QUA}	Y^{M}_{HP}	Y^{M}_{LIN}	Y^{M}_{QUA}	Y^{Q}_{HP}	Y^{Q}_{LIN}	Y^{Q}_{QUA}
ρ				0.75*** (0.02)	0.51*** (0.05)	0.64*** (0.03)				0.76*** (0.09)	0.72*** (0.07)	0.89*** (0.03)
a_0	-0.30*** (0.07)	0.08** (0.03)	1.83*** (0.19)	-0.42*** (0.06)	-0.06 (0.07)	0.75** (0.28)	-0.38*** (0.07)	0.57*** (0.13)	2.11*** (0.21)	-0.07 (0.16)	1.01*** (0.16)	1.33** (0.52)
a_π	1.01** (0.44)	0.83*** (0.20)	1.09*** (0.29)	2.75*** (0.23)	1.19*** (022)	1.64*** (0.29)	-0.01 (0.29)	1.09*** (0.26)	0.38** (0.18)	0.17 (1.31)	1.30** (0.47)	2.82*** (0.58)
a_y	0.14 (0.16)	0.32*** (0.04)	0.76*** (0.07)	0.71*** (0.15)	0.31*** (0.04)	0.44*** (0.09)	0.37** (0.17)	0.80*** (0.12)	0.74*** (0.07)	1.75** (0.66)	1.01*** (0.13)	0.47*** (0.16)
Adj R^2	0.27	0.59	0.52	0.78	0.72	0.76	0.30	0.61	0.81	0.90	0.79	0.87
J-stat	0.17 (0.55)	0.18 (0.53)	0.13 (0.69)	0.28 (0.69)	0.25 (0.56)	0.28 (0.56)	0.17 (0.58)	0.19 (0.62)	0.21 (0.45)	0.11 (0.44)	0.22 (0.66)	0.25 (0.67)

Notes: GMM estimates, *, **, *** denote significance at the 10%, 5%, 1% level, standard errors are in parenthesis, for J-statistic p-values are in parenthesis; Q – quarterly estimate, HP – HP-filter, LIN – linear trend, QUA – quadratic trend used. Sample period adjusted to 2000Q4-2007Q2.

For current period forecasts without interest rate smoothing (columns 5.1 to 5.3) we now find a decrease in the reaction to inflation compared to the real time and AR forecasted estimates (columns 1.10 to 1.12 and 3.4 to 3.6). However, this result might be driven by the fact that the sample period of staff projected forecasts begins later and especially in the first two years of the ECB (1999 and 2000) the inflation rate was far below the target of two percent which in turn makes a more aggressive response (and with this a higher inflation coefficient) more likely. For the output gap coefficient the overall evidence is mixed. While the importance of this coefficient decreases when using the HP-filtered output gap (column 3.1 compared to 1.10 and 3.4) it increases for the remaining two specifications (columns 3.2-3.3 compared to 1.11-1.12 and 3.5-3.6). For the "true" forecasts (columns 5.7 to 5.9) the same conclusion can be drawn as for the AR generated forecast estimates, namely that the output response increases while the reaction to inflation falls.

When adding an interest rate smoothing term it turns out that in the two specifications which we are able to compare with the real time estimates (columns 5.5-5.6 and 5.11-5.12), the Taylor principle of an inflation coefficient exceeding unity is now always fulfilled which was not the case for our AR-forecasted estimates. However, whether the response to inflation increases or decreases compared to the real-time estimates depends crucially on the construction of the output gap. In the specifications using the linear detrended output gap (columns 5.5 and 5.11) the response decreases while the opposite is true for the estimates relying on a quadratic trend

[1] For quarterly data, we compare only the results of the Taylor rules using a linear and a quadratic detrended output gap because in real time the results generated by the output gap with the HP-filter delivered insignificant inflation and output gap coefficients due to the high interest smoothing parameter. Therefore, a comparison between this real-time estimate and the forecasts is not possible.

output gap (columns 5.6 and 5.12). For the output gap using current forecasts the influence decreases compared to the real-time estimates (columns 5.5-5.6 compared to 2.11-2.12). In case of "true" forecasts the evidence is mixed since the output gap response increases in one specification (column 4.11) and decreases in the other (4.12).

