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Should Monetary Policy Respond to Money Growth? New Results for the Euro Area

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Abstract

In recent years, the relevance of money growth indicators for the conduct of monetary policy has been questioned in the mainstream academic literature. It is widely argued that monetary policy should directly relate short-term interest rates to inflation and the output gap. The present paper investigates whether the performance of this type of interest rate rule can be significantly improved by adding a policy response to money growth. In contrast to most previous studies, our analysis explicitly takes into account the fact that real-time data on both actual and potential output, and hence the output gap, may be subject to substantial measurement errors. Broadly speaking, we find that the greater the degree of output gap uncertainty, the greater the benefits of incorporat-

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ing a money growth response are in terms of reducing volatility in output, inflation and interest rates. The main reason is that real-time data on money growth contain valuable information on the true level of current output growth, which is not otherwise known to policy makers in real time with a sufficient degree of precision. Hence, we conclude that policy makers should explicitly account for money growth in the setting of policy rates.

I. Introduction

In recent years, the use of monetary indicators has received little support in the mainstream academic literature on optimal monetary policy (see e.g. Woodford 2008). Instead, monetary policy is discussed in terms of a monetary policy reaction function that relates short-term interest rates to the final targets of monetary policy. These, in turn, are captured by some measure of the business cycle and price developments. An essential element of the implementation of interest rate rules is which information is available to policy makers at the time decisions are made. This is important, as the initial estimates of some variables that enter the interest rate setting process may differ substantially from their ex-post revised values. Real-time uncertainty about key variables, like actual and potential output (and their rates of growth), opens up a role for other potential feedback variables that are related to the 'true' values of the uncertain variables through structural relationships, but are less subject to measurement error (ME). We concentrate on the role of money as an additional feedback variable, since the usefulness of monetary indicators has been intensively discussed in monetary history, theory and practice.[1]

An important reason for the neglect of money in the mainstream literature is the fact that in the canonical New Keynesian model that underlies much of the recent literature on optimal monetary policy, money is irrelevant for the determination of real output, inflation and the interest rate (at least in the short run, see Nelson 2008). Still, even in this type of model, optimal policy may respond to money if it contains useful information about the underlying state of the economy. Dotsey and Hornstein (2003) analyse this issue in a model calibrated to the US economy. They conclude that, in the United States, money demand is too volatile for observations on money to be of much value for policy makers. In a similar analysis of the euro area, Coenen et al. (2005) find that the information content of money is limited by the low value of the

[1]See e.g. the papers in the December 2008 issue of the JMCB and Gerberding et al. (2005b), Section V, as well as the ECB's two-pillar strategy.

estimated short-run income elasticity of money and the sizeable standard error of the money demand shocks. One limitation of both studies is that they focus on short-lived MEs in output data and treat potential output as exogenously given and known to all agents. In contrast, Beck and Wieland (2007, 2008) allow for persistent central bank misperceptions regarding potential output. They show that, under this assumption, cross-checking the optimal policy response derived from Keynesian-style models with money-based estimates of trend inflation can generate substantial stabilization benefits.

The present paper differs from the existing literature on the topic in two important dimensions. First, we analyse the usefulness of money in optimized simple interest rate rules, while Dotsey and Hornstein (2003), Coenen et al. (2005) and Beck and Wieland (2007, 2008) all restrict their attention to optimal discretionary policy. Our interest in simple rules is motivated by their potential advantages over discretionary policy. These advantages are a result of the stabilizing effect the rules have on private-sector expectations.[2] Second, we assume that the central bank faces measurement problems with respect to both actual and potential output. In order to gauge the nature and magnitude of the MEs, we draw upon the real-time data sets for Germany and other countries, which have become available in recent years. The lessons that can be derived from these data sets for the design of monetary policy are discussed in some detail in Section II of the paper.

From a theoretical point of view, augmenting a standard Taylor rule (TR) with a money growth term may be advantageous because it introduces inertia and history dependence into the policy rule (see Söderström 2005). However, this can also be achieved by including the lagged interest rate and output growth directly among the feedback variables (as in Stracca 2007). Still, even in this case, an additional response to money may be beneficial because money growth may have information content about the 'true' rate of output growth, which can only be measured imperfectly. To gauge the relevance of these arguments for the euro area, we extend the set of simple rules analysed by Stracca (2007) to include variants of the TR and the speed limit rule (SPL), which feature an additional response to money growth. We then go on to calculate the optimal feedback coefficients and compare the performance of the optimized rules in a small estimated model of the euro area. The model that we use is a variant of the hybrid New Keynesian model, which has been proposed by Rudebusch (2002) and estimated on euro area data by Stracca (2007). The model equations, the set of policy rules we consider and the

[2]The usefulness of simple rules for monetary policy is discussed by Williams (2003) and Berg et al. (2006).

central bank objective function, which we need to pin down the optimal values of the feedback coefficients, are all described in Section III of the paper.

In Section IV.A, we present our results on the relative performance of the rules under different degrees of output gap uncertainty. The main finding is that, even at low levels of output gap uncertainty, an additional response to money significantly improves the performance of both the TR and the SPL. The positive indicator function of money arises because it is the *true* level of output that determines money demand. In Sections IV.B and IV.C, we show that the superior performance of the money-augmented SPL is robust to variations in key parameter values as well as to misperceptions about some key parameters, such as the degree of inflation inertia. Section V concludes.

II. Modelling Data Uncertainty – Lessons from German Data

Data uncertainty arises because the relevant statistics provide only incomplete or unreliable information about the actual state of the economy. A second, maybe even more important, reason is that the interpretation of the available data often depends on the assessment of their development relative to their trend or long-run equilibrium levels that are unobservable and can only be estimated with large margins of error. A well-known example is the measurement problem regarding the output gap, a variable that figures prominently in much of the academic literature on monetary policy rules. Differences between real-time and revised estimates of the output gap may arise from three sources: (a) revisions in GDP data, (b) the arrival of new data that changes the assessment of past developments and (c) changes in the method used for estimating potential output. In order to assess their implications for monetary policy, one needs to form a judgement on the magnitude and the exact nature of the MEs. Real-time data sets containing subsequent historical vintages of key macro variables constitute a valuable source for this kind of information.

With respect to the euro area, the usefulness of existing real-time data sets for aggregate data (like the one constructed by Gerdesmeier and Roffia 2004) is limited by the short sample period and, in particular, by the lack of real-time data on policy makers' perceptions of potential output. Gerdesmeier and Roffia tackle these problems by using an average of estimates published by the Organization for Economic Cooperation and Development and the European Commission and three measures based on their own calculations. In the present paper, we take a different route and draw on the Bundesbank's real-time data set for Germany, the biggest euro area country. The data set covers all variables in question, including the Bundesbank's own estimates of potential output, over the sample period 1974–98 (see Gerberding et al. 2004). Figure 1 illustrates the extent of revisions between the Bundesbank's

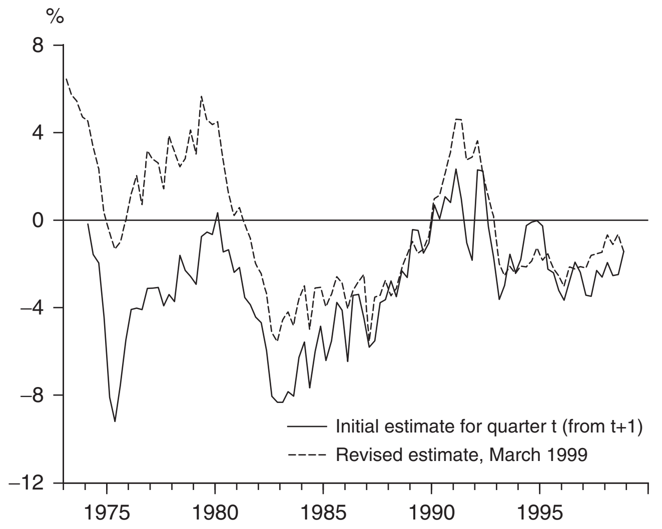

Figure 1: Initial and ex-post estimates of the output gap, Germany 1974–98*

*Calculation based on Bundesbank estimates of potential output.

real-time estimates of the output gap (that is, the initial estimates available at $t+1$) and a series of ex-post revised estimates which is based on the last available vintage of Bundesbank estimates of the production potential dating from January 1999 and on the March 1999 vintage of GDP data. The pattern that emerges from Figure 1 is very similar to the one found for other countries, e.g. by Orphanides (2001), Nelson and Nikolov (2001) and Kamada (2004) for the United States, the United Kingdom and Japan, respectively. With few exceptions, the ex-post series is always above the real-time series, suggesting that from today's perspective, the initial estimates of the output gap persistently overestimated the amount of slack in the economy. When splitting up the overall ME in the output gap into its components (Figure 2), it becomes apparent that the errors were mainly due to a persistent overestimation of potential output. In fact, there is only one subsample – the early 1990s – when revisions in actual GDP data dominate the overall forecast error.

The magnitude and persistence of these MEs suggest that monetary policy makers would have been ill-advised to respond strongly to real-time estimates of the level of the output gap. Of course, other potential feedback variables, like the change in the output gap, the rate of inflation or money growth may be subject to their own set of MEs. However, with a high degree of level persistence, the errors in the estimates of the *change* in the output gap should be less severe than the errors in the *level* of the gap.[3] As shown in the first graph of Figure 3, this is indeed the case. The MEs in the output

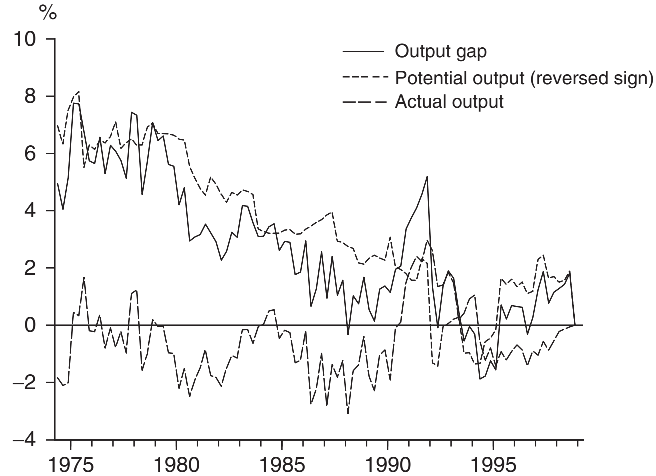

Figure 2: Components of measurement error in the output gap[1]

[1]Measurement error defined as difference between ex-post and initial figures.

gap's change can again be split into two components (second graph). Comparing the resulting time series with those depicted in the first graph yields the interesting result that the MEs in output growth almost mimic those in the change in the output gap, while the MEs in potential output growth are much smaller, but more persistent. Finally, as illustrated by Figure 3, revisions in consumer prices and in money growth were even smaller in size throughout the sample period, with money growth figures hardly being revised. While this may not have been true for other countries over different sample periods (see Amato and Swanson 2001), Coenen et al. (2005) reach very similar conclusions with respect to euro area data since 1999.

Table 1 provides some statistics on the extent and nature of the revisions which will later be used to calibrate the parameters of the ME processes. In order to allow some time for revisions between the initial and the ex-post observations, we shorten the sample period to 1974Q1–1995Q1 (which has the additional advantage of leaving us with West German data only). We also report results for the – arguably more 'normal' – sample 1980Q1–1995Q1. As the data frequency of the model underlying the analysis in the next section is quarterly, we focus on quarter-to-quarter rates of change.[4]

[3]As shown by Walsh (2004), the variance of the error in the measured change of the output gap depends negatively on the degree of persistence in the measurement error of the corresponding level estimates.

[4]The corresponding statistics for the four-quarter rates of change are available on request.

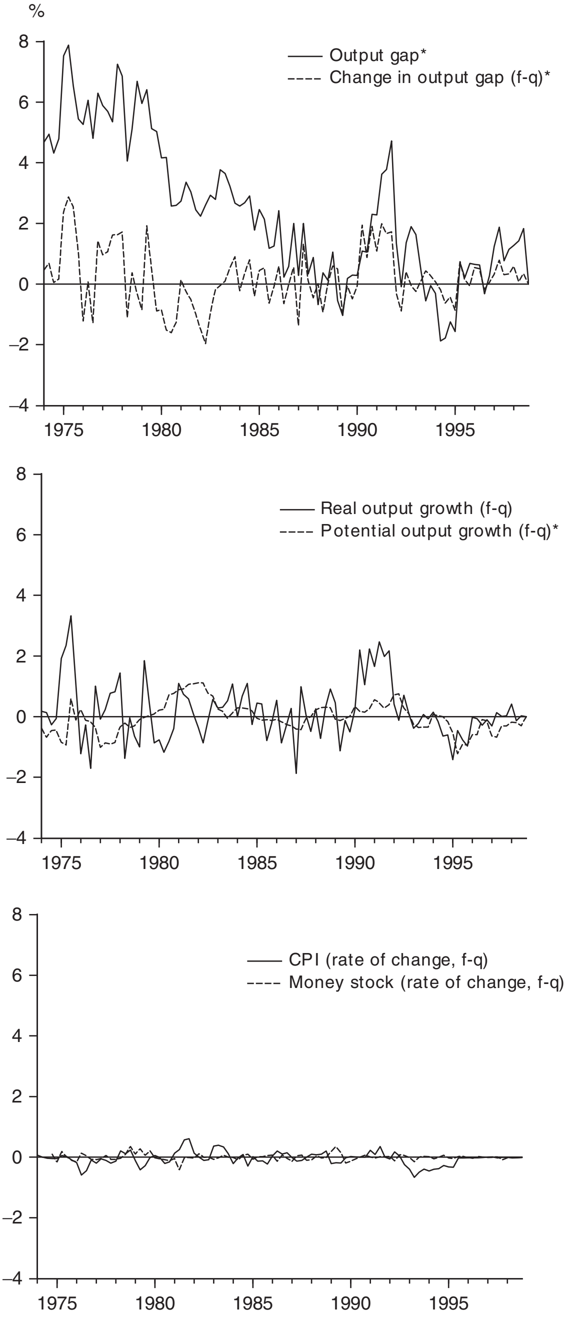

Figure 3: Measurement errors in key monetary policy indicators, 1975–98[1]

[1]The measurement errors are defined as the differences between the ex-post figures (March 1999 vintages) and the initial figures.
The calculation is based on Bundesbank estimates of potential output.

Table 1: Statistics on Historical Errors in the Measurement of Key Macro Variables

Assumed model: $\eta_t = (1 - \rho_\eta)\mu_\eta + \rho_\eta \eta_{t-1} + e_{\eta t}$

Measurement error for	Unconditional mean of η_t	Unconditional standard deviation of η_t	μ_η	ρ_η	Standard deviation of $e_{\eta t}$
Output gap					
Ex-post series: March 1999; production function approach					
1974:1–1995:1	3.10	2.37	–	0.96**	1.06
1980:1–1995:1	1.99	1.68	1.47*	0.89**	0.99
Ex-post series: September 2005 HP-filtered GDP					
1974:1–1998:4	2.86	1.90	2.75**	0.86**	1.01
1980:1–1998:4	2.78	2.11	2.45*	0.89**	0.98
Gap between actual and trend growth (q.o.q)					
Ex-post series: March 1999					
1974:1–1995:1	0.08	0.91	–	− 0.39**	0.84
1980:1–1995:1	0.01	0.81	–	− 0.41**	0.74
Ex-post series: September 2005					
1974:1–1998:4	0.10	0.86	–	− 0.35**	0.82
1980:1–1998:4	0.06	0.77	–	− 0.36**	0.73
Real output growth (q.o.q)					
Ex-post series: March 1999					
1974:1–1995:1	0.09	0.92	–	− 0.39**	0.85
1980:1–1995:1	0.06	0.84	–	− 0.38**	0.78
Ex-post series: September 2005					
1974:1–1998:4	0.05	0.86	–	− 0.38**	0.80
1980:1–1998:4	0.03	0.77		− 0.37**	0.72
Potential output growth (q.o.q)					
Ex-post series: March 1999					
1974:1–1995:1	0.01	0.15		0.76**	0.10
1980:1–1995:1	0.05	0.13		0.80**	0.09
Ex-post series: September 2005					
1974:1–1998:4	− 0.06	0.19		0.93**	0.06
1980:1–1998:4	− 0.03	0.20		0.95**	0.05

Notes: The HP series is calculated by detrending the September 2005 vintage of GDP data with a HP-filter. To ensure comparability with the real-time series, the ex-post series is based on data for West Germany up to 1995Q1 and on all German data from 1995Q2 (adjusted for the jump). ** and * Significance at the 1% and 5% levels, respectively.

To capture the potential persistence in the MEs, we follow Orphanides et al. (2000) and assume that they follow an AR(1) process. Of course, such a first-order process represents a simplification of the true revision process in the data, but it offers a parsimonious way of capturing the size and persistence of the errors. Not surprisingly, the estimates of the persistence parameter ρ turn out to be highly significant and quite close to one for the

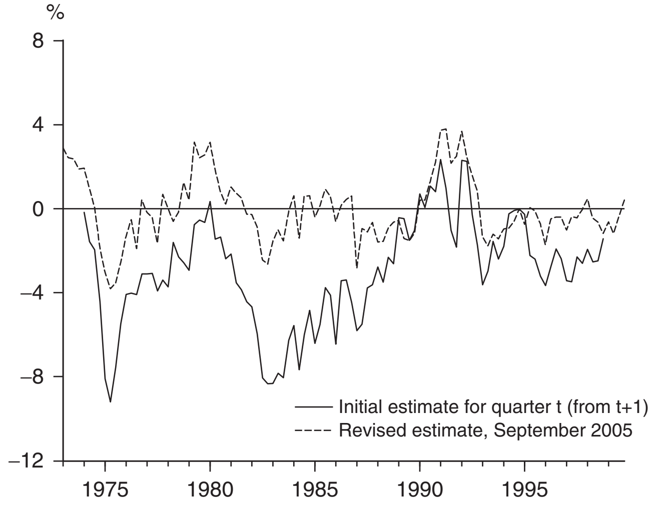

Figure 4: Measurement error in the output gap when the ex-post series is based on the September 2005 series of GDP data*

*With the revised series calculated by detrending the September 2005 vintage of GDP data with an HP-filter.

ME in the level of the output gap. By contrast, the estimates of ρ for the ME in the change in the output gap as well as for real output growth are negative. On the other hand, the MEs in potential output growth are again quite persistent, but much smaller in size (with very low standard deviations).

Although the unconditional mean of the ME in the level of the output gap amounts to 3.10 for the sample period 1974Q1–1995Q1, the intercept term is not significant. This is not inconsistent but reflects the fact that a high positive serial correlation in the errors may create the appearance of a bias in the real-time data relative to the final series, even though the underlying process is in fact unbiased.

For comparison's sake, we also report statistics on the MEs of the variables with respect to a second set of ex-post series, which is based on a much later vintage of GDP data (September 2005). Despite some differences in the distribution of the MEs over time (see Figure 4), the parameter estimates of the ME processes are very similar.

III. Model Specification

A. Aggregate Demand, Aggregate Supply and Money Demand

The model that we use is a variant of the New Keynesian model, which has been estimated by Rudebusch (2002) using quarterly US data and adapted by

Stracca (2007) for empirical analysis of the euro area. Specifically, the model contains a hybrid Phillips curve and a purely backward-looking specification of aggregate demand

$$\pi_t = \gamma\pi_{t-1} + (1-\gamma)E_{t-1}\bar{\pi}_{t+3} + ky_{t-1} + \varepsilon_t^{\pi}, \qquad (1)$$

$$y_t = \alpha_1 y_{t-1} + \alpha_2 y_{t-2} - \sigma(i_{t-1} - E_{t-1}\bar{\pi}_{t+3} - \bar{r}_{t-1}) + \varepsilon_t^{y}, \qquad (2)$$

where y is a measure of the output gap, i is the short-term nominal interest rate, π is the inflation rate, $E_{t-1}\bar{\pi}_{t+3}$ is a measure of the rate of inflation expected to prevail over the subsequent four quarters (lagged one quarter), $\bar{r}_t$ is the time-varying equilibrium real rate of interest and ε_t^{π} and ε_t^{y} are white noise (supply and demand) shocks.

The generalized Phillips curve (1) captures the New Keynesian consensus on price dynamics. In the canonical New Keynesian model derived from first principles, inflation is purely forward-looking (that is γ equals zero). This result can be derived, for instance, within a model of Calvo price setting (Calvo 1983). However, a number of reasons have been advanced for why inflation may depend on its own past values as well as on expected future inflation.[5] The purely backward-looking nature of the IS curve reflects the empirical problems associated with estimating hybrid IS curves (Stracca 2007, p. 24).

The model features transmission lags of monetary policy (from interest rates to the output gap and from the output gap to inflation) as well as an expectational lag in the Phillips curve. Rudebusch (2002, p. 405) argues that these lags are appropriate 'given real-world recognition, processing and adjustment lags'. Stracca (2007) estimates the model on euro area data from 1987Q1–2006Q2 and gets coefficient values of $\gamma = 0.20$, $k = 0.31$, $\sigma_{\pi}^2 = 0.94$, $\alpha_1 = 1.47$, $\alpha_2 = -0.53$, $\sigma = 0.17$ and $\sigma_y^2 = 0.20$. With an estimated value of 0.80 for $(1-\gamma)$, Stracca finds the Phillips curve for the euro area to be quite forward-looking, which is in line with other evidence on the low degree of intrinsic persistence in euro area inflation (see Galí et al. 2001; Smets and Wouters 2003; ECB 2005). In contrast, movements in the output gap are very persistent, implying that demand shocks have a more protracted effect on output and inflation than cost-push shocks.

Models of the type described by equations (1) and (2) are usually closed with an interest rate rule and/or a central bank objective function. However, as we want to analyse the role of money growth as a potential feedback variable in the interest rate rule, we have to add a money demand relation to the model. Following Rudebusch and Svensson (2002) and Coenen et al.

[5]For instance, following Galí and Gertler (1999), it is often assumed that a fraction of price setters adjust their prices in a backward-looking fashion (following simple rules of thumb).

(2005), we use a standard specification of the error correction type:

$$\Delta m_t^r = -\kappa_m(m_{t-1}^r - \kappa_q q_{t-1} + \kappa_i i_{t-1}) + \kappa_1 \Delta m_{t-1}^r + \kappa_{\Delta q}\Delta q_t + \varepsilon_t^m, \quad (3)$$

where $m_t^r = m_t - p_t$ is the real money stock, q_t is the *true* level of actual output and ε_t^m captures shocks to money demand. For the baseline version of the model, we use the parameter values $\kappa_m = 0.15$, $\kappa_q = 1.20$, $\kappa_i = 0.80$, $\kappa_{\Delta m} = 0.40$, $\kappa_{\Delta q} = 0.10$ and $\sigma_m^2 = 0.20$, which are in line with standard estimates for the euro area (see, inter alia, Banque de France 2003; Bruggemann et al. 2003; Carstensen 2006; Dreger and Wolters 2010).[6]

The fact that money demand depends on the level of actual output rather than on the output gap requires us to specify the relationship between these variables

$$y_t = q_t - q_t^*, \quad (4)$$

as well as the process governing potential output, q_t^*. Here, we follow Ehrmann and Smets (2003) and assume that potential output follows a highly persistent AR(1) process:[7]

$$q_t^* = \rho_q q_{t-1}^* + \varepsilon_t^q, \quad (5)$$

where ε_t^q is a white noise shock.

B. Monetary Policy Rules

As noted in the introduction, our analysis takes place within a simple rules framework and focuses on the relative performance of several variants of the basic TR, taking into account that policy makers observe only a noisy measure of the output gap. The rules are simple because they model the interest rate as a function of a limited set of specified state variables while the fully optimal rule would involve all state variables of the model. Given the constraint on the number of feedback variables, the feedback coefficients are chosen so as to minimize policy makers' expected loss (see Section III.D). A potential advantage of simple rules is that they are easier to understand, communicate

[6]These papers (and others) usually conclude that long-run money demand in the euro area is stable. The standard deviation of the money demand shock is one aspect of money demand stability on which we concentrate in the paper (see Section IV (B)). Other aspects, such as parameter stability or the stability of the money-price nexus, are beyond the scope of the paper.

[7]It may be criticized that, in reality, potential output is a highly non-stationary variable. However, in numerical simulations of the kind we are conducting here, setting the persistence parameter ρ_q equal to one would create invertibility problems. Therefore, we follow common practice and set ρ_q to a value slightly smaller than one. This should not affect the results (see Ehrmann and Smets 2003, fn. 6).

and monitor than the (complex) optimal commitment solution. Furthermore, simple rules may be more robust to model uncertainty.[8]

The first simple rule that we consider is a TR with interest rate smoothing

$$\hat{i}_t = \phi_1 \cdot \hat{i}_{t-1} + \phi_2(\pi_{t|t} - \pi_t^*) + \phi_3 \cdot y_{t|t}, \qquad \text{(TR)}$$

where $\hat{i}_t$ is the deviation of the nominal interest rate from its steady-state value and $t|t$ indicates the information on the contemporaneous value of a specific variable available at time t.[9] The second rule is a simple growth rate targeting or SPL of the kind advocated by Orphanides (2003b) and Walsh (2003), which involves a response to the change rather than to the level of the output gap

$$\hat{i}_t = \phi_1 \cdot \hat{i}_{t-1} + \phi_2(\pi_{t|t} - \pi_t^*) + \phi_4 \cdot (y_{t|t} - y_{t-1|t}). \qquad \text{(SPL)}$$

However, central banks need not be limited to a discrete choice among these two simple rules. Especially with output gap uncertainty, it may be advantageous to respond to the level as well as to the change in the output gap (see Rudebusch 2002). Hence, we also consider a 'hybrid' rule that nests both cases:

$$\hat{i}_t = \phi_1 \cdot \hat{i}_{t-1} + \phi_2(\pi_{t|t} - \pi_t^*) + \phi_3 \cdot y_{t|t} + \phi_4 \cdot (y_{t|t} - y_{t-1|t}). \qquad \text{(TRSPL)}$$

Finally, we consider a variant of the TR and a variant of the SPL with an additional response to deviations of money growth from target m^*:

$$\hat{i}_t = \phi_1 \cdot \hat{i}_{t-1} + \phi_2(\pi_{t|t} - \pi_t^*) + \phi_3 \cdot y_{t|t} + \phi_5(\Delta m_{t|t} - \Delta m_t^*), \qquad \text{(TRM)}$$

$$\begin{aligned} \hat{i}_t = {} & \phi_1 \cdot \hat{i}_{t-1} + \phi_2(\pi_{t|t} - \pi_t^*) + \phi_4(y_{t|t} - y_{t-1|t}) \\ & + \phi_5(\Delta m_{t|t} - \Delta m_t^*). \end{aligned} \qquad \text{(SPLM)}$$

Our motivation for including money among the right-hand side variables of the policy rule is twofold. First, Söderström (2005) has shown that in models with forward-looking expectations, stabilizing money growth around a target can be a sensible strategy for a central bank acting under discretion because it introduces inertia and history dependence into monetary policy. Augmenting the TR by a response to the money growth gap allows the relevance of this argument in a simple rules framework to be tested. Second, Coenen et al. (2005) have demonstrated that monetary aggregates may have substantial information content about the 'true' level of aggregate output if

[8]For further discussion, see Taylor (1999), Williams (2003) and Berg et al. (2006).

[9]The steady-state value of the nominal interest rate, i_t^*, depends on the equilibrium real interest rate, r_t^*, and the inflation target, π_t^*. Both variables are assumed to be constant and normalized to zero. Hence, our analysis abstracts from uncertainty about the equilibrium real interest rate. However, Rudebusch (2001) has shown that in this kind of analysis, uncertainty about r^* is of little importance in terms of altering the optimal rule coefficients or the expected loss.

the environment is characterized by (a) significant MEs in GDP data, (b) a strong contemporaneous link between money demand and real output and (c) a low variability of money demand shocks.

C. MEs in the Feedback Variables

Simple rules like the ones considered here typically specify the interest rate in period t as a function of the contemporaneous values of key macro variables like the rate of inflation and the level of the output gap. However, as noted in Section II, real-time data sets suggest that policy makers face substantial uncertainty about the 'true' values of these variables, especially regarding the output gap. Here, we focus on errors in the measurement of the level and the change in the output gap and ignore errors in the measurement of inflation and money growth on the grounds that the latter have been shown to be relatively minor in Germany and the euro area (see Section II).

To capture the implications of real-time output gap uncertainty, we follow Rudebusch (2001, 2002), Orphanides (2003c) and others and assume that the estimates of the output gap available to policy makers at the time the decisions are made (t) differ from the true series (y_t) by an ME $\eta_{y,t}$

$$y_{t|t} = y_t + \eta_{y,t}. \tag{6a}$$

According to this specification, the ME $\eta_{y,t}$ is correlated with the initial estimates, but uncorrelated with the final estimates, implying that the initial estimates contain an element of inefficient noise relative to the final estimates.[10] Alternatively, one could use optimal filtering to infer the true state of the economy. However, this presupposes that the central bank has the true model of the economy at its disposal (which, in practice, it does not). The 'best' (model-consistent) estimate of unobservable variables like the output gap is a complicated function of past observables and characteristics of the central bank's loss function which is at odds with the simple rules framework used here.[11] This is especially true if the information set of the private sector differs from that of the central bank (see Svensson and Woodford 2002), which is the case we consider here.[12]

[10]An alternative formulation would be $y_t = y_{t|t} + \eta_{y,t}$, implying that the forecast errors are uncorrelated with the initial estimates, but correlated with the final estimates (the revisions are 'news'). However, the correlations in the data favour a substantial noise element (results available on request).

[11]For a discussion, see Svensson and Woodford (2002, 2003), Orphanides (2003a) and Swanson (2004). For an application of the method to a model of the euro area, see Ehrmann and Smets (2003) and Coenen et al. (2005).

[12]For a justification of the assumption of asymmetric information, see Aoki (2006). In Aoki's model, the economy behaves as if it is a representative-agent economy in which the

To capture the potential persistence in the ME $\eta_{y,t}$, we follow Orphanides et al. (2000) and assume that it follows an AR(1) process:[13]

$$\eta_{y,t} = \rho_{ny}\eta_{y,t-1} + \varepsilon_t^{ny}, \tag{6b}$$

where ε_t^{ny} is the ME shock. The ME $\eta_{y,t}$ subsumes errors in assessing the contemporaneous levels of actual and potential output, $q_{t|t}$ and $q^*_{t|t}$. For the purpose of our analysis, it is not necessary to model each of the underlying error processes explicitly. However, we need to make an assumption about the ME in the change in the output gap, $\eta_{\Delta y,t}$.[14] We assume that this ME is approximately equal to the change in the ME of the level of gap, $\Delta\eta_{y,t}$:[15]

$$y_{t|t} - y_{t-1|t} = y_t - y_{t-1} + \eta_{\Delta y,t} \approx y_t - y_{t-1} + \Delta\eta_{y,t}. \tag{7a}$$

Accordingly, the variance of the ME in the change of the output gap is $2\sigma_\varepsilon^2/(1+\rho_{\eta y})$, whereas the variance of the ME in the level of the output gap is $\sigma_\varepsilon^2/(1-\rho_{\eta y}^2)$. Thus, as long as $\rho_{\eta y}>0.5$, the error variance in the change is smaller than that in the level. Parameter estimates of the ME process are obtained from our real-time data set. We take the estimates for the shorter sample period 1980–95, as baseline values which exclude the large MEs of the 1970s. In addition, we consider a high-uncertainty scenario that is based on the estimates for the full sample period (1974–95), and a low-uncertainty scenario that is characterized by the baseline degree of persistence, but a smaller variance of the shocks. As shown in Table 2, the parameter values underlying our analysis are very close to the estimates reported by Orphanides et al. (2000) for the United States.

representative agent has perfect information while the central bank has partial information, although each agent observes only a subset of the data (that is, the factors influencing her/his own consumption decisions).

[13]We do not explore the implications of a significantly positive intercept term (see Nelson and Nikolov 2001).

[14]It may be argued that the measurement error in potential output growth should be modelled explicitly since the money growth target depends on the central bank's real-time estimate of potential output growth. However, as shown in Section II, the historical measurement errors of potential output *growth* were quite small, so that modelling them would not change the results.

[15]Strictly speaking, this is only true if the measurement error in the level of the output gap is so persistent that the second estimate of the output gap, $y_{t-1|t}$, does not differ too much from the initial estimate, $y_{t-1|t-1}$, which is a feature of the historical measurement errors described in Section II.

Table 2: Alternative Estimates for the Degree of Output Gap Uncertainty

Assumed model: $\eta_t = \rho_\eta \eta_{t-1} + \varepsilon_t^\eta$	$\hat{\rho}_n$	$sd(\varepsilon_t^\eta)$ (in %)
Based on real-time data for Germany[a]		
Baseline case – output gap revisions 1980:Q1–1995:Q1	0.89	0.99
Worst case – revisions 1974:Q1–1995:Q1	0.96	1.06
Low-uncertainty case	0.89	0.60
Based on real-time data for the US[b]		
Baseline case – output gap revisions 1980:Q1–1994:Q4	0.84	0.97
Worst case – output gap revisions 1966:Q2–1994:Q4	0.96	1.09
Best case – capacity utilization revisions 1980:Q1–1994:Q4	0.80	0.51

[a]Based on real-time GDP data and Bundesbank estimates of potential output for Germany.
[b]*Source*: Orphanides et al. (2000).

D. Central Bank Preferences

Deriving the optimal feedback coefficients requires an objective function. We use a fairly standard one in which the central bank is assumed to minimize fluctuations in interest rates, the inflation rate and the output gap around the target levels (which are normalized to zero)[16]

$$L_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left[\omega_\pi (\pi_t - \pi^*)^2 + \omega_y y_t^2 + \omega_{\Delta i}(i_t - i_{t-1})^2\right], \tag{8}$$

where the parameters ω_π, ω_y and $\omega_{\Delta i}$ are the relative weights on the three elements of the loss function. If the discount factor β approaches unity from below, this loss function can be rewritten as the weighted sum of the unconditional variances of the three target variables (Rudebusch and Svensson 1999)

$$E(L_t) = \omega_\pi Var(\pi_t) + \omega_y Var(y_t) + \omega_{\Delta i} Var(\Delta i_t). \tag{8a}$$

This specification has been widely used in the literature on monetary policy rules (see e.g. Ehrmann and Smets 2003 or Coenen et al. 2005). In the initial exercise, we follow Coenen et al. (2005) and set $\omega_\pi = 1$, $\omega_y = 0.5$ and $\omega_{\Delta i} = 0.1$. This may be viewed as a reasonable representation of a policy maker whose primary objective is to stabilize inflation around a target, while also seeking to stabilize output and avoid large interest rate volatilities.[17] Alternatively, it is sometimes assumed that policy makers care about the deviation of the interest rate from its steady-state level (rather than about its

[16]The target for output is assumed to be equal to the natural rate, so that the target for the output gap is also zero.

[17]Within a welfare-optimizing framework, Calvo pricing with reasonable parameters typically suggests that the central bank should care relatively more about inflation variability.

change against the previous period).[18] Below, we will perform some sensitivity analysis regarding the robustness of our results to the details of the loss function (such as the exact specification of the interest rate variable and the weights on the elements of the loss function).

IV. Performance of the Rules

A. Results of Model Simulations with Optimized Feedback Coefficients

As a first step, we use the model described in Section III.A and summarized in Table 3 to compare the relative performance of the five interest rate rules under different degrees of output gap uncertainty (that is no uncertainty, low uncertainty, baseline uncertainty and high uncertainty). We assume that the central bank minimizes equation (8a) subject to the rule in question and the model, while taking into account that its estimate of the output gap is imperfect. Furthermore, we assume that the policy rule is perfectly credible, so agents know the rule and assume (correctly) that it will be followed.[19]

Table 4 reports the values of the optimized coefficients, the standard deviations of the variables that enter the loss function and the values of the period loss function. In order to obtain a better understanding of the role of output gap uncertainty, we first consider the hypothetical case of perfectly observable output gaps. Here, our results regarding the TR and the SPL closely resemble the ones presented by Stracca (2007) despite the fact that we use a slightly different objective function. In particular, the optimal TR is found to have a very low degree of inertia, while the optimal SPL is very persistent (in fact, it is identical to a first difference rule). Stracca argues that the different values of Φ_1 likely reflect the fact that the TR feeds back strongly from the highly persistent level of the output gap, while the SPL reacts (again strongly) to the less persistent change in the output gap. Another interesting result is that the reaction to the output variable is in any case much stronger than the response to current inflation, especially in regards the SPL. Again, this makes sense, since in an environment characterized by transmission lags and a low degree of inflation inertia, demand shocks that affect current output are much more relevant for future inflation than cost-push shocks that matter only for current inflation.

[18]See, for instance, Stracca (2007). As shown by Woodford (2003), concern about the *level* of the nominal interest rate (relative to some target value) can be motivated by the presence of non-negligible transactions frictions and/or by the desire to keep away from the zero bound on nominal interest rates.

[19]All calculations are done using DYNARE for Matlab. The optimization is based on the OSR routine.

Table 3: Overview of the Model

(1) Aggregate demand	$y_t = \alpha_1 y_{t-1} + \alpha_2 y_{t-2} - \sigma(i_{t-1} - E_{t-1}\bar{\pi}_{t+3} - \bar{r}_{t-1}) + \varepsilon_t^y$
	Benchmark values: α_1=1.47, α_2=− 0.53, $\sigma = 0.17$, $\sigma_y^2 = 0.20$
(2) Aggregate supply	$\pi_t = \gamma\pi_{t-1} + (1-\gamma)E_{t-1}\bar{\pi}_{t+3} + ky_{t-1} + \varepsilon_t^\pi$
	Benchmark values: $\gamma = 0.20$, $k = 0.31$, $\sigma_\pi^2 = 0.94$
(3) Money demand	$\Delta m_t^r = -\kappa_m(m_{t-1}^r - \kappa_q q_{t-1} + \kappa_i i_{t-1}) + \kappa_1 \Delta m_{t-1}^r + \kappa_{\Delta q}\Delta q_t + \varepsilon_t^m$
	Benchmark values: $\kappa_m = 0.15$, $\kappa_q = 1.20$, $\kappa_i = 0.80$, $\kappa_1 = 0.40$, $\kappa_{\Delta q} = 0.10$, $\sigma_m^2 = 0.20$
(4) Output gap and potential output	$y_t = q_t - q_t^*$
	$q_t^* = \rho_q q_{t-1}^* + \varepsilon_t^q$
	Benchmark values: $\rho = 0.95$, $\sigma_{q*}^2 = 0.13$
(5) Policy rules	$\hat{i}_t = \phi_1 \cdot \hat{i}_{t-1} + \phi_2(\pi_{t\mid t} - \pi_t^*) + \phi_3 \cdot y_{t\mid t}$ (TR)
	$\hat{i}_t = \phi_1 \cdot \hat{i}_{t-1} + \phi_2(\pi_{t\mid t} - \pi_t^*) + \phi_4 \cdot (y_{t\mid t} - y_{t-1\mid t})$ (SPL)
	$\hat{i}_t = \phi_1 \cdot \hat{i}_{t-1} + \phi_2(\pi_{t\mid t} - \pi_t^*) + \phi_3 \cdot y_{t\mid t} + \phi_4 \cdot (y_{t\mid t} - y_{t-1\mid t})$ (TRSPL)
	$\hat{i}_t = \phi_1 \cdot \hat{i}_{t-1} + \phi_2(\pi_{t\mid t} - \pi_t^*) + \phi_3 \cdot y_{t\mid t} + \phi_5(\Delta m_{t\mid t} - \Delta m_t^*)$ (TRM)
	$\hat{i}_t = \phi_1 \cdot \hat{i}_{t-1} + \phi_2(\pi_{t\mid t} - \pi_t^*) + \phi_4(y_{t\mid t} - y_{t-1\mid t}) + \phi_5(\Delta m_{t\mid t} - \Delta m_t^*)$ SPLM
(6) Output gap uncertainty	$\tilde{y}_t = y_t - \eta_t$
	$\Delta\tilde{y}_t = \Delta y_t - \Delta\eta_t$
	$\eta_t = \rho_\eta \eta_{t-1} + \varepsilon_t^\eta$
	Benchmark values: $\rho_\eta = 0.89$, $\sigma_\eta^2 = 0.98$

Allowing for an additional response to money growth somewhat changes the optimal coefficients of the TR, but the associated reduction in the overall loss is fairly limited. Augmenting the SPL by a response to the output gap (TRSPL) or to money growth (SPLM) has even less impact on the optimal coefficients and on the overall losses.

Allowing for ME in the output gap changes these results in several directions. First of all, output gap uncertainty attenuates the optimal response to the output gap and to the output growth gap across all policy rules. The intuition for this result is straightforward: as the reliability of an indicator is reduced, one should place less emphasis on the information it conveys. Second, the optimal reaction to inflation increases with the degree of output gap uncertainty. While this result is in line with the literature on

Table 4: Performance of Policy Rules under Different Degrees of Output Gap Uncertainty

	No uncertainty					
	TR	TRM	SPL	SPLM	TRSPL	OC
Φ_1	0.04	0.09	1.00	1.00	0.95	–
Φ_2	0.96	0.80	0.00	0.00	0.05	–
Φ_3	2.26	2.22	–	–	0.15	–
Φ_4	–	–	2.62	2.63	2.48	–
Φ_5	–	0.45	–	− 0.00	–	–
sd(π_t)	1.08	1.08	1.09	1.09	1.07	1.07
sd(y_t)	0.88	0.87	0.75	0.75	0.76	0.72
sd(Δi_t)	2.31	2.28	1.58	1.58	1.59	1.58
$E(L)$	2.08	2.06	1.71	1.71	1.70	1.65
	Low uncertainty ($\rho_\eta = 0.89$, $\sigma(\varepsilon_t^\eta) = 0.60$)					
	TR	TRM	SPL	SPLM	TRSPL	All
Φ_1	0.09	0.25	0.74	0.81	0.68	0.77
Φ_2	1.53	1.09	0.76	0.51	0.81	0.54
Φ_3	0.48	0.41	–	–	0.07	0.04
Φ_4	–	–	1.74	1.66	1.63	1.59
Φ_5	–	1.19	–	0.71	–	0.72
sd(π_t)	1.51	1.47	1.40	1.37	1.39	1.36
sd(y_t)	1.51	1.47	1.32	1.29	1.32	1.28
sd(Δi_t)	2.60	2.59	2.25	2.23	2.28	2.25
$E(L)$	4.11	3.92	3.33	3.20	3.31	3.19
	Baseline uncertainty ($\rho_\eta = 0.89$, $\sigma(\varepsilon_t^\eta) = 0.99$)					
	TR	TRM	SPL	SPLM	TRSPL	All
Φ_1	0.09	0.28	0.50	0.62	0.45	0.58
Φ_2	1.61	1.08	1.13	0.73	1.17	0.76
Φ_3	0.23	0.18	–	–	0.06	0.03
Φ_4	–	–	1.07	1.00	0.97	0.94
Φ_5	–	1.42	–	1.08	–	1.09
sd(π_t)	1.57	1.52	1.50	1.45	1.50	1.45
sd(y_t)	1.64	1.57	1.52	1.46	1.51	1.46
sd(Δi_t)	2.66	2.64	2.50	2.47	2.51	2.48
$E(L)$	4.52	4.23	4.04	3.79	4.01	3.78
	High uncertainty ($\rho_\eta = 0.96$, $\sigma(\varepsilon_t^\eta) = 1.06$)					
	TR	TRM	SPL	SPLM	TRSPL	All
Φ_1	0.09	0.30	0.40	0.54	0.39	0.54
Φ_2	1.66	1.06	1.29	0.85	1.30	0.85
Φ_3	0.07	0.06	–	–	0.01	0.00
Φ_4	–	–	0.88	0.80	0.86	0.80

Table 4: Continued

	High uncertainty ($\rho_\eta = 0.96$, $\sigma(\varepsilon_t^\eta) = 1.06$)					
	TR	TRM	SPL	SPLM	TRSPL	All
Φ_5	–	1.56	–	1.20	–	1.20
sd(π_t)	1.61	1.54	1.53	1.48	1.53	1.48
sd(y_t)	1.71	1.62	1.56	1.50	1.56	1.50
sd(Δi_t)	2.70	2.68	2.55	2.53	2.56	2.53
$E(L)$	4.78	4.40	4.21	3.94	4.21	3.94

TR, Taylor rule (with interest rate smoothing); TRM, Taylor rule with money; SPL, speed limit rule; SPLM, speed limit rule with money; TRSPL, Taylor rule with speed limit term; OC, outcome under optimal commitment policy; All, rule with all five terms. ρ_η measures the persistence in the measurement error of the output gap and ε^η is the measurement error shock.

the consequences of output gap uncertainty in an optimal targeting rules framework (see Swanson (2004), Rudebusch (2001) and Smets (2002)) find that higher output gap uncertainty moderates the reaction to the inflation rate in the optimal simple rules they consider. As pointed out by Leitemo and Lonning (2006), this apparent contradiction can be explained by the presence of two countervailing effects. On the one hand, in the case of a demand shock, a stronger policy reaction to the inflation rate can substitute for a reaction to an imprecisely measured output gap. *Ceteris paribus*, this effect will increase the optimal coefficient on inflation. On the other hand, in the presence of cost-push shocks, a stronger reaction to inflation will destabilize the output gap even further. Hence, with increasing output gap uncertainty, it will be optimal for the central bank to reduce its response to both the output gap and inflation. Apparently, in the model considered here, the first effect dominates.

A third important result is that output gap uncertainty generates a non-trivial role for money as a feedback variable. Allowing for output gap uncertainty significantly increases the optimal coefficient on money growth, Φ_5, in both the money-augmented TR and the money-augmented SPL.[20] At baseline (high) levels of uncertainty, Φ_5 reaches a value of 1.42 (1.56) in the TRM rule and of 1.08 (1.20) in the SPLM rule. More importantly, even at low degrees of uncertainty, the additional response to money growth reduces the loss by 4.6% relative to the standard TR and by 3.9% relative to the standard SPL (without money). Under baseline (worst case) assumptions about output gap uncertainty, the welfare gain increases by 6.4% (8.0%) for the TR and by 6.2% (6.4%) for the SPL. One explanation for the welfare gains compared with the standard rules is that responding to money growth allows the central bank to reduce its response to inflation in both the TRM and the

[20]The parameterization of the measurement error process is based on Table 2.

SPLM rule, thus enabling it to avoid inefficient reactions to cost-push shocks. In contrast, augmenting the SPL with a response to the output gap (TRSPL) reduces the loss relative to the standard SPL rule only marginally.

Figure 5 plots the optimized coefficients of the TR, the SPL and their money-augmented variants for different levels of persistence (left) and shock variability (right) in the ME process. It shows that the main insights to be gained from Table 4, such as the negative impact of increasing output gap uncertainty on the optimal response to the output gap (and the change in the output gap) and the corresponding rise in the coefficient on the money growth gap, are independent of whether the increased uncertainty comes in the form of higher persistence or higher shock variability. The vertical dashed lines mark the baseline assumptions about the ME process.

Figure 6 plots the rule-specific losses as a function of the degree of persistence in the ME (left) and of the variability of the ME shock (right). Again, the main insight is that, for realistic degrees of output gap uncertainty, the SPL outperforms the classic TR, especially if it is augmented with an additional response to the money growth gap.

B. Some Sensitivity Analysis

In this section, we carry out some robustness checks regarding the key results of the paper. In particular, we test whether the superior performance of the money-augmented SPL is robust to changes in the parameters of the central bank loss function and to variations in key coefficients of the underlying model.

Figure 7 shows the efficiency frontiers of the TR, the SPL and the money-augmented SPL for the baseline level of output gap uncertainty. The frontiers trace out the minimum standard deviation of the goal variables as the relative weight on the output gap, ω_y, in the period loss function is increased from 0.1 to 0.9.[21] According to Figure 7, the efficiency frontier of the money-augmented SPL is always below the frontiers of the other two rules, implying that it delivers a lower variability in both the output gap and inflation for any choice of the relative weight ω_y. Hence, the ranking of the policy rules is robust to the choice of the relative weight on output gap versus inflation stabilization.

Although the hybrid New Keynesian model has been used widely to analyse the performance of monetary policy rules, there is still considerable disagreement about the appropriate choice of values for key model parameters. Depending on the details of the specification, the estimation method and the sample period, existing estimates of these parameters differ. Hence,

[21] For this purpose, the loss function is redefined as $E(L_t) = (1-\omega_y)Var(\pi_t) + \omega_y Var(y_t) + \omega_{\Delta i} Var(\Delta i_t)$.

it is important to analyse the robustness of the results to variations in the numerical values of key coefficients. In this exercise, we assume that policy makers know the concrete underlying model and optimize the coefficients of the respective rules subject to this information (this assumption is changed in the next section). Figure 8 shows the losses associated with three policy rules, namely TR, SPL and SPLM, for different values of (a) the degree of backward-lookingness of the Phillips curve γ, (b) the degree of backward-lookingness of the IS curve, (c) the interest rate elasticity of aggregate demand σ, (d) the output-gap elasticity k, (e) the standard deviation of the cost-push shock ε^{π}, (f) the standard deviation of the IS shock ε^{y} and (g) the standard deviation of the money demand shock ε^{m}.

Overall, the ranking of the policy rules is quite robust to reasonable changes in these model coefficients. However, some of the results deserve a closer look. First, increasing the degree of backward-lookingness in the Phillips curve affects the ranking of the policy rules in so far as the losses associated with the SPLs increase more strongly than the losses associated with the standard TR. This makes sense as the benefits of a speed limit policy over a conventional TR rest on its ability to stabilize private-sector inflation expectations. In a purely backward-looking model, this channel is absent, and hence, there is no further role for inertia and history dependence. For high values of γ, the standard TR outperforms not only the simple SPL, but also its money-augmented version. Actually, in this case, the money-augmented TR (not shown) ranks first. However, as described in Section III.A, the available evidence suggests that the degree of intrinsic inflation inertia is rather low in the euro area, so that values of γ beyond 0.5 may be considered to lie outside the range of plausible values, at least as far as the euro area is concerned.

Second, it is also interesting to consider the implications of introducing a forward-looking element into the IS curve. To do so, we follow Rudebusch (2002) and Stracca (2007) and rewrite the IS curve as

$$y_t = (1-\mu_y)E_{t-1}y_{t+1} + \mu_y(\alpha_1 y_{t-1} + \alpha_2 y_{t-2}) - \sigma(i_{t-1} - E_{t-1}\bar{\pi}_{t+3} - \bar{r}_{t-1}) + \varepsilon_t^{y},$$

where μ_y is the degree of backward-lookingness in the IS curve. As shown in the second graph (first row) of Figure 8, introducing a forward-looking

Figure 5: Optimized coefficients for different forms and degrees of output gap uncertainty – Taylor rules (TR)

Note: ϕ_2, ϕ_3 and ϕ_5 denote the parameters of the TR as described in Section III.B; TRM, Taylor rule with money. ϕ_2, ϕ_4 and ϕ_5 denote the parameters of the speed limit rules (SPL) as described in Section III.B; SPLM, speed limit rule with money.

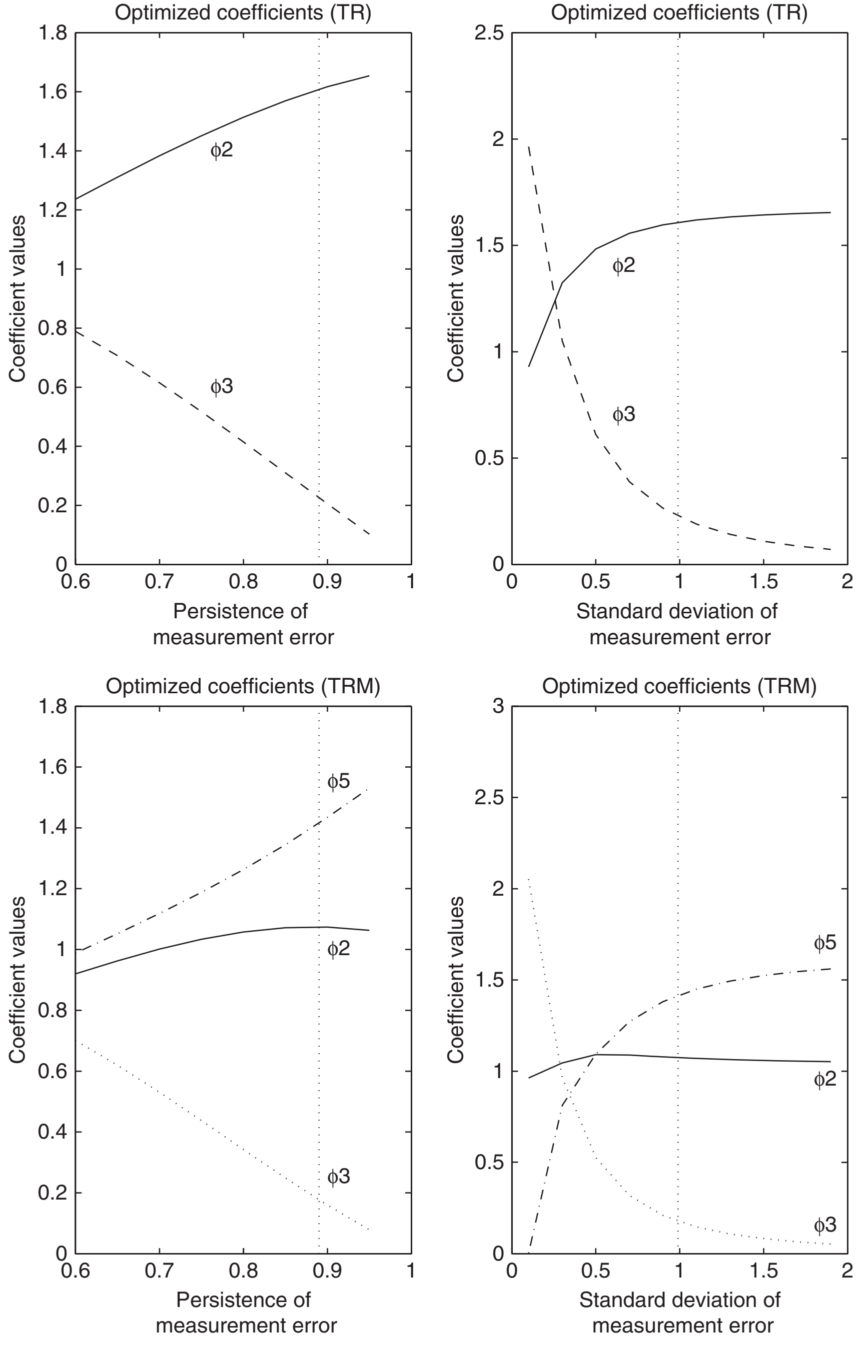

Figure 5: Continued

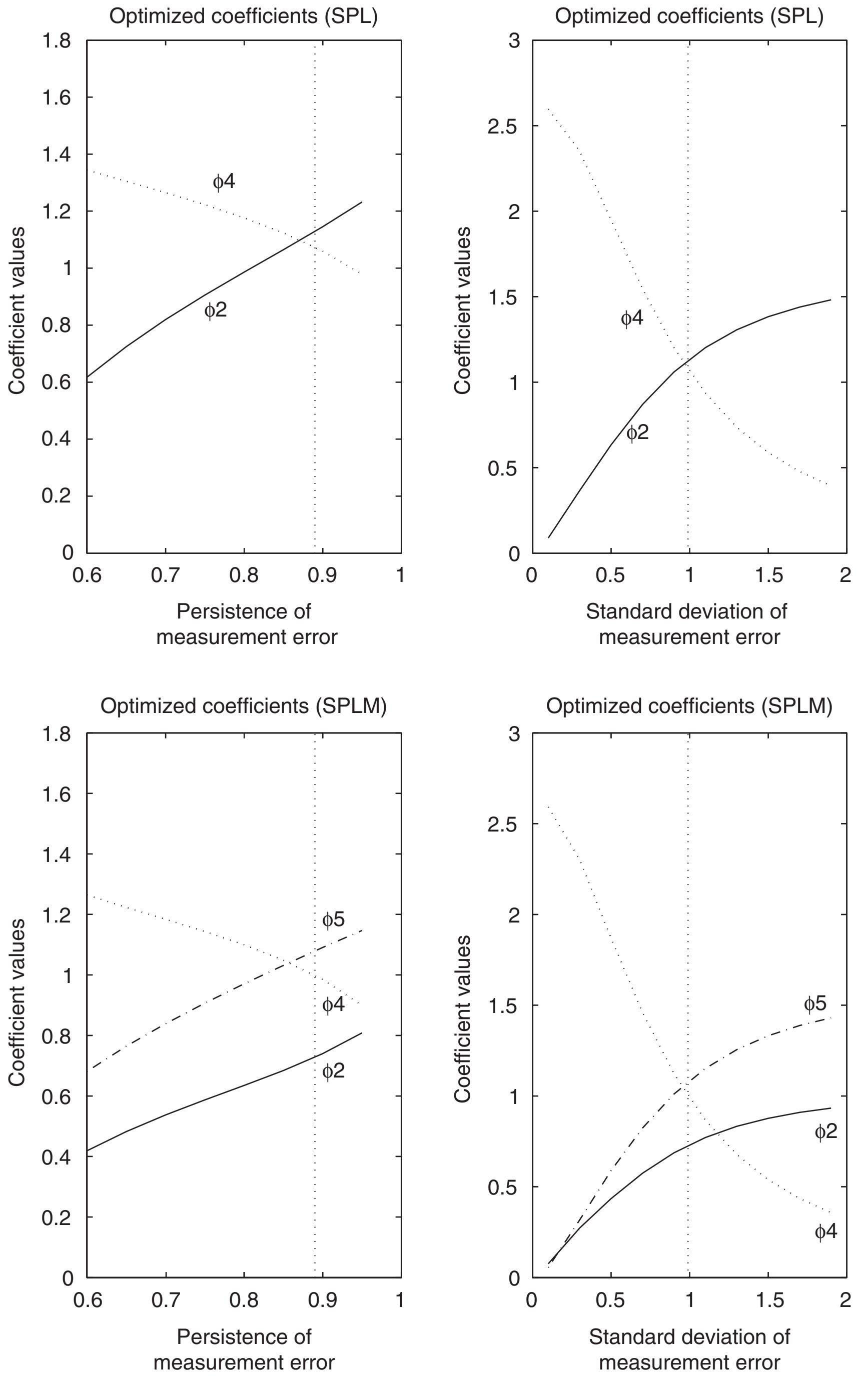

Figure 5: Continued

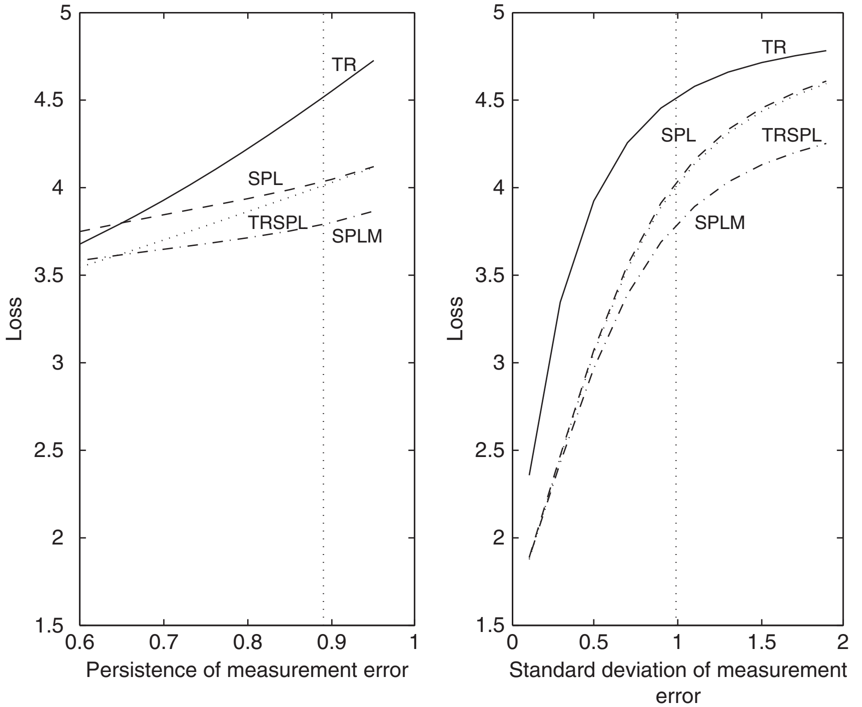

Figure 6: Comparing the central bank losses under different forms and degrees of output gap uncertainty

Note: TR, Taylor rule (with interest rate smoothing); SPL, speed limit rule; SPLM, speed limit rule with money; TRSPL, Taylor rule with speed limit term.

element into the IS curve does not change the overall ranking of the rules, but rather it decreases the expected losses as well as the differences in expected loss between the respective rules. As we have seen above, in the benchmark model with a purely backward-looking IS curve and a high degree of persistence in output movements, it is optimal for policy makers to respond strongly to demand shocks. However, if demand becomes more forward-looking, the current level of output will increasingly depend on expected future interest rates. With a positive output gap, rational agents will realize that future interest rates will increase as the present output gap contributes to future inflation, and the increase in interest rate expectations will have a contractionary effect on demand. Hence, there will be less need to react strongly to output (growth). On the other hand, it will become increasingly attractive to reinforce the interest rate expectations channel by responding to the lagged interest rate. Hence, the coefficient on the lagged interest rate in the TR will increase and the rules will become more similar.

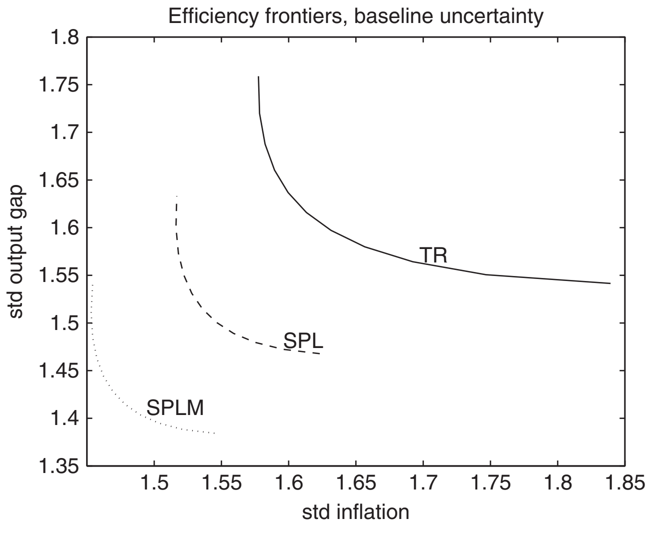

Figure 7: Efficiency frontiers

Note: TR, Taylor rule (with interest rate smoothing); SPL, speed limit rule; SPLM, speed limit rule with money; Std., standard deviation.

Third, and unsurprisingly, the performance of the money-augmented SPL relative to the other two rules depends upon the prevalence of money demand shocks. This result is in line with Coenen et al. (2005) and Dotsey and Hornstein (2003) who also analyse data uncertainty and the role of money, but use different models. As shown in the last graph of Figure 8, increasing the standard deviation of the money demand shock leads to a deterioration in the performance of SPLM relative to the simple SPL, which gradually erodes the welfare gain present at baseline parameter values. On the other hand, as pointed out in Section IV.A, increasing the degree of output gap uncertainty increases the welfare gain, which can be achieved by augmenting the standard versions of the TR and the SPL with a money growth term. Hence, in our framework, the usefulness of money as an additional feedback variable primarily depends on the degree of output gap uncertainty relative to the stability of money demand, which is captured by the variance of the money demand shock.

C. Robustness to Parameter Uncertainty

In the last section, we examined the relative performance of the rules considered under different parameterizations of the hybrid New Keynesian model. However, as pointed out by Rudebusch (2002), exercises of this type

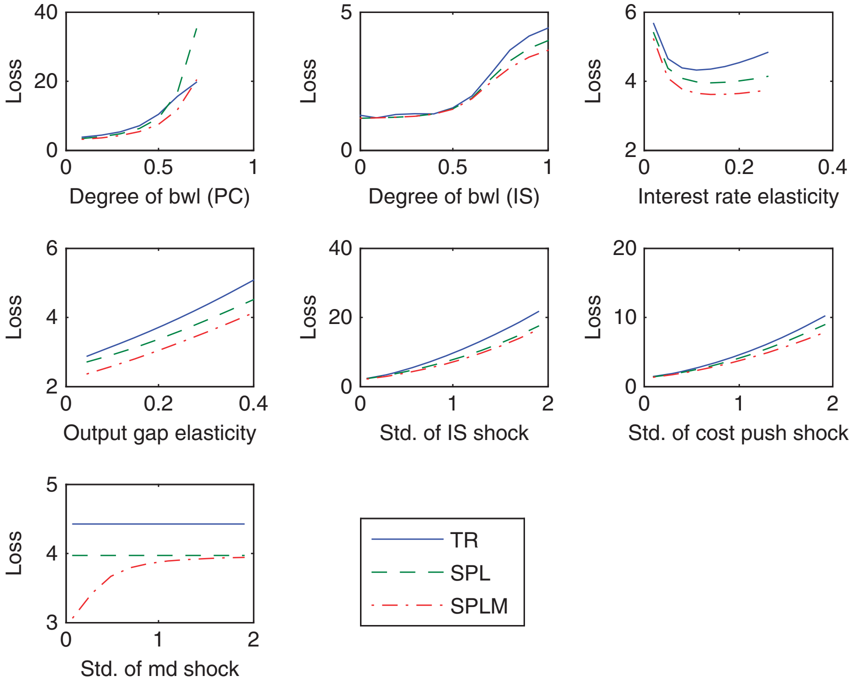

Figure 8: Comparing the central bank losses under different parameters

Note: TR, Taylor rule (with interest rate smoothing); SPL, speed limit rule; SPLM, speed limit rule with money; PC, Phillips curve; Std., standard deviation; bwl the degree of backward-lookingness and md, money demand.

do not capture all the model uncertainty faced by monetary policy makers. In practice, policy makers do not know the true values of the model coefficients and would like to have a strategy for monetary policy that will work well even if the coefficients deviate from their best (baseline) guess. During the past decade, the academic literature has developed a growing number of methods to deal with this issue, ranging from the robust control approach developed by Hansen and Sargent (2003) to approaches that allow for competing reference models (for an overview, see Brock et al. 2003). While a fully fledged application of these methods is beyond the scope of the present paper, we will try to shed some light on the issue of robustness to parameter uncertainty by looking at a few special cases.

As mentioned above, the existing literature has identified the degree of endogenous inertia in the inflation process as one of the most critical parameters affecting the evaluation of alternative policies. Hence, it is of particular interest to examine the robustness of our results to misperceptions about the degree of inflation persistence. Table 5 shows the losses that result from applying the rules optimized for three different values of γ (0.0,

Table 5: Losses for Different Assumptions about True and Perceived Degree of Backward-Lookingness of the Phillips Curve

	Perceived value of γ		
True value of γ	0.0	0.2	0.4
Taylor rule			
0.0	3.53	3.68	4.92
0.2	4.76	4.52	5.18
0.4	16.52	9.15	7.37
Speed limit rule			
0.0	3.18	3.28	3.95
0.2	4.19	4.04	4.45
0.4	11.11	7.58	6.44
Speed limit rule plus money			
0.0	3.04	3.11	3.64
0.2	3.91	3.79	4.11
0.4	8.72	6.60	5.82

Note: γ measures the degree of backward-lookingness of the Phillips curve.

0.2, 0.4) in a range of models with varying true values of γ. For example, the results in the middle column are relevant for the policy maker who perceives 0.2 to be the most likely value of γ and optimizes the policy rule for that situation. However, the policy maker must consider the performance of the rule if the actual value is not equal to 0.2. As becomes apparent when comparing the losses of the three rules optimized for different perceived and true values of γ, the money-augmented SPL dominates the other two rules in all possible cases. Therefore, we can conclude that the ranking of the rules under the baseline model parameterization is robust to misperceptions about the degree of inflation inertia within an empirically plausible range of uncertainty about this parameter.

Taking a closer look at the losses under the money-augmented SPL, we find that the rule is quite robust to overestimation of the degree of inflation inertia: if the perceived γ is greater than the true one, losses go up (compared with the case when policy makers correctly estimate γ), but the increase is fairly limited. Underestimating the degree of inflation inertia results in somewhat higher losses, especially if the true degree of inflation inertia lies at the upper end of the range. Hence, a risk-averse policy maker may prefer to adopt the rule that has been optimized for $\gamma = 0.4$. In this respect, our results are in line with those of Walsh (2004) who finds that overestimating inflation persistence results in a more robust rule than in the case of underestimation.

Another important aspect is whether the optimized rules are robust to misperceptions about the true level of output gap uncertainty. Table 6 shows

Table 6: Losses for Different Assumptions about Output Gap Uncertainty

	Perceived degree of uncertainty			
True uncertainty	No	Low	Baseline	High
Taylor rule				
No	2.08	3.62	4.21	4.66
Low	12.12	4.11	4.32	4.68
Baseline	29.39	4.96	4.52	4.70
High	451.25	9.49	5.40	4.78
Speed limit rule				
No	1.71	2.60	3.42	3.69
Low	12.94	3.33	3.64	3.84
Baseline	32.28	4.59	4.04	4.08
High	276.57	5.57	4.27	4.21
Speed limit rule plus money				
No	1.71	2.57	3.28	3.53
Low	13.05	3.20	3.47	3.64
Baseline	32.57	4.29	3.79	3.83
High	279.52	5.19	4.00	3.94

the losses under different assumptions regarding the true and perceived parameters of the ME process. Consider first the case where the rules have been optimized for baseline model coefficients and baseline uncertainty. Again, we find that the money-augmented SPL dominates the other two rules when all possible degrees of output gap uncertainty are considered. The same is true when the policy rules are optimized for a low or a high degree of uncertainty. However, when policy makers use the optimized no-uncertainty rules, the results are somewhat different. In that case, the TR dominates the SPLs when the true degree of output gap uncertainty is low or baseline. On the other hand, if the true degree of output gap uncertainty is high, the naïve use of the optimized no-uncertainty TR results in a much higher loss than either variant of the SPL.

The fact that strongly underestimating the true degree of output gap uncertainty leads to substantial losses, especially in cases where policy makers do not account for uncertainty, suggests that it may be better to overestimate the level of output gap uncertainty rather than underestimate it. In fact, a policy maker who follows a strategy of minimizing the worst-case loss will always choose the money-augmented SPL, with the coefficients optimized under the assumption of worst-case output gap uncertainty. Overall, these results are in line with those of Orphanides and Williams (2002) who find that the costs of underestimating the degree of uncertainty are much larger than the costs of overestimating it. Thus, a risk-avoidance strategy would call for overemphasizing the problem of data uncertainty and MEs.

V. Conclusions and Future Research

In the present paper, we have extended the analysis of simple monetary policy rules to the case where policy makers face measurement problems with respect to both actual and potential output. To sum up, we have found that an SPL that includes an additional response to money growth outperforms both the standard SPL and more conventional TRs (with and without money) once we account for a realistic degree of output gap uncertainty. The main reasons for the welfare gain are that money growth contains information on current output growth and that money stock data in the euro area are subject to only negligible MEs.

One reason we consider these results to be interesting is that they differ from those of Rudebusch (2002), who concludes that augmenting the TR with a response to output growth does little to improve its performance for the postwar US economy even with plausible data MEs. Moreover, they also differ from the findings of Lippi and Neri (2007), who conclude that money has fairly limited information content as an indicator of contemporaneous aggregate demand in the euro area. However, these authors substitute the output gap with real unit labour costs and disregard persistence in MEs as well as the fact that revisions to money growth figures are negligible in the euro area. Obviously, all of these results are conditional on the structure of the models used, and it is certainly necessary to check their robustness in richer models of the monetary transmission mechanism. One obvious limitation is that money has no causal role in influencing output or inflation in the simple New Keynesian model underlying our analysis; it is simply one potential indicator of current economic activity (and thus of incipient inflationary pressure). In this sense, our results provide a lower boundary for the usefulness of money in simple monetary policy rules. Obviously, it would be interesting to repeat the analysis in a model that captures the empirically well-established role of money as a leading indicator of trend inflation. This is an important task for future research.

We did not analyse the potential role of other variables in the monetary policy reaction function besides money, as this would go beyond the scope of the paper. Asset prices (e.g. stock prices, long-term interest rates) in particular have been discussed extensively in the literature with renewed interest since the onset of the financial market turmoil in 2007. However, as Bernanke and Woodford (1997) have shown, because asset prices are mainly driven by expectations, central bank targeting of asset prices may have some undesirable properties such as indeterminacy, self-fulfilling prophecies and arbitrary volatility in inflation. In that sense, a central bank should be careful not to tie monetary policy too closely to any variable that is too sensitive to expectations of the public. An investigation of these questions is again left to future research.

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References

Amato, J., and N. Swanson (2001), 'The Real-Time Predictive Content of Money for Output', *Journal of Monetary Economics*, 48, 3–24.

Aoki, K. (2006), 'Price-Level Determination Under Dispersed Information and Monetary Policy', *The Japanese Economic Review*, 57, 406–25.

Banque de France (2003), 'Estimation of a Money Demand Function for the Euro Area: A Summary of the Results', Bulletin Digest No. 113, May, 23–48.

Beck, G., and V. Wieland (2007), 'Money in Monetary Policy Design: A Formal Characterization of ECB-Style Cross-Checking', *Journal of the European Economic Association*, 5, 524–33.

Beck, G., and V. Wieland (2008), 'Central Bank Misperceptions and the Role of Money in Interest-Rate Rules', *Journal of Monetary Economics*, 55, 1–17.

Berg, C., P. Jansson and A. Vredin (2006), 'How Useful are Simple Rules for Monetary Policy? The Swedish Experience', Riksbank Research Paper Series No. 12, August.

Bernanke, B. S., and M. Woodford (1997), 'Inflation Forecasts and Monetary Policy', *Journal of Money, Credit and Banking*, 29, 653–84.

Brock, W., S. Durlauf and K. West (2003), 'Policy Evaluation in Uncertain Economic Environments', *Brookings Papers on Economic Activity*, 1, 235–301.

Bruggemann, A., P. Donati and A. Warne (2003), 'Is the Demand for Euro Area M3 Stable?', in European Central Bank (ed.), *Background Studies for the ECB's Evaluation of its Monetary Policy Strategy*. Frankfurt/Main, 245–300.

Calvo, G. (1983), 'Staggered Prices in a Utility Maximizing Framework', *Journal of Monetary Economics*, 12, 383–98.

Carstensen, K. (2006), 'Stock Market Downswing and the Stability of European Monetary Union Money Demand', *Journal of Business and Economic Statistics*, 24, 395–402.

Coenen, G., A. Levin and V. Wieland (2005), 'Data Uncertainty and the Role of Money as an Information Variable for Monetary Policy', *European Economic Review*, 49, 975–1006.

Dotsey, M., and A. Hornstein (2003), 'Should Optimal Discretionary Monetary Policy Look at Money', *Journal of Monetary Economics*, 50, 547–79.

Dreger, C., and J. Wolters (2010), 'Investigating M3 Money Demand in the Euro Area', *Journal of International Money and Finance*, 29, 111–22.

Ehrmann, M., and F. Smets (2003), 'Uncertain Potential Output, Implications for Monetary Policy', *Journal of Economic Dynamics and Control*, 27, 1611–38.

European Central Bank (2005), 'Price-Setting Behaviour in the Euro Area', Monthly Bulletin, November, 63–74.

Galí, J., and M. Gertler (1999), 'Inflation Dynamics, A Structural Econometric Analysis', *Journal of Monetary Economics*, 44, 195–222.

Galí, J., M. Gertler and D. Lopez-Salido (2001), 'European Inflation Dynamics', *European Economic Review*, 45(7), 1121–50.

Gerberding, C., F. Seitz and A. Worms (2004), 'How the Bundesbank Really Conducted Monetary Policy, An Analysis Based on Real-Time Data', Deutsche Bundesbank Discussion Paper Series 1, No 25/2004.

Gerberding, C., