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Based on Quasi-Real Time Data**



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Corresponding author: Yvonne Adema  
e-mail: [y.adema@uvvt.nl](mailto:y.adema@uvvt.nl)

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## A Taylor Rule for the Euro Area Based on Quasi-Real Time Data

Yvonne Adema\*

### ABSTRACT

One of the main criticisms on the original Taylor rule is the so-called real time critique; because data on especially the output gap are only available after some quarters the original Taylor rule is not operational. Moreover, Taylor rules estimated with ex post revised data could result in misleading descriptions of monetary policy. The aim of this paper is to develop a modified Taylor rule based on (quasi-)real time data for the euro area. We find that modified Taylor rules based on (quasi-)real time data and an interest rate smoothing term give a good description of monetary policy in the euro area during the 1994-2000 period. These Taylor rules could serve as indicators of the monetary stance in the euro area. But the forecasts of the interest rate obtained from the Taylor rules are too imprecise to get an exact interest rate forecast. Further on, actual monetary policy was more expansionary than what is expected of the estimated Taylor rules. We also find that using final data to estimate a Taylor rule, while in reality only (quasi-) real time data are available, does not lead to more misleading policy descriptions compared to using a Taylor rule estimated with (quasi-)real time data.

Key words: Taylor rule, Quasi-Real Time Data, Euro Area

JEL codes: E32, E 2, E 8

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## 1 INTRODUCTION

In the 20<sup>th</sup> century different rules for monetary policy were proposed by economists. Examples are Friedman's k% rule for money growth, the McCallum rule for the monetary base, Svensson's inflation forecast targeting rule, and the Taylor rule for the short-term nominal interest rate. In the last two decades there has been a renewed interest in the issue of monetary policy rules. The rule proposed by John Taylor in 1993 for example received a lot of attention in the financial press, and has been discussed by academics, policy makers, and financial practitioners. This was mainly because this simple rule described monetary policy in the US surprisingly well during a period where it is believed that monetary policy was very successful (the first Greenspan period, 1987-1992). Other studies showed that a Taylor-type rule could also give a good explanation of central bank behaviour in Germany (see for example Clarida et al., 1998) and in the EMU as a whole (see for example Gerlach and Schnabel, 1999). This paper focuses on this Taylor rule, because this simple rule could be informative when one wants to analyse or predict the monetary policy of the European Central Bank (ECB). Moreover, the Taylor rule could be used by the ECB itself as one of the indicators in the second pillar of the monetary policy strategy. The Taylor rule is an instrument rule for the short-term interest rate, where the nominal interest rate responds to the current deviation of inflation from its target and the current value of the output gap. One of the main problems with the original Taylor rule is that it is based on ex post revised data, while in reality output gap data are not known with accuracy until several quarters or perhaps years later. So it is unrealistic to assume that policy makers respond to the true values of the current-period realisations of the output gap. Orphanides (2001) showed that the use of so-called real-time data, i.e. information that is available at the time the policy maker has to decide on about the interest rate, in the original Taylor rule leads to a much poorer description of monetary policy in the US compared to the case where ex post revised data are used. So the original Taylor rule can be of questionable value for understanding how policy makers react to the information available to them in real time. Therefore it is useful to develop a modified Taylor rule, which is based on real time data. The main purpose of this paper is to develop a modified Taylor rule based on quasi-real time data<sup>1</sup> for the euro area and the central question of this paper is:

*Does a modified Taylor rule based on quasi-real time data give a better description of monetary policy in the euro area, in terms of the fit, than a Taylor rule based on final data?*

<sup>1</sup> The reason that quasi-real time data are used instead of real time data, is that no real time data are available for the euro area. The difference between real time data and quasi-real time data will be explained in sections 2.3 and 3.1.2.

The structure of the paper is as follows. First, we explain the Taylor rule carefully and discuss the advantages and disadvantages of the Taylor rule. The information and measurement problems of the output gap are described in detail. Several economists argue that an interest rate smoothing term should be included and that a monetary policy rule should be forward-looking. Therefore, we will also pay attention to these two issues. Section 3 reports the results of different estimations of the Taylor rule for the euro area for the 1994 – 2000 period. First, the informational problems in implementing the original Taylor rule are illustrated. This will be done by comparing the interest rate outcomes of the original Taylor rule based on final estimates of the output gap with the outcomes of the same Taylor rule but then based on quasi-real time output gap data. Second, we estimate some modified Taylor rules for the 1994-2000 period, with and without interest rate smoothing and with different definitions of the output gap. Thirdly, a forward-looking Taylor rule will be estimated where quasi-real time forecasts of the output gap are used. Finally, the estimated Taylor rules will be used to generate forecasts of the interest rate in 2001 and 2002. These interest rate forecasts are compared with the actual interest rate, and in this way it is possible to see whether the estimated Taylor rules really provide a good description of monetary policy in the euro area. This exercise may also give additional information regarding the relative performance of the Taylor rules estimated with quasi-real time and final data. The fifth and last section summarises and concludes.

From the estimations it can be concluded that modified Taylor rules based on quasi-real time data and an interest rate smoothing term give a good description of monetary policy, in terms of the R-squared, in the euro area for the period 1994 – 2000. The out-of-sample exercise reveals that although there can be large differences between the actual interest rate and the interest rates implied by the Taylor rules, the Taylor interest rates move in the same direction as the actual interest rate. From these results it might be concluded that the estimated Taylor rules based on quasi-real time data could serve as indicators of the stance of euro area monetary policy. But the forecasts of the interest rate obtained from the Taylor rules are too imprecise to get an exact interest rate forecast. Further on, actual monetary policy was more expansionary during the last two years than what is expected of the estimated Taylor rules. We also find that, in contrast to Orphanides (2001), using final data to estimate a Taylor rule, while in reality only quasi-real time data are available, does not lead to more misleading policy descriptions compared to using a Taylor rule estimated with quasi-real time data. This implies that it is not so important for the euro area as for the US to work with quasi-real time data instead of ex post revised data in estimating a Taylor rule.

## 2 THE TAYLOR RULE

Nowadays the ECB follows a monetary policy strategy consisting of three main elements: a quantitative definition of price stability, and the two ‘pillars’. Price stability is defined as the year-on-year increase in the Harmonised Index of Consumer Prices (HICP) in the euro area of below two percent and price stability is to be maintained over the medium term. At the same time, the ECB pursues price stability by aiming to maintain inflation rates close to two percent over the medium term, to guard against deflation. The first pillar is a prominent role for money, as signalled by the announcement of a quantitative reference value for the growth rate of a broad monetary aggregate. Nowadays this reference value is 4. percent for M3. The second pillar is a broad-based assessment of the outlook for price developments and risks to price stability in the euro area as a whole (see Eijffinger and De Haan, 2000 and the website of the ECB: [www.ecb.int](http://www.ecb.int)). The short-term interest rate is used as the instrument to achieve price stability, and is thus the most important guide of monetary policy in the short term. Therefore an instrument rule like the Taylor rule can be very useful for the Eurosystem and could be used as one of the indicators in the second pillar. Several authors (Peersman and Smets, 1998; Taylor, 1999a; Kakes, 2000) have discussed the usefulness of the Taylor rule as a guideline for the ECB. This section will describe the Taylor rule and discuss the advantages and disadvantages of the rule.

### 2.1 Description of the Taylor rule

In 1993 John Taylor<sup>2</sup> developed a monetary policy rule, which received a lot of attention in the financial press and has been discussed by academics, policy makers, and financial practitioners. This was mainly because Taylor showed that this simple rule described the actual behaviour of the federal funds rate remarkably well during a period where it is believed that monetary policy was very successful (the first Greenspan period, 1987-1992). This suggested that the rule could serve as a prescription for desirable policy. Other studies showed that a Taylor rule could also give a good explanation of central bank behaviour in Germany (see Clarida et al., 1998) and in the EMU as a whole (see Gerlach and Schnabel, 1999).

Taylor proposed that a central bank should adjust the real interest rate  $r_t$  in response to three variables: the ‘equilibrium’ real interest rate ( $r^*$ ), the current deviation of inflation ( $\pi_t$ ) from its target ( $\pi^*$ ), and the current value of the output gap ( $y_t - y_t^*$ ). In general, a Taylor rule looks as follows:

<sup>2</sup> Taylor, J.B., 1993, Discretion versus Policy Rules in Practice, *Carnegie-Rochester Conference Series on Public Policy*, 39, 19 -214.



$$r_t = r^* + \alpha(\pi_t - \pi^*) + \beta(y_t - y_t^*) \quad (1)$$

where  $y_t^*$  is potential real GDP. In Taylor's specification the weights on inflation and the output gap,  $\alpha$  and  $\beta$ , had the value of 0. . The real interest rate should be increased when inflation or output are above their targets to bring these variables back to equilibrium. Using the Fisher equation ( $i = r + \pi$ ) the Taylor rule can be specified in nominal terms:

$$i_t = i^* + (\alpha + 1)(\pi_t - \pi^*) + \beta(y_t - y_t^*) \quad (2)$$

and when  $\gamma = \alpha + 1$ , the equation becomes:

$$i_t = i^* + \gamma(\pi_t - \pi^*) + \beta(y_t - y_t^*) \quad (3)$$

where  $i_t$  and  $i^*$  are the nominal interest rate and the 'equilibrium' nominal interest rate, respectively. Taylor took the values 4 for  $i^*$  and 2 for  $\pi^*$ , and for  $\pi_t$  he took the change in the log of the GDP deflator over the previous four quarters. The output gap ( $y_t - y_t^*$ ) was measured as the percent deviation of real GDP from its trend. The weight on inflation is always larger than one, because  $\gamma$  is equal to  $\alpha + 1$ . This reflects the importance of responding to inflation above its target rate by raising the nominal interest rate by more than the amount by which inflation exceeds the target. This is called the Taylor principle. The rationale behind this is that in response to a rise in (expected) inflation, nominal rates should rise sufficiently to increase real rates, so demand is contracted. In that case the real interest rates adjusts to stabilise inflation, as well as output (given  $\beta > 0$ ). When  $\gamma < 1$ , the central bank still raises the nominal rate in response to an (expected) rise in inflation, but it does not increase the nominal rate sufficiently to keep the real rate from declining, and output and inflation are not stabilised. So the estimated magnitude of the parameter  $\gamma$  provides an important measure for evaluating a central bank's policy rule.

There can be two reasons for the presence of the output gap in the Taylor rule. First, it can reflect the fact that minimising the output gap (or minimising employment fluctuations) is a key objective of the central bank along with low inflation. Or alternatively, it can be argued that the output gap is an important indicator of future inflation and therefore the central bank needs to react to this variable. The underlying argument is that the output gap is an indicator of excess demand or supply in the aggregated goods market. Thus, if excess demand increases, inflationary pressures are building up. So even if inflation is the only target variable (the only variable in the loss function), it is generally better to respond to both current inflation and the output gap, since both are determinants of future inflation.

Bolt and Van Els (2000) find evidence that an aggregate European output gap significantly precedes aggregate European inflation.

Taylor's objective was to find a simple, understandable rule that would capture the key results from simulations of many different models. So the goal of the original Taylor rule was not to describe the actual behaviour of the Federal Reserve, but to develop a normative recommendation of what interest rates should be. Policy makers can use a Taylor rule in two ways. The first thing they can do is use the rule as one of the inputs to the decision making process of the central bank. If the policy rule gives a good description of the actual interest rate behaviour in recent years and the central bank believes that its policy was good and should be continued in the future even when the circumstances change, a Taylor rule could provide some guide to future decisions. A second possible approach to make the Taylor rule operational is to use the general principles of the rule, where the policy maker only looks at the signs of the response coefficients of the rule. The Taylor rule could also be used as a means to communicate monetary policy decisions to the public, as a benchmark for predicting future policy, as well as for judging whether past policy was appropriately set<sup>3</sup>.

## **2.2 Reactions to the Taylor rule**

The big advantage of a simple instrument rule like the Taylor rule is that adherence to such a rule can easily be verified by outside observers. When the public understands monetary policy better, central bank behaviour is more predictable and this in turn makes monetary policy more effective. That is, the central bank is able to reduce inflation at lower cost in terms of output. Further on, because in reality there exists a lot of uncertainty about the true model of the economy it is important that a monetary policy rule is robust across models. That is, the rule has to produce desirable results in different macroeconomic frameworks. Different studies find that variants of the Taylor rule perform reasonably well in a variety of different models (see also Peersman and Smets (1998) for the euro area and Levin et al. (1998) for the US). Together with the fact that theoretical work by Svensson (1997), Ball (1997), and others suggests that Taylor-type rules in which the central bank reacts to current inflation and the output gap may in many circumstances be approximately optimal in a closed economy implies that these simple rules can serve a useful role as rough guidelines.

But the proposed rule of Taylor also received a lot of criticism. For example, Svensson (2003) argues that in the case of a simple monetary policy rule like the Taylor rule, where the interest rate only reacts to two variables, there is no room for judgement and extra-model information. Another criticism is

<sup>3</sup> As Taylor does in chapter 7 in his book 'Monetary Policy Rules' (1999b).

that it is very difficult to measure the appropriate level of the equilibrium real interest rate, moreover this variable may well vary over time. Third, there is a measurement problem concerning the output gap. It is not clear which method is most appropriate to estimate potential output. There is also the problem that due to data revisions the output estimates may change over time. The fourth point of criticism is related to the previous, this is the so-called real time critique put forward by Orphanides (2001). Real time policy recommendations differ considerably from those obtained with ex post revised data. And estimated reaction functions based on ex post revised data provide misleading descriptions of historical policy. Fifthly, it is argued that the original Taylor rule leads to much more volatility in the interest rate than what is observed in practice. It seems that monetary policy makers do not tolerate the variability in the interest rates prescribed by the Taylor rule. This phenomenon is called 'interest rate smoothing'. Finally, there has been some critique on the Taylor rule with respect to its backward-looking nature; monetary policy should be forward-looking. Monetary policy affects the economy with a lag, so it may not be appropriate to move interest rates in reaction to current values of inflation and output.

The last four points of criticism (measurement problems, real-time critique, interest rate smoothing, and forward-looking) will be discussed in more detail in the following sub-sections.

### **2.3 Measurement of the output gap and the real time critique<sup>4</sup>**

McCallum (1993) commented on Taylor's original paper and he mentions one of the most important points of criticism. He argues that it is unrealistic to pretend that policymakers can respond to the true values of current-period realisations for nominal GDP, real GDP, or the current price level. This is especially the case for GDP figures (like potential output, nominal output, and real output), because there exists a lot of uncertainty about the measurement of these concepts. These uncertainties are resolved only slowly and perhaps never completely, therefore data of the output gap are revised routinely. Several authors, including Kuttner (1994), Gerlach and Smets (1999), and Orphanides and Van Norden (1999), have shown that the output gap is estimated with a considerable margin of uncertainty. Output gap estimates available to the policy maker in real time differ from subsequent estimates because of revisions and conceptual changes regarding real output. In addition, because output gap estimates reflect measures of both actual and potential output, revisions and conceptual changes in potential output are also reflected in revisions of the output gap.

<sup>4</sup> As said in the previous sub-section there are also measurement problems related to the equilibrium real interest rate. Although this is a major problem, this paper will not pay attention to it, instead we focus on the informational problems related to the measurement of the output gap.

Orphanides (1998, 2000, 2001) mentions four reasons why informational problems can have a significant impact on the analysis of the Taylor rule. First, the original Taylor rule requires the central bank to make use of data about current output and inflation that it does not actually have when it sets the current interest rate. In that case the monetary policy rule is not operational. Second, policy recommendations for the interest rate may become different when data are revised. Policy that was in accordance with the Taylor rule at the time the policy was set may appear wrong after some time. Thirdly, in the case of significant informational problems, evaluation of monetary policy rules where the instrument is specified in terms of ex post revised data can lead to misleading results. Fourth, reliance on ex post revised data can also prove misleading in efforts to identify the historical pattern of policy. Policy reaction functions estimated with ex post revised concepts and data can be of questionable value for understanding how policy makers react to the information available to them in real time. Therefore it is essential to rely on information actually available to policymakers in real time when analysing a monetary policy rule like the Taylor rule.

There are three types of uncertainty, which lead to the problems with the measurement of the output gap: model uncertainty, statistical uncertainty, and data uncertainty.

*Model uncertainty* regards the uncertainty that exists about the appropriate empirical definition of potential output, and the accompanying output gap. Several different strategies have been proposed to estimate potential output. Much of the policy rule literature, including Taylor (1993) and Rotemberg and Woodford (1997), simply use deviations from a fitted linear time trend for the output gap, thereby implicitly estimating potential output as the fitted trend. There are two reasons why this method seems inappropriate. First, the resulting measure of potential output can be very sensitive to the sample period used in fitting the trend. Second, the fitted trend method does not reflect the influence of technology shocks. Woodford (2003) refers to Friedman (1968) when he gives the definition of potential output. According to Woodford the right measure of potential output is the natural rate of output, this is the equilibrium level of output with *flexible* wages and prices, given current real factors (tastes, technology, government purchases etc.). Woodford emphasised that it is the gap between actual output and this natural rate, rather than the gap between output and its trend, to which interest rates should respond if a Taylor rule is to be a successful approach to inflation stabilisation. But the measurement problems with this definition of potential output are huge; it is impossible to determine what the output level would be in case of flexible prices and wages. In the ECB's area-wide model (AWM) the production function approach is used to estimate potential output. Potential output is defined as output consistent with the long-run equilibrium employment of the economy, but not the

The area-wide model (AWM) is a quarterly estimated structural macroeconomic model for the euro area, in other words it treats the euro area as a single economy. For a detailed description of this model see Fagan et al. (2001).

flexible price unemployment. This seems an appropriate method to estimate the output gap. In the following section we will use the estimates of the output gap of the AWM's dataset. Further on, an HP-filter is used to estimate the output gap to show the implications of using a different estimation method (see Box 1 in sub-section 3.1 for a more detailed explanation about the ways the output gap is estimated).

*Statistical uncertainty* is due to the fact that the models contain unknown parameters, which have to be estimated from small samples. When a model is re-estimated this could lead to new parameters and different estimates of potential output. Since it may require relatively long time series to get relatively precise parameter estimates, statistical uncertainty is probably the largest source of uncertainty for euro area models.

*Data uncertainty* is due to the fact that data about output, employment and other variables are not available in real time and that these data are revised very often until their final publication. Especially for the output gap data uncertainty is a serious problem. However, if the data revision process in the euro area is comparable to that in the US, data uncertainty is much less important for the output gap than statistical uncertainty (see Orphanides and Van Norden, 1999). Currently there is no dataset covering the euro area or individual EMU countries available that documents the revision history of real time data (Duarte et al., 2003).

In constructing real time data this data uncertainty and statistical uncertainty should be taken into account. Because statistical uncertainty is probably the most important source of uncertainty about the output gap in the euro area and there does not exist any dataset that shows the data uncertainty in the euro area output gap, the constructed real time data in this paper only take statistical uncertainty into account. Since these data only take statistical uncertainty into account and not data uncertainty, they will be called quasi-real time data. Further on, the fact that data on output are only available with a lag is considered. How these quasi-real time data are constructed precisely will be explained in the next section.

Several authors have looked at how serious the informational problems of the output gap were for the implementation of the Taylor rule. They find different results. For example Orphanides (1998, 2000, 2001) finds that Taylor rules based on real time data lead to very different outcomes than rules based on final data. In his analysis the use of real time data in the original Taylor rule leads to a much poorer description of monetary policy compared to the case where ex post revised data are used. Further on, when he uses real time data instead of final data to estimate Taylor rules, forward-looking Taylor rules appear to provide a more accurate description of policy than a Taylor rule based on current data. Orphanides argues that the imprecision in output gap estimates makes the output gap a less useful guide to setting the interest rate, and leads to an increase in the variability of output and inflation. The policy maker should take into account this presence of noise in the data and respond more cautiously

to apparent imbalances in the economy, that is, the output gap coefficient in the Taylor rule should be reduced. Orphanides' most important lesson is that, when analysing the Taylor rule, you need to make realistic informational assumptions about what policy makers can and do know when policy decisions are made, otherwise the benefits from following activist stabilisation policy may appear greater than what is likely to be achievable in practice. Smets (1998) also shows that output gap uncertainty reduces the response to the current estimated output gap relative to current inflation.

Other authors such as Bernanke and Boivin (2000) and Gruen et al. (2002) find that it does not really matter whether a central bank uses revised ex post data, as opposed to real time data. Ehrman and Smets (2001) find that an efficient Taylor rule in first-difference form performs very well even with imperfect information about potential output, as long as the central bank uses its best estimate of the output gap.

So economists do not reach the same conclusions about the implications of output gap uncertainty for the Taylor rule. This paper analyses how big the informational problems of the output gap are for the euro area and what the implications are for the outcomes of the Taylor rule.

#### 2.4 Interest rate smoothing

The original Taylor rule predicts a much more variable path of interest rates than what is observed in practice. It seems that monetary policy makers do not tolerate the variability in interest rates, which is prescribed by the Taylor rule. This phenomenon is called 'interest rate smoothing'. In that case an alternative Taylor rule can be specified:

$$i_t = \lambda i_{t-1} + (1 - \lambda) [i^* + \gamma(\pi_t - \pi^*) + \beta(y_t - y_t^*)] \quad (4)$$

Where  $\lambda \in [0, 1]$  is a parameter that reflects the degree of interest rate smoothing. In this equation the interest rate is a weighted average of the previous period interest rate and some desired value that depends on the state of the economy. In the literature the estimates of  $\lambda$  are often around 0.8 on a quarterly basis, which implies a slow adjustment. Especially in ex post analyses of Taylor rules this partial adjustment model gives a better fit of actual policies (see, for example, Orphanides, 2001; Rotemberg and Woodford, 1999; Rudebusch, 2000; Levin et. al, 1998).

There are several reasons why central banks would smooth their interest rates. First, measurement errors may reduce the response of the interest rate to disturbances in the economy. When policy makers, for example, do not know the true parameters in their model of the economy, they cannot be sure of the impact of policy changes on the economy. This uncertainty may help explain the relatively low variability of interest rates in the data. It may explain why the coefficients on the inflation gap and the output gap could be smaller than the ones Taylor calculated. However, it does not explain why the

interest rate depends so strongly on its lagged value. Rotemberg and Woodford (1997) give a possible explanation for this. Interest rate smoothing represents a way of allowing the central bank to commit itself to raise interest rates later, in response to an increase in inflation. When the public understands this commitment and is forward-looking, the central bank is able to influence long-term interest rates, and thus aggregate demand, with smaller movements in the short-term interest rates than what would otherwise be necessary, because of the lagged dependence in the interest rate. This kind of rule enables the central bank to stabilise the economy with relatively modest movements in the short-term interest rates. Two other explanations for interest rate smoothing are fear of disrupting financial markets, and disagreement among policymakers (Clarida et al., 1999).

However, Rudebusch (2002) argues that the large lag coefficients ( $\lambda$ ) should not be interpreted as interest rate smoothing behaviour of the central bank, but as serially correlated shocks. In that case the Taylor rule is specified as follows:

$$i_t = i^* + \gamma(\pi_t - \pi^*) + \beta(y_t - y_t^*) + \varepsilon_t, \text{ with } \varepsilon_t = \phi\varepsilon_{t-1} + u_t \quad ( )$$

The reason for this other interpretation is that there is an empirical inconsistency: on the one hand there is evidence of partial adjustment of monetary policy, which implies that future movements in the interest rate are forecastable. On the other hand there is proof that there is little predictive information in financial markets about the future path of short-term interest rates beyond a horizon of three months. This inconsistency can be solved when the large lag coefficients in the estimated Taylor rules are interpreted as serially correlated or persistent special factors or shocks that cause the central bank to deviate from the rule. When a Taylor rule is estimated with serially correlated shocks it appears to have the same fit as the interest rate smoothing rule, but it is also consistent with the evidence that the term structure is largely uninformative about the future course of the policy rate. Rudebusch (2002) provides a procedure to test whether the rule should be estimated with serially correlated shocks or with partial adjustment. In section 3.2 we will perform this test to determine the right specification of the rule.

## 2. A forward-looking rule

Some economists (for example Clarida et al., 1999; Orphanides, 2001) argue that monetary policy reaction functions such as the Taylor rule should be forward-looking, because monetary policy operates with a lag. Alan Greenspan once gave a good explanation of this: 'Because monetary policy works with a lag, it is not the conditions prevailing today that are critical but rather those likely to prevail six to twelve months, or even longer, from now. Hence, as difficult as it is, we must arrive at some judgement about the most probable direction of the economy and the distribution of risks around

that expectation' (January 21, 1997 testimony by Greenspan before the Senate Committee on the Budget). When a central banker is forward-looking he uses all relevant current information to make forecasts of inflation and the output gap.

Several authors find opposite results, some find that performance can be improved when one uses forecast rules instead of simple benchmark rules (for example Drew and Hunt, 1998, Rudebusch and Svensson, 1999, and Batini and Haldane, 1999), others find that forecast rules do not outperform rules based on current and lagged variables. In order to investigate this, we will also estimate a forward-looking Taylor rule with quasi-real time forward-looking output gap data in section 3 of this paper.



### 3 A TAYLOR RULE FOR THE EURO AREA AND THE INFORMATIONAL PROBLEMS

In this section several Taylor rules will be estimated for the euro area. But first the informational problems with the Taylor rule are illustrated. We apply the original Taylor rule with final output gap data as well as with quasi-real time output gap data and compare the two outcomes. We also explain the sources of the data and how we constructed the quasi-real time data for the output gap. With the data used in this first sub-section it is possible to estimate Taylor rules for the euro area, this will be done in the next sub-section. As explained in the previous section, it would be more realistic to estimate a forward-looking Taylor rule, because monetary policy operates with a lag and a central banker will use all relevant available information to make forecasts of inflation and the output gap. In the third sub-section of this section we estimate a forward-looking Taylor rule with quasi-real time forecasts of the output gap. Finally, we check from a different perspective whether our estimated Taylor rules provide a good description of the ECB's behaviour. In an out-of-sample exercise we compare the actual interest rate in 2001 and 2002 with the rates predicted by our estimated policy rules. This exercise may also give additional information regarding the relative performance of the Taylor rules estimated with quasi-real time and final data.

#### 3.1 The Taylor interest rate estimated with final and quasi-real time data

In this sub-section we illustrate the informational problems in implementing the Taylor rule. As explained in the previous section it is expected that real time estimates of the output gap are unreliable. Real time estimates of the output gap will differ from later estimates because there exists a lot of uncertainty about the actual outcome of the statistical measurement of GDP. This is especially the case for the euro area, where aggregate time series have only been developed fairly recently and have been subject to ongoing refinement. So it can be expected that a Taylor rule based on real time estimates of the output gap leads to a different policy description than a Taylor rule based on ex post data. This sub-section illustrates this by applying the original Taylor rule with final estimates of the output gap as well as with quasi-real time estimates of the output gap.

##### 3.1.1 Final data

The original Taylor rule looks as follows:

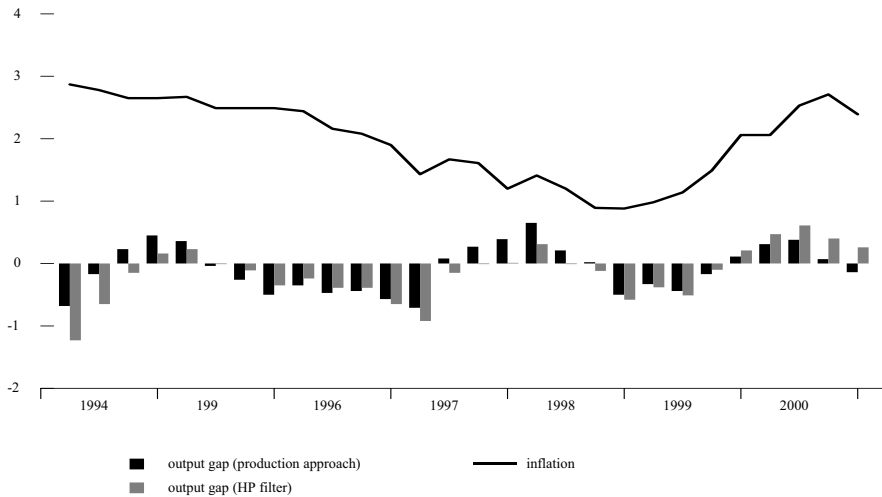
$$i_t = i^* + 1. (\pi_t - \pi^*) + 0.5 (y_t - y_t^*)$$

In order to apply the rule data from the area-wide model (AWM) dataset are used. The interest rate implied by the rule is compared to  $i_t$ , the actual short-term three-month interest rate. The Maastricht treaty was signed in 1992 so it would be logical to start the estimation period in that year. But in the years 1992 and 1993 there was a lot of exchange rate turmoil, for that reason it is decided to start in 1994. The estimation period ends in 2000, because the AWM dataset does not have data after 2000. The average real interest rate could serve as a measure for the equilibrium real interest rate. However, Gerlach and Schnabel (1999) argue that this strategy will lead to an overestimation of the likely equilibrium real interest rates in the EMU area, since countries in which the credibility of monetary policy is low, had relatively high ex post real interest rates. Therefore we decided to take the estimate of  $r^*$  by Gerlach and Schnabel (1999). Their estimate of the 'credibility adjusted' equilibrium real interest rate is 3. for the period 1982-1997 (the average real interest rate for the euro area for this period was 4.42). The inflation rate,  $\pi_t$  is calculated as the annual change in quarterly averages of the Harmonised Index of Consumer Prices (HICP). The main reason to choose this inflation measure is that the ECB defined price stability in terms of this index. The ECB defined price stability as the year-on-year increase in the HICP in the euro area of below two percent and price stability is to be maintained over the medium term. This is probably the reason why Gerlach and Schnabel (1999) assumed that the target inflation rate is two percent for the ECB. In a recent paper, Surico (2003) also takes a target value of two percent for the ECB. Moreover, on May 8th last Duisenberg made clear that the Governing Council of the ECB 'will aim to maintain inflation rates close to 2% over the medium term' (May 8, 2003, ECB press release). Therefore, we will also assume a target rate of two percent for inflation for the ECB.

There are several ways to estimate potential output and thus the output gap. In the AWM dataset of the ECB the production function approach is used to estimate potential output, these estimates will be used in the Taylor rules. Moreover, an HP-filter is often used to estimate the output gap. Often both approaches lead to similar output gap estimates. Therefore both approaches will be analysed. Data on the output gap are based on the AWM dataset and obtained from the ECB<sup>6</sup> (see Box 1 for a more detailed explanation about the ways the output gap is estimated). Figure 1 plots the output gaps and the inflation rate.

<sup>6</sup> Thanks to Ricardo Mestre for making recent estimates available.

**Figure 1 Output gaps and inflation in the euro area in percentages**



So the applied Taylor rules with the original Taylor weights are:

$$\text{Taylor rule 1} = (3. \quad \% + 2\%) + 1. \pi(-2\%) + 0. (\hat{y}_t - y_t^*)_{fip}$$

$$\text{Taylor rule 2} = (3. \quad \% + 2\%) + 1. \pi(-2\%) + 0. (\hat{y}_t - y_t^*)_{fihp}$$

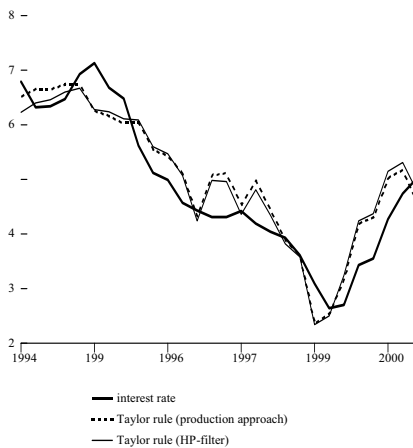
The subscripts fip and fihp stand for the final output gap estimated with the production function approach and the HP-filter respectively. Figure 2 compares the outcomes of the interest rates implied by the Taylor rules with the actual short-term three-month interest rate.

**Figure 2 Interest rate implied by the Taylor rules vs. the actual interest rate**



From Figure 2 the following conclusions can be drawn. First, both Taylor rules do not describe the behaviour of the short-term three-month interest rate very well. Second, the two different approaches to estimate the output gap do not lead to very different policy descriptions for the interest rate. And third, it can be seen that after 1999 the Taylor rule provides a very poor description of monetary policy in comparison to the years before the foundation of the EMU. A reason for this could be that there has been a structural break in the real interest rate during the transition to the EMU. It could be that the establishment of the EMU caused a decrease in the risk premium, and thus in the real interest rate, in some countries (for example Italy). Figure 3 shows the Taylor interest rate where the equilibrium real interest rate is lowered with 1. percentage points from the first quarter of 1999 onwards, together with the actual interest rate.

**Figure 3 Interest rate implied by the Taylor rules together with the actual interest rate**



Then the Taylor interest rate tracks the actual interest rate better. These outcomes need to be compared with the outcomes when quasi-real time data of the output gap are used, to examine how big the information problems really are. This will be done in the next part of this sub-section.

### 3.1.2 *Quasi-real time data*

There are three types of uncertainty: model, statistical and data uncertainty. To take into account these sources of uncertainty it is necessary to construct real time data. Real time data are data that are available to the monetary authority at the moment it has to make its decision about the interest rate. The problem is that the ECB exists since January 1999 and that there are no real time data for GDP available for the euro area. This unavailability of real time data for the euro area is solved as follows. First, recursive estimates (from the ECB and DNB) of the output gap from the AWM dataset were

used to take into account the revisions due to statistical uncertainty, which is probably the most important information problem. Recursive data are obtained by using a sub-sample to estimate the output gap and extend the sub-sample with one period every time. The size of revisions of the real time output gap due to statistical uncertainty is revealed by comparing the first estimate of the output gap for a given quarter with its final estimate based on the whole sample. The initial output gap estimates will be called *quasi-real time* estimates because the sub-samples are drawn from the final dataset, so the fact that the data available in real time are not equal to the final published data (data uncertainty) is ignored (Duarte et al., 2003). Second, it is also necessary to analyse what the publication lag of inflation and real output is. This is important because these data are needed to calculate the interest rate implied by the Taylor rule. In this first part of the paper it is assumed that the central bank uses the latest available estimates to calculate the interest rate. Table 1 shows from which date onwards data about real GDP and inflation were available at the time the Monthly Bulletin was published. From the table it can be seen that in December the latest data available about real GDP are from the third quarter. So in a quarter, data about the previous quarter become available in the last month of that quarter. In the first two months (October and November) the latest available data about real GDP are from the second quarter. So within a quarter in the first two months there is a lag of two quarters for real GDP and in the last month there is only a lag of one quarter. For the quasi-real time estimate of the output gap a lag of two quarters will be used, because two out of three months have this lag for the availability of real GDP data, and these data are necessary to estimate the output gap. Moreover, the data of the short-term three-month interest rate are an average of a quarter, in that case it is consistent to look which lag you have in the middle of a quarter. In sum, the quasi-real time estimates of the output gap are constructed as follows. First, for each quarter the first available recursive estimate of the output gap is taken and then this estimate is lagged with two quarters to take the publication lag into account. So the quasi-real time estimate of the output gap in the third quarter of 1996, for example, is equal to the first recursive estimate of the output gap of the first quarter of 1996. So it is assumed that the central bank uses the latest available output gap estimate, and does not use other information to get an estimate of the output gap in the current quarter. In sub-section 3.3 of this paper we will make the more realistic assumption that the central bank makes an estimate of the output gap in the current quarter, i.e. that the central bank is not simply backward-looking.

It can also be seen that the HICP has a lag of one month: data about inflation are available pretty quickly. To estimate the quasi-real time inflation rate it is assumed that there is no lag in the availability of data, because inflation data about the previous month are already available at the beginning of the month. Moreover, the recursive estimate of inflation coincides with the final estimate of inflation.

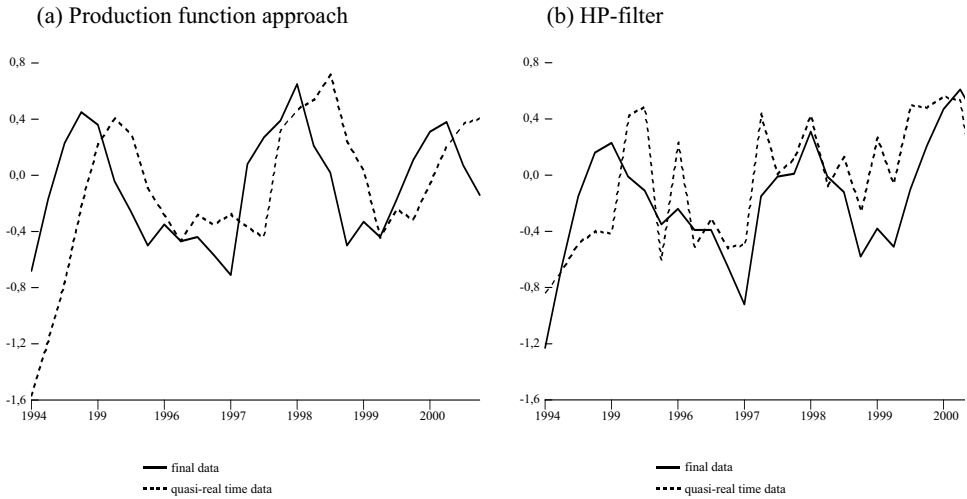
**Table 1 Date of the latest available observation of real GDP and HICP**

Publication date*	Real GDP	HICP
October 2002	2002Q2	Sept 2002
November 2002	2002Q2	Oct 2002
December 2002	2002Q3	Nov 2002
January 2003	2002Q3	Dec 2002
February 2003	2002Q3	Jan 2003

\* This is the publication date of the Monthly Bulletin.

As explained probably there are differences between the real time estimate and the final estimate of the output gap. But how large is the difference between these two estimates of the output gap precisely? To make this clear, Figure 4 shows the quasi-real time estimates of the output gap as well as the final estimates of the output gap. From this figure it can be seen that there are differences between the data actually available to the central bank in real time about the output gap and the final estimate of this variable. In Figure 4a it can be seen that the recursive estimates of the output gap based on the production approach do not differ very much from the final estimates. When the information lag is ignored the two lines almost coincide. The reason for this could be that the recursive estimates of the output gap based on the production function approach are not fully recursive estimates. It is pretty complicated to estimate the output gap with the production function approach because you have to make a lot of assumptions (see also box 1). The ECB staff, who made these recursive estimates, did not re-estimate the parameters of the production function when the sub-sample was extended. The parameters were the same every time; therefore these estimates are not actual recursive estimates. From Figure 4b it can be seen that there are larger differences between the recursive and final estimates of the output gap when calculated with an HP-filter. This is because these are actual recursive estimates.

**Figure 4 Quasi-real time and final data of the output gap**

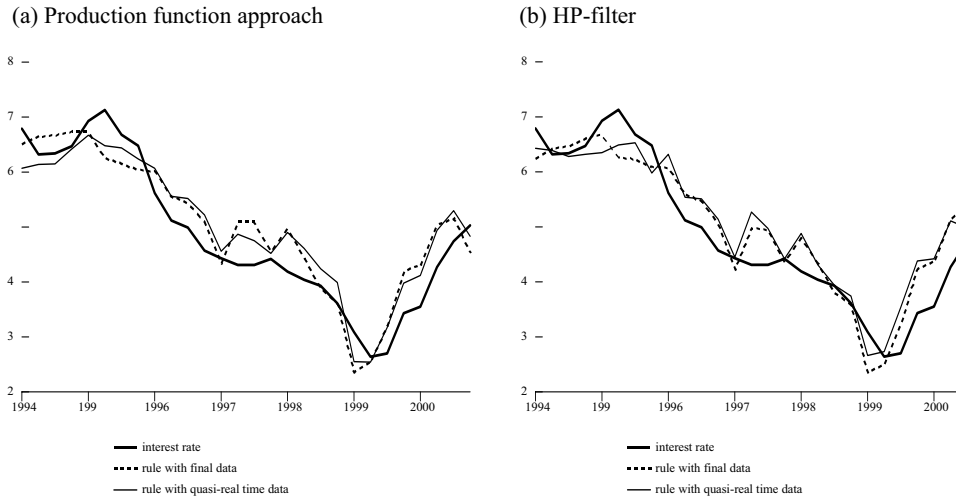


These differences between the quasi-real time and final estimates of the output gap could result in different estimates of the interest rate implied by the Taylor rule. To compare the outcomes of the different Taylor rules we applied the same Taylor rules as with final data but now the quasi-real time estimates are used for the output gap. So the applied Taylor rules, again with the original Taylor weights, are:

$$\begin{aligned} \text{Taylor rule 3} &= (3. \quad \% + 2\%) + 1. \pi(-2\%) + 0. (\psi_t - y_t^*)_{r_{ip}} \text{ (for the period 1994.1 – 1998.4)} \\ &\quad (2.0 \% + 2\%) + 1. \pi_t(-2\%) + 0. (\psi_t - y_t^*)_{r_{ip}} \text{ (for the period 1999.1 – 2000.4)} \\ \text{Taylor rule 4} &= (3. \quad \% + 2\%) + 1. \pi(-2\%) + 0. (\psi_t - y_t^*)_{r_{ihp}} \text{ (for the period 1994.1 – 1998.4)} \\ &\quad (2.0 \% + 2\%) + 1. \pi_t(-2\%) + 0. (\psi_t - y_t^*)_{r_{ihp}} \text{ (for the period 1999.1 – 2000.4)} \end{aligned}$$

So again it is assumed that the equilibrium real interest rate was 1. percent lower after the establishment of the EMU. Figure compares the quasi-real time rendition of the Taylor rule (light solid line) with the actual short-term three-month interest rate (fat solid line) and the comparable rule obtained using final data (dashed lines).

**Figure Taylor rules based on quasi-real time and final data**



As can be seen in the figures it is not very clear which rule describes the movements in the interest rate best. But there are small differences between what the rule appears to have recommended in real time and what would be believed to have been recommended based on final data. Table 2 makes things more clear, it shows some descriptive statistics about the differences between the alternative interest rates.

**Table 2 Descriptive statistics of Taylor rules, 1994.1 – 2000.4**

	Mean	Median	Max	Min	SD
$i_t - i_{f,p}^T$	-0.18	-0.31	0.87	-0.79	0.49
$i_t - i_{f,hp}^T$	-0.1	-0.12	0.8	-0.88	0.49
$i_t - i_{r,p}^T$	-0.17	-0.34	0.72	-0.71	0.43
$i_t - i_{r,hp}^T$	-0.20	-0.11	0.64	-0.96	0.49
$i_{f,p}^T - i_{r,p}^T$	0.01	-0.004	0.0	-0.37	0.2
$i_{f,hp}^T - i_{r,hp}^T$	-0.06	-0.06	0.33	-0.33	0.18

Notes: The superscript T means that the interest rate is calculated by the Taylor rule. The subscripts f, r, p, hp stand for final data, quasi-real time data, production approach and HP-filter respectively.

From this table a couple of things can be noticed (results based on the output gap estimates calculated with the production function approach outside parentheses and results based on the HP-filter estimates of the output gap between parentheses). First, the standard deviation of the difference between the Taylor interest rate based on quasi-real time estimates of the output gap and the Taylor interest rate based on final data ( $i_f^T - i_r^T$ ) is 0.2 (0.18), with the maximum difference approaching 0 (33) basis



points. So there is a difference between the Taylor interest rate based on final data and quasi-real time data, but this difference is not as big as the difference Orphanides (2001) finds for the US. It seems that the information problems related to the estimation of the output gap do not have such large implications for the outcomes of the original Taylor rule in the euro area as in the US. This may be related to the fact that the Fed has an objective function which includes both inflation and economic growth, whereas for the ECB its inflation target is the dominant objective.

Second, regarding the fit of the rule, the standard deviation between the actual interest rate  $i_t$  and the rule based on final data  $i_r^T$  is 49 (49) basis points. The corresponding standard deviation with the quasi-real time data  $i_r^T$  is 43 (49) basis points. This result indicates that the fit of the original Taylor rule calculated with quasi-real time data is almost the same as the fit of the Taylor rule based on final data. This is in contrast with Orphanides (2001) who finds that prescriptions obtained from the rule using real time data are worse than recommendations of the rule based on final data. On the other hand, the standard deviation of the quarterly change in the interest rate ( $i_t - i_{t-1}$ ) over this period is only 39 basis points. So a one-quarter-ahead forecast of the interest rate, which assumes that the interest rate will not change, would be more accurate than the forecast of the interest rate, which is obtained from the original Taylor rule. This illustrates that a Taylor rule with the original weights on inflation and the output gap does not give such a good description of the interest rate behaviour in the euro area. Probably the weights are different for the euro area. Therefore we will estimate the weights on inflation and the output gap in the next section.

### **Box 1: The estimation of the output gap**

The data used on the output gap are from the AWM dataset. Two different methods to estimate the output gap are used: the production function approach and the HP-filter. This box explains these two methods in more detail.

The basic idea behind the *production function approach* is that the level of potential output is given by the production function. In the area-wide model in the short run output is determined by aggregate demand ( $Y \equiv C + I + \bar{G} + X - M$ ), where the main components (consumption, investment, net trade etc.) are modelled separately. In the long run, however, the supply curve is vertical with actual and potential output determined by technology, the long-run equilibrium capital stock and employment. Potential output is assumed to be described by a constant-returns-to-scale Cobb-Douglas production function, i.e.:  $Y_{pot} = TFT \cdot K^\beta \cdot (\bar{L}^s)^{1-\beta}$ , where TFT is trend total factor productivity. The percentage difference between  $Y$  and  $Y_{pot}$  is equal to the output gap (Fagan et al., 2001). The main disadvantage of the use of production functions to determine potential GDP and the output gap is that this method requires a lot of information, and hence may not be calculated very frequently. An assumption on the

production technology, the estimation of equilibrium employment, and information on the level of the capital stock are needed (Chagny and Döpke, 2001). The output gap here is from the AWM dataset. The *Hodrick-Prescott (HP) filter* (Hodrick and Prescott, 1997) is obtained by minimising actual output ( $y$ ) around trend output ( $y_t^*$ ) subject to a constraint with respect to the variation of the growth rate of trend output, i.e.;  $\min \sum_{t=1}^T (y_t - y_t^*)^2 + \lambda \sum_{t=2}^{T-1} [(y_{t+1}^* - y_t^*) - (y_t^* - y_{t-1}^*)]^2$ . Smoothness of the trend estimates for output is achieved by determining a value for the Lagrangian multiplier  $\lambda$ . For quarterly data a common choice for  $\lambda$  is 1600. Shortcomings of this filter are that it is completely mechanistic, it has no explicit foundation in any economic theory; and, a long lasting negative (or positive) output gap is ruled out a priori by the HP-filter. Further on, there is an end-of-sample problem when a HP-filter is used to estimate the output gap (Chagny and Döpke, 2001). So the use of an HP-filter to estimate the output gap is easy, but highly controversial. Before we applied the HP-filter the sample is extended with ARIMA-based forecasts of the output gap series (see Kaiser and Maravall, 1999), to take into account the end-of-sample problem.

### 3.2 Estimating the Taylor rule

In the previous sub-section it was shown that the Taylor rules with the original Taylor weights on the output gap and inflation did not describe the movements in the short-term three-month interest rate very well. It is quite likely that the weights in the Taylor rule are different for the euro area because the ECB follows a different monetary policy strategy than the Federal Reserve in the United States. Therefore different Taylor rules, and thus the weights, are estimated in this sub-section. The Taylor rules are estimated with final and quasi-real time data of the output gap, and with the output gap calculated with the production approach and the HP-filter. Moreover, we decided to include a dummy from the first quarter of 1999 until the fourth quarter of 2000, taking account of the structural break in the equilibrium real interest rate after the foundation of the EMU.

Before we estimate the different Taylor rules it is necessary to search for the right specification of the rule. Often there is serial correlation in the residuals, which calls for inclusion of a partial adjustment term or an AR(1) term in the residuals. As explained in sub-section 2.4, economists do not agree whether the Taylor rule should be estimated with partial adjustment or with serially correlated shocks. In our analysis we also found serial correlation in the residuals, so we have decided to estimate the Taylor rules as:

$$i_t = \lambda i_{t-1} + (1 - \lambda) [i^* + \alpha d_t + \gamma(\pi_t - \pi^*) + \beta(y_t - y_t^*)] + \varepsilon_t \quad (6)$$

or as:

$$i_t = i^* + \alpha d_t + \gamma(\pi_t - \pi^*) + \beta(y_t - y_t^*) + \varepsilon_t, \text{ with } \varepsilon_t = \phi \varepsilon_{t-1} + u_t \quad (7)$$

where  $d_t$  is the dummy. Equation (6) is a Taylor rule specification with partial adjustment and no serial correlation in the residuals. In this specification there is an immediate jump in the equilibrium interest rate after the foundation of the EMU ( $i_t^* = i^* + \alpha d_t$ ), but a smooth adjustment of the actual interest rate. The rationale for this is that the central bank also wants to smooth interest rates after a permanent shock in the equilibrium interest rate. Equation (7) is a Taylor rule that has immediate policy adjustment but allows for serially correlated shocks (and  $u_t$  is white noise). Using the Rudebusch (2002) approach with the difference that a dummy is included, the next equation should be estimated to test which specification should be used:

$$i_t = \lambda_1 i_{t-1} + (1 - \lambda_1 + \lambda_2) [i^* + \alpha d_t + \gamma(\pi_t - \pi^*) + \beta(y_t - y_t^*)] - \lambda_2 [i^* + \alpha d_{t-1} + \gamma(\pi_{t-1} - \pi^*) + \beta(y_{t-1} - y_{t-1}^*)] + u_t \quad (8)$$

The AR(1) shock rule (7) is estimated under the restriction that  $\lambda_1 = \lambda_2 = \phi \in (-1, 1)$ , while the interest rate smoothing rule (6) is represented by:  $\lambda_2 = 0$  and  $\lambda_1 = \lambda \neq 0$ . For all four different definitions of the output gap equation (8) is estimated and for each the two hypotheses are tested. In the case of the final and quasi-real time estimates of the output gap based on the production function approach both the hypothesis of serially correlated shocks and the hypothesis of partial adjustment are rejected. With the final and quasi-real time estimates of the output gap calculated with the HP-filter, the hypothesis of serially correlated shocks is rejected, but the hypothesis of partial adjustment is not rejected. This is also the case when forecasts of the output gap in the current quarter are used (sub-section 3.3 will be about this measure of the output gap). On the basis of the results of these tests we decide to estimate the Taylor rules with interest rate smoothing and not with an AR(1) term in the residuals.

So we estimate Taylor rules for the euro area for the period 1994 – 2000, with an interest rate smoothing term and a dummy from the first quarter of 1999 onwards. Table 3 presents the results:

**Table 3 Taylor type estimated rules with alternative data, 1994.1-2000.4**

	$\lambda$	$i^*$	$\gamma$	$\beta$	dummy	adj.R-squared
(1) Final (P)	0.7 *** (0.09)	4.9 *** (0.23)	1.92*** (0.37)	1.66* (0.96)	-0.4 (0.6)	0.964
(2) Quasi-real time (P)	0.62*** (0.0)	.17*** (0.19)	2.06*** (0.24)	0.96*** (0.24)	-1.03*** (0.19)	0.970
(3) Final (HP)	0.7 *** (0.07)	.23*** (0.28)	1.80*** (0.27)	1.72* (0.8)	-1.08*** (0.30)	0.964
(4) Quasi-real time (HP)	0.64*** (0.06)	.08*** (0.26)	1.89*** (0.32)	0.46 (0.34)	-1.06*** (0.40)	0.93

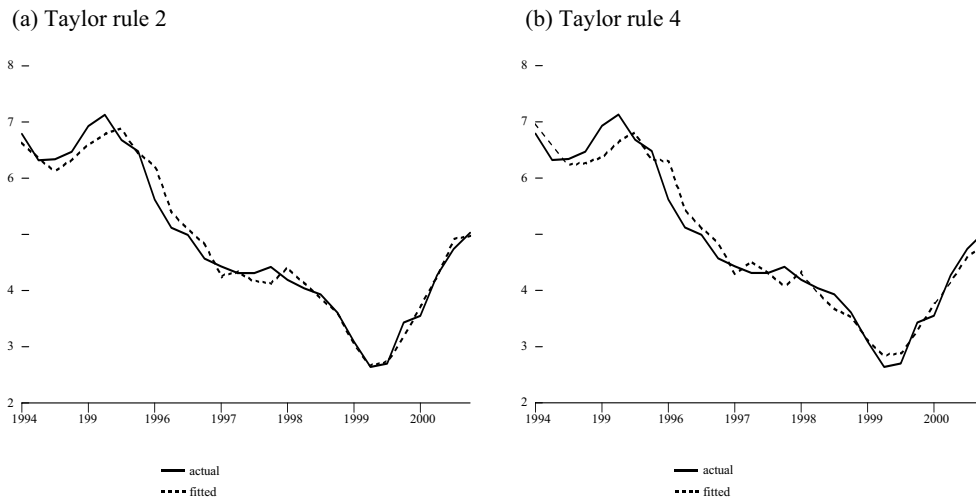
Notes: \*\*\*/\*\* denote significance at the 10%/5%/1% level respectively, Newey-West HAC standard errors in parenthesis. The regressions shown are least-squares estimates of the equation

$$i_t = \lambda i_{t-1} + (1 - \lambda)[i^* + \alpha \Delta i_t + \gamma(\pi_t - \pi^*) + \beta(y_t - y_t^*)] + e_t$$

for the 1994.1 – 2000.4 period, with  $\pi^* = 2$ . The rows correspond to alternative vintages of output gap data shown.

Figure 6 compares the interest rates implied by the estimated Taylor rules based on quasi-real time data with the actual short-term three-month interest rate.

**Figure 6 Estimated Taylor rules and the actual interest rate**



Before we discuss the results of the estimated Taylor rules, it is necessary to pay attention to some required features of the variables used and the estimated residuals. First, every variable that is included in a regression has to be stationary. That is, the underlying stochastic process that generates the series has to be invariant with respect to time. When a series has a unit root or is non-stationary and this variable is included in a regression this would lead to spurious results. So it is necessary to test for this and adjust the series if they are non-stationary. To test for stationarity for each variable an (Augmented) Dicky Fuller (ADF) test is performed. The short-term three-month interest rate and the inflation series are not stationary. All four output gap series are stationary. Because the interest rate and inflation have a unit root you should take the first difference of these series before estimating an equation in order to avoid the problem of a spurious regression. However, Engle and Granger (1987) pointed out that a linear combination of two or more non-stationary series may be stationary. If such a stationary linear combination exists, the non-stationary time series are said to be cointegrated. When two series are cointegrated, this can be interpreted that there is a long-run relationship among the two variables. Since the Fisher equation predicts such a long run relationship between  $\pi$  and  $i$ , we expect these variables to be cointegrated. In this case a regression in levels is correctly specified. We tested for cointegration by testing the residuals for stationarity. In all four estimated Taylor rules the residuals are stationary, so we can use all series in levels.

Second, we tested whether the residuals of the estimated Taylor rules follow a normal distribution. For none of the residuals the hypothesis that the residuals have a normal distribution can be rejected by the Jarque-Bera test.

The last performed test is a Wald test to test the joint hypothesis that the coefficient on the output gap ( $\beta$ ) is 0 and the coefficient on inflation ( $\psi$ ) is 1. This test investigates whether the two coefficients are equal to the ones Taylor originally suggested. For equations 1, 3 and 4 the Wald test cannot reject the joint hypothesis that the parameters  $\beta$  and  $\gamma$  have the original Taylor values. For equation 2 the Wald test rejects the joint hypothesis. So the estimated weights for the euro area are not that different from the weights Taylor originally suggested.

From Table 3 a couple of things can be noticed. First, the *interest rate smoothing parameter* ( $\lambda$ ) is always significant at the 1% level and its values are as expected. A Taylor rule with interest rate smoothing gives a good description of the monetary policy in the euro area, this can also be seen in Figure 6. It should be mentioned however that the 95% confidence intervals of these estimated Taylor rules are rather wide, on average it is about 1 percentage point. So there is a lot of inherent uncertainty of the fitted Taylor rule interest rates and we should be prudent with the interpretation of the Taylor rules. Second, the values of the *equilibrium nominal interest rate* ( $i^*$ ) are reasonable.  $i^*$  is equal to the sum of  $r^*$  and  $\pi^*$ . In the previous sub-section it was assumed that  $r^*$  is equal to 3% and  $\pi^*$  is equal to 2%, in that case  $i^*$  is equal to 5%. The estimated  $i^*$ 's are somewhat lower than these values. All the  $i^*$ 's

are significant at the 1% significance level. Third, the *inflation parameter* ( $\gamma$ ) always has its desired value, i.e.  $\gamma > 1$ . This reflects the so-called Taylor principle, which is a necessary condition for an inflation stabilising monetary policy. Moreover, the estimated values of this inflation parameter are not very different from what you would expect from Taylor's work (expected values of  $\gamma$  lie between 1 and 2) and all the estimated  $\gamma$ 's are significant at the 1% level. Fourth, the estimates of the *output gap parameter* ( $\beta$ ) are a little bit more difficult to interpret. Expected values of this parameter lie between 0 and 1. It is significant in three cases, but in two cases its value is pretty high ( $\beta = 1.66$  and  $\beta = 1.72$ ). But these  $\beta$ 's are estimated quite imprecisely, the standard errors are quite large. In both cases the Wald test could not even reject the joint hypothesis that the parameters  $\beta$  and  $\gamma$  have the original Taylor values. Other authors (for example Peersman and Smets, 1998, and Ball, 1997) also find a weight on the output gap around 1. In a recent paper John Taylor (1999a) seems to acknowledge that his original proposal may be inefficient and considers rules with a weight on the output gap of 1.0. Fifth, the *dummy* is significant at the 1% significance level in three out of four cases and it is negative. You would expect that after the establishment of the EMU the equilibrium interest rate decreased, so the dummy has the right sign. Sixth, using *quasi-real time data* instead of final data does not change the fit very much, the adjusted R-squared does not change a lot. But the interest rate smoothing parameter and the output gap parameters change when quasi-real time data are used to estimate the output gap instead of ex post data. Both parameters become lower when quasi-real time data are used. Furthermore, the significance of the output gap parameter changes. In the case of the use of the output gap based on the production function approach the significance of the weight on the output gap increases, whereas this weight becomes insignificant when the output gap is calculated with an HP-filter. So the use of quasi-real time data leads to different specifications of the Taylor rule. Therefore it is essential to rely on quasi-real time data, otherwise this would lead to misleading views on monetary policy. Finally, the two different *estimation methods of potential output*, the production function approach and the HP-filter, do not have big consequences for the fit of the rules and also the size of the different estimated parameters do not change dramatically. But in the case of the rules calculated with quasi-real time data, the weight on the output gap is significant when the production function approach is used, whereas this weight is not significant when an HP-filter is used to estimate the output gap. The significance of the output gap when calculated with the production function approach may indicate that the output gap is an important input for the ECB for deciding on the interest rate.

From these estimations the following conclusions can be drawn. First, the estimated weights on inflation and the output gap do not differ so much from the ones Taylor originally suggested. Second, the Taylor rules with interest rate smoothing give a good description of monetary policy in the euro area, but the inherent uncertainty of the fitted Taylor interest rates is rather large. Third, probably the

equilibrium interest rate decreased after the foundation of the EMU. Fourth, it is necessary to use quasi-real time data in the Taylor rule, otherwise you would get a misleading description of monetary policy. And finally, the output gap may be an important input for the ECB when deciding on the interest rate.

### 3.3 A forward-looking Taylor rule

As explained in sub-section 2. of this paper, one point of criticism is that monetary policy needs to be forward-looking, because it operates with a lag. A central banker will use all relevant available information to make forecasts of inflation and the output gap and does not only use the latest available data of inflation and the output gap. A forward-looking Taylor rule with interest rate smoothing looks as follows:

$$i_t = \lambda i_{t-1} + (1 - \lambda) \left[ i^* + \beta (E[\pi_{t+k} | \Omega_t] - \pi^*) + \gamma (E[y_{t+l} | \Omega_t] - y_t^*) \right] \quad (9)$$

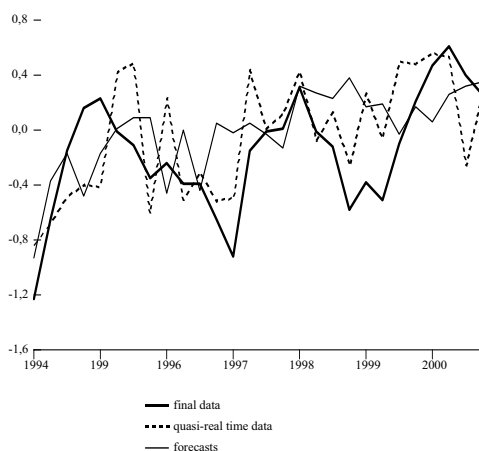
Here,  $k$  and  $l$  reflect the ‘target’ horizons relative to the quarter during which interest rate decisions are taken and the information set in  $t$  ( $\Omega_t$ ) contains all past realisations of the output gap up to period  $t - 2$  and of inflation up to the current period. In this equation the central bank makes a forecast of inflation in period  $t + k$  and a forecast of the output gap in period  $t + l$  with all relevant information available at time  $t$ . Some authors take a horizon of  $l = 0$  for the output gap. This means that they assume that the central bank uses current information to get the best estimate of the output gap at time  $t$ . The idea behind taking  $l = 0$  is that the central bank reacts to the current output gap because it contains information about future price pressures. So the central bank can be forward-looking even when it reacts to the current output gap.

A method which is often used in the literature to estimate a forward-looking Taylor rule is the GMM estimation method (see for example Clarida et al., 1998; Peersman and Smets, 1998). With this method a forward-looking policy reaction function is estimated based on ex post revised data, where actual realisations of the output gap and inflation are taken as forecasts. These forecasted values are instrumented by the realisations of the output gap and inflation rate contained in the information set. Since the GMM approach replaces forecasts by future realisations, it is not applicable to real time data sets. In real time data sets, future realisations are simply not available. Therefore, we use a two-step approach to estimate a forward-looking Taylor rule. In the first step we construct quasi-real time forecasts of the output gap. In the second step we estimate the Taylor rule using the forecasts constructed in the first step as regressor. Quasi-real time forecasts of the output gap are based on the HP-filter. As explained in box 1 in sub-section 3.1 there is an end-of-sample problem when the HP-filter is used to estimate the output gap. We address this end-of-sample problem of the HP-filter by

extending the sample by ARIMA-based forecasts of the output series before applying the HP-filter (see Kaiser and Maravall, 1999). The output gap thus obtained for the extended sample, which contains information on actual output up to period  $t - 2$ , also provides us with a forecast of the current period's output gap. This can be done for every quarter, and in this way you get recursive estimates of the forecasts of the output gap and these can be used as quasi-real time data. These quasi-real time estimates of the forecast of the output gap are used to estimate a forward-looking Taylor rule. With respect to inflation, we assume again that the central bank can observe current inflation<sup>7</sup>.

Figure 7 shows the quasi-real time forecasts of the current output gap (dashed lines) together with the final estimates (fat solid lines) and the quasi-real time estimates (light solid lines) of the output gap, all three variables are calculated with the help of the HP-filter. It can be seen that the quasi-real time forecasts of the current output gap differ considerably from the quasi-real time output gaps as well as from the final estimates of the output gap.

**Figure 7 Output gaps estimated with the HP-filter**



The difference between the current quarter output gap forecasts using current information and the first available output gap estimates could lead to another specification of the Taylor rule. Table 4 shows the new estimation of a Taylor rule where quasi-real time forecasts of the output gap in the current quarter are used.

<sup>7</sup> It would be more realistic to make a forecast of inflation for one year ahead, for example. But real time forecasts of inflation are not available for euro area and for this paper it goes too far to make good real time forecasts of inflation.



**Table 4 Estimation of a forward-looking Taylor rule**

	$\lambda$	$i^*$	$\gamma$	$\beta$	dummy	Adj.R-squared
( ) Forecasts (HP)	0.6 ***	.09***	2.09***	1.2 **	-1.14***	0.97
	(0.06)	(0.24)	(0.33)	(0.46)	(0.27)	

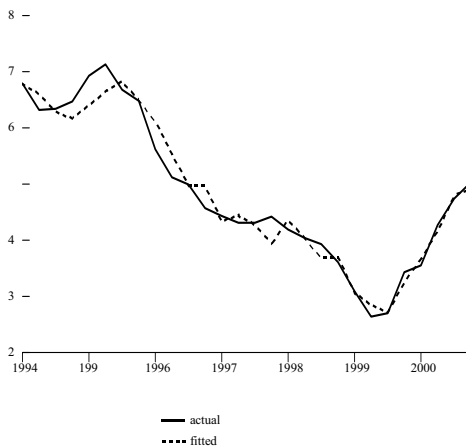
Notes: \*\*\*/\*\*/\* denote significance at the 10%/ %/1% level respectively, Newey-West HAC standard errors in parenthesis. The regressions shown are least-squares estimates of the equation

$$i_t = \lambda i_{t-1} + (1-\lambda)[i^* + \alpha d_t + \gamma(\pi_t - \pi^*) + \beta(y_t - y_t^*)] + e_t$$

for the 1994.1 – 2000.4 period, with  $\pi^* = 2$ .

Figure 8 compares the fitted interest rate implied by rule ( ) with the actual interest rate.

**Figure 8 Taylor rule and the actual interest rate**



In this equation there is no serial correlation in the residuals and the hypothesis that the residuals have a normal distribution could not be rejected. As before, we find that the residuals are stationary and that the weights on inflation and the output gap do not differ significantly from the original Taylor values ( $\beta = 0$  and  $\gamma = 1$  ). Comparing this Taylor rule with Taylor rule (4) in sub-section 3.2 it can be noticed that the interest rate smoothing parameter ( $\lambda$ ) and the equilibrium interest rate ( $i^*$ ) do not change very much. But the weights on inflation and the output gap ( $\gamma$  and  $\beta$ ) become larger. And the weight on the output gap becomes significant at the % significance level, while it was not significant when normal quasi-real time output gap data calculated with an HP-filter were used. An interpretation of this could be that the central bank indeed reacts to the output gap when it uses its best estimate of

the output gap in the current quarter. The dummy is a little bit more negative compared to rule (4), but is still significant at the 1% significance level. Finally, the adjusted R-squared increases slightly.

From this and the previous sub-section it can be concluded that Taylor rules based on quasi-real time data or quasi-real time forecasts of the output gap and an interest rate smoothing term give a good description of monetary policy, in terms of the R-squared, in the euro area for the 1994 – 2000 period. However, the inherent uncertainty of the Taylor interest rates, in terms of the 95% confidence interval, is rather large. So we should be prudent with the interpretation of the estimated Taylor rules. In the next sub-section we will check from a different perspective whether our estimated Taylor rules provide a good description of the ECB's behaviour. In an out-of-sample forecasting exercise we will compare the actual interest rate in 2001 and 2002 with the rates predicted by our estimated policy rules. This exercise may also provide additional information regarding the relative performance of the Taylor rules estimated with quasi-real time and final data. Since actual monetary policy is based on real time data, we would expect that our quasi-real time Taylor rule outperforms the Taylor rule estimated with final data.

### 3.4 Out-of-sample forecasts

In the previous two sub-sections three types of Taylor rules were estimated with quasi-real time data (rule 2, 4, and 5). From the figures and the adjusted R-squared values it could be seen that all of these rules gave a pretty good description of monetary policy in the euro area. From these results it seems that the estimated Taylor rules could be quite informative when one wants to analyse or predict the monetary policy of the ECB. Moreover, these Taylor rules could be used by the ECB itself as one of the indicators in the second pillar of the monetary policy strategy. This sub-section examines to what extent the interest rates implied by the different Taylor rules follow the actual interest rate movements in 2001 and 2002. To calculate the out-of-sample interest rate forecasts with the different rules it is necessary to have out-of-sample data of the output gap and inflation. The inflation data are not a problem, but there are problems with the output gap data. Although the output gap according to the HP-filter can be easily calculated, we had no estimates with the production function approach for 2001/2002. Therefore, this section is limited to the HP-filter gap.

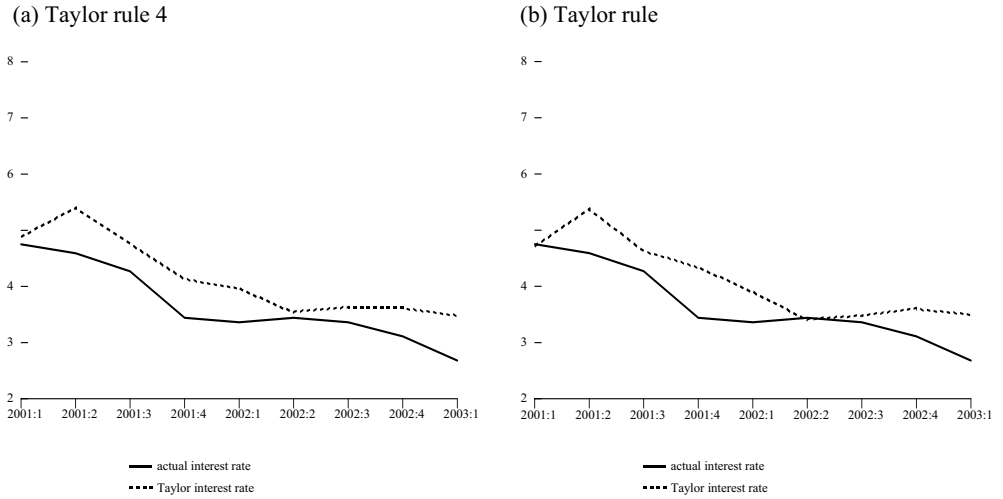
So the Taylor rules used for calculating the forecasts of the interest rate are:

$$\text{Taylor rule 4: } i_t = 0.64i_{t-1} + (1 - 0.64) [ 0.08\% + 1.89(\pi_t - 2\%) + 0.46(y_t - y_t^*) - 1.06\% ]$$

$$\text{Taylor rule 5: } i_t = 0.6 i_{t-1} + (1 - 0.6) [ 0.09\% + 2.09(\pi_t - 2\%) + 1.2y_t(-y_t^*) - 1.14\% ]$$

Figure 9 shows the interest rates implied by the two Taylor rules with the actual interest rate.

**Figure 9 interest rate forecasts implied by Taylor rules 4 and together with the actual interest rate**



When these two figures are compared with Figures 6b and 8 it can be seen that for 2001 and 2002 the two Taylor rules do not give such a good description of monetary policy in the euro area as for the 1994 – 2000 period. On the other hand, the Taylor interest rates move in the same direction as the actual interest rate. To make some things clearer Table shows some descriptive statistics for the difference between the actual interest rate and the Taylor interest rates.

**Table Descriptive statistics, 2001.1 – 2003.1**

	Mean	Median	Max	Min	SD
$i_t - i_{r, hp}^T$	-0.49	-0.2	-0.10	-0.81	0.27
$i_t - i_{fc, hp}^T$	-0.44	-0.49	0.0	-0.91	0.37

*Notes:* The superscript T means that the interest rate is calculated by the Taylor rule. The subscript r, hp means that the quasi-real time output gap estimate calculated with the HP-filter is used, while the subscript fc, hp stands for the quasi-real time forecast of the current output gap calculated with the HP-filter.

From this table the following things can be noticed. First, regarding the fit of the rule, the standard deviation of the difference between the actual interest rate ( $i_t$ ) and the rule where quasi-real time output gap data are used ( $i_{r, hp}^T$ ) is 27 basis points. The corresponding standard deviation with quasi-real time forecasts of the current output gap ( $i_{fc, hp}^T$ ) is 37 basis points. In sub-section 3.1 where the original Taylor rule was applied, the standard deviation of the difference between the actual interest rate and the Taylor rule based on quasi-real time data was 49 basis points. So estimating the weights in

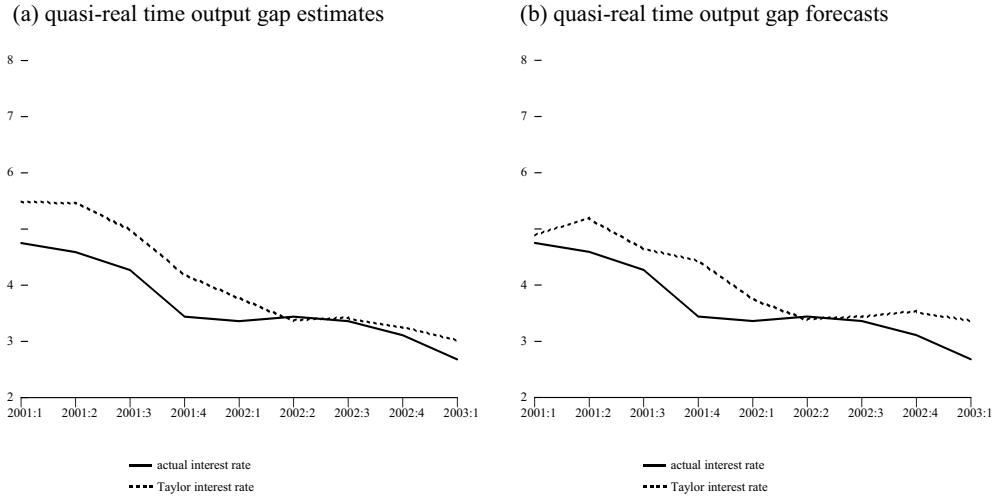
the Taylor rule and including an interest rate smoothing term leads to a better description of the ECB's monetary policy. Moreover, the standard deviations of the differences between the actual interest rate and the interest rate implied by the two rules are also lower than the standard deviation of the quarterly change in the interest rate ( $i_t - i_{t-1}$ ), which is 39 basis points. This means that assuming that the interest rate does not change will not lead to a better interest rate forecast than the two Taylor rules. Although the two modified Taylor rules give a better description of monetary policy in the euro area than the original Taylor rule, fact is that there are still large differences between the actual interest rate and the interest rate implied by one of the Taylor rules. The maximum difference between 2001.1 and 2003.1 was 81 basis points for the Taylor rule based on quasi-real time output gap estimates and 91 basis points for the Taylor rule based on quasi-real time forecasts of the current output gap. Moreover, on average the difference between the actual interest rate and the Taylor interest rate is 49 basis points for rule 4 and 44 basis points for rule 3. From these results it might be concluded that these two Taylor rules could serve as indicators of the monetary policy stance. But these Taylor rules should not be used to get an exact forecast of the interest rate, for that purpose the interest rate forecasts calculated with the two Taylor rules are not precise enough. From Figure 9 it can also be seen that the actual interest rate is almost always higher than the Taylor interest rate. This indicates that monetary policy in the euro area has been more expansionary during the last two years than what is expected from the estimated Taylor rules.

In sub-section 2.3 we explained that one has to rely on real time data when estimating a Taylor rule because of the measurement problems with the output gap. When this fact is ignored and the Taylor rule is estimated with final output gap data, while in reality only real time data are available, this Taylor rule could result in misleading descriptions of monetary policy. In that case it is expected that a Taylor rule based on quasi-real time data outperforms a Taylor rule based on final data. In this part of this sub-section we will investigate this as follows. We assume that Taylor rule 3, which is based on final output gap estimates, is used to calculate the interest rate forecast. Further on, we assume that in fact only quasi-real time output gap estimates/forecasts are available. So we put the quasi-real time output gap estimates/forecasts in Taylor rule 3 to get an interest rate forecast. Taylor rule 3 is specified as follows:

$$\text{Taylor rule 3: } i_t = 0.7 i_{t-1} + (1 - 0.7) \left[ 2.23\% + 1.80\% \left( \frac{C}{Y} - 2\% \right) + 1.73\% \left( -y_t^* \right) + 1.08\% \right]$$

Figure 10 shows the interest rate forecasts of this Taylor rule both where in fact quasi-real time output gap estimates are available and where in fact quasi-real time forecasts of the current output gap are available together with the actual interest rate.

**Figure 10 Taylor rule 3 using quasi-real time output gap estimates/forecasts**



Comparing these figures with Figures 9a and 9b it is not immediately clear whether the use of final data, while in fact quasi-real time data are available, leads to a worse description of monetary policy in the euro area. Therefore, Table 6 presents some descriptive statistics of the difference between the actual interest rate and the Taylor interest rates.

**Table 6 Descriptive statistics, 2001.1 – 2003.1**

	Mean	Median	Max	Min	SD
$i_t - i_{f, hp r, hp}^T$	-0.4	-0.42	0.06	-0.89	0.3
$i_t - i_{f, hp fc, hp}^T$	-0.41	-0.40	0.0	-1.00	0.33

*Notes:* The superscript T means that the interest rate is calculated by the Taylor rule. The subscript (f, hp|r, hp) means that the quasi-real time output gap estimate is used in the Taylor rule based on final output gap data, while the subscript (f, hp|fc, hp) stands for using the quasi-real time forecast of the output gap in the Taylor rule based on final output gap data.

When quasi-real time output gap estimates are used in the Taylor rule based on final output gap data, the standard deviation of the difference between the actual interest rate and the Taylor interest rate ( $i_t - i_{f, hp|r, hp}^T$ ) is 3 basis points, whereas the standard deviation of this difference is 27 basis points when these quasi-real time output gap estimates are used in the Taylor rule based on quasi-real time estimates (see Table ). However, the mean of this difference is 4 basis points in the case of Taylor rule 3 and 49 basis points with Taylor rule 4. When the quasi-real time forecasts of the current output gap are used in the Taylor rule based on final data, the standard deviation of the difference between the actual interest rate and the Taylor interest rate ( $i_t - i_{f, hp|fc, hp}^T$ ) is 33 basis points. This standard deviation is 37 basis points when Taylor rule based on quasi-real time forecasts is used. The mean

deviation is also lower when Taylor rule 3 is used instead of Taylor rule 2, 41 basis points instead of 44 basis points. From these results we cannot conclude that Taylor rules estimated with quasi-real time data outperforms the Taylor rule estimated with final data. In contrast to Orphanides (2001) we find that the use of final data to estimate a Taylor rule, while in reality quasi-real time data are available, does not lead to more misleading policy descriptions compared to using a Taylor rule estimated with quasi-real time data. This implies that it is not so important for the euro area as for the US to work with quasi-real time data instead of ex post revised data in estimating a Taylor rule.

In this sub-section we made out-of-sample forecasts of the interest rate for 2001 and 2002. We concluded that the two estimated Taylor rules 4 and 5 can be used to get an idea of the monetary policy stance. But the two Taylor rules should not be used to get an exact interest rate forecast, the interest rate forecasts obtained from the two rules are too imprecise. The figures also indicated that monetary policy in the euro area was more expansionary than what is expected of the estimated Taylor rules. Moreover, it was shown that using quasi-real time data instead of final data to estimate a Taylor rule does not increase the performance of the rule.

#### 4 SUMMARY AND CONCLUSIONS

In the beginning of the nineties John Taylor (1993) showed that a very simple monetary policy rule gave a very good description of monetary policy during the first Greenspan period. Taylor's idea was that his rule could be used as one of the inputs to the decision making process of the central bank and as a means to communicate monetary policy decisions to the public. The rule could also be used as a benchmark for predicting future policy. Although this Taylor rule described monetary policy quite well in the US, it also received some criticism. One of the main criticisms was the so-called real time critique; because data on especially the output gap are only available after some quarters the original Taylor rule is not operational. Moreover, Taylor rules estimated with ex post revised data could result in misleading descriptions of monetary policy. Therefore data actually available to policy makers in real time should be used when estimating and analysing Taylor-type rules. The Taylor rule was also criticised for not taken into account interest rate smoothing behaviour and that a monetary policy rule should be forward-looking. This paper developed a modified Taylor rule for the euro area where these criticisms are taken into account, in order to answer the following question:

*Does a modified Taylor rule based on quasi-real time data give a better description of monetary policy in the euro area, in terms of the fit, than a Taylor rule based on final data?*

First, the informational problems in implementing the Taylor rule were illustrated. This was done by applying the original Taylor rule with final output gap data as well as with quasi-real time output gap data and these two outcomes were compared with each other. We found that there is a difference between the Taylor interest rate calculated with final data and the Taylor interest rate calculated with quasi-real time data, but this difference is not as big as the difference Orphanides (2001) finds for the US. It seems that the information problems related to the estimation of the output gap do not have such large implications for the outcomes of the original Taylor rule in the euro area as in the US. Moreover, the fit of the original Taylor rule calculated with quasi-real time data is almost the same as the fit of the original Taylor rule based on final data. This is in contrast to Orphanides (2001) who finds that prescriptions obtained from the original rule using real time data are worse than recommendations of the rule based on final data.

Second, we estimated Taylor rules for the euro area for the period 1994 – 2000. Because we found serial correlation in the residuals it was necessary to include an interest rate smoothing term or an AR(1) term in the residuals. On the basis of a test provided by Rudebusch (2002) we decided to estimate the Taylor rules with an interest rate smoothing term. We also included a dummy from 1999 onwards, to take into account the structural break in the equilibrium real interest rate after the foundation of the EMU. Because it is more realistic to assume that the central bank uses available

information to get an estimate of the output gap in the current quarter, we also estimated a forward-looking Taylor rule. In this forward-looking Taylor rule we used quasi-real time forecasts of the current output gap. From the estimations the following things could be concluded. First, in four out of five cases the joint hypothesis that the inflation parameter and the output gap parameter have their original Taylor values could not be rejected. Hence the weights for the euro area are not so different from the ones Taylor originally suggested. Second, a Taylor rule based on quasi-real time data and an interest rate smoothing gives a good description of the monetary policy, in terms of the R-squared, in the euro area during the 1994 – 2000 period. But the inherent uncertainty of the fitted Taylor rules is rather large. Third, the dummy is significantly negative at the 1% significance level in four out of five cases. So probably the equilibrium interest rate decreased after the establishment of the EMU. Fourth, using quasi-real time data instead of final data does not lead to a very different fit. But the use of quasi-real time data does change the specification of the Taylor rules, some parameters change. Therefore it is necessary to rely on quasi-real time data when estimating a Taylor rule, otherwise this could lead to misleading descriptions of monetary policy. And finally, the weight on the output gap is significant at the % significance level when the production function approach and forecasts calculated with the HP-filter are used. This indicates that the output gap is an important input for the ECB for deciding on the interest rate.

In order to analyse whether our estimated Taylor rules also have a good predictive value of the ECB's monetary policy, we compared the actual interest rate in 2001 and 2002 with the rates predicted by our estimated rules. This exercise revealed that although there can be large differences between the actual interest rate and the Taylor interest rates, the interest rates implied by the Taylor rules move in the same direction as the actual interest rate. From this result it might be concluded that the estimated Taylor rules based on quasi-real time data could serve as indicators of the monetary policy stance. But the interest rate forecasts obtained from the Taylor rules are too imprecise to get an exact interest rate forecast. It could also be seen that actual monetary policy was more expansionary than what is expected of the estimated Taylor rules. Finally, it was shown that, in contrast to Orphanides (2001), using final data to estimate a Taylor rule, while in reality only quasi-real time data are available, does not lead to more misleading policy descriptions compared to using a Taylor rule estimated with quasi-real time data. This implies that it is not so important for the euro area as for the US to work with quasi-real time data instead of ex post revised data in estimating a Taylor rule.



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