Seen on the whole, thus, the following empirical picture emerges based on our partial results summarized in Tables 1 to 5 (Sections 4.1 to 4.5). When estimating Taylor rules for the euro area with ex-post data, the estimated coefficient of inflation tends to be biased downwards and, in contrast, the estimated output gap coefficient turns out to be biased upwards (Section 4.1) when compared to estimates using real-time data. When we add an interest rate smoothing term to our empirical Taylor rule specification, our previous results are to a large extent reinforced. In this case, the estimations using a linear detrended output gap seem to perform best since they generate significant estimates of the Taylor rule coefficients.

When it comes to the implementation of forward looking elements into the Taylor rules using real time data (Sections 5.3 and 5.4), the results are mainly reinforced at least as far as forecasts for the current period are concerned. In this case, the use of AR generated forecasts even strengthens the already identified differences between ex-post and real time data, i.e., that the inflation coefficient is rising while the output gap coefficient is falling slightly[1]. Thus, when using "current period" forecasts the two effects of using real time instead of ex-post data and forecasts in real-time rather than actual real-time data tend to move in the same direction, meaning that both increase the response to inflation and lowering the output gap coefficient independently of each other.

However, when using "true" forecasts, our empirical results change. In this case, inflation turns out to be less important (in fact taking even values lower than unity, thus, violating the Taylor principle) while the output gap variable appears to be more in the focus of the ECB governing council. Hence, the effects of differences between ex-post and real-time data and those induced by the use of real-time forecasts instead of real-time data tend to move in opposite directions. Here, the importance of dividing comparisons of ex-post data and forecasts using real-time data into two separate steps becomes obvious as when applying a comparison between ex-post and real time data it turns out that inflation gets more important and output gap less important in real-time while the use of forecasts lessens the importance of inflation and strengthens the response to the output gap.

Conclusions

In this contribution we have shown that, in the case of the ECB, considerable *differences* of the estimated parameter values between Taylor rules emerge *when ex-post data are used instead of real-time data and vice versa*. Accordingly, we are able to reproduce a pattern of results which has quite frequently been identified in the literature for other central banks as well[2].

However, our empirical results reveal that in real time *the inflation rate is of greater importance than it has been ex-post while the reverse is true for the output gap*. Thus, our results do not give support to the results gained by Gerdesmeier and Roffia (2005) who found a stronger reaction to output and a weaker response to inflation in the real-time data case. According to our analysis, these differences could be attributed to the different sample period and the different choice of instruments when estimating using GMM. However, our results are in line with those found by Sauer and Sturm (2007), but only if we employ the Taylor rule without interest rate smoothing.

When it comes to the discussion of using forecasted variables in Taylor rule estimation equations the overall evidence is mixed. However, when preparing its interest rate decisions, the ECB governing council is well known to react not only to currently available data but also to (medium-term) forecasts concerning future key variables as, above all, the inflation rate and the output gap. However, when using forecasts in Taylor rule estimations, the problem is that these forecasts need to be as close as possible to the unknown forecasts the ECB governing council actually bases its decision on. Using staff projections, as we did in this paper, might be one opportunity to come close to these, but as full coincidence can never be guaranteed, using forecasts always tends to introduce an additional but unavoidable source of differences of estimation results which is not at all related to the difference between ex-post and real-time data.

In our analysis, we separated the two effects – the first induced by the use of ex-post instead of real-time data and the second caused by the use of forecasts based on real-time data instead of the original real-time data – to show whether the use of forecasts

[1] However this pattern is revised when using staff projected forecasts. But the fact that inflation reaction is stronger and output response is weaker using forecasts compared to ex-post data is also reinforced by these estimates.

[2] See Orphanides et al. (2000) for a Fed evaluation, Nelson and Nikolov (2003) for the Bank of England, Sterken (2003) for the Bundesbank and Horvath (2009) for the Czech National Bank.

promotes or distorts the results given by a mere comparison between ex-post and real-time data. We found that any sound judgment on this question depends crucially on the choice of the forecast horizon and the forecast technique/survey used. That is why we feel legitimized to recommend comparing Taylor rule coefficients with ex-post data and forecasts based on real-time data within the three-step approach used here in order to single out the driver of the differences between these two estimates.

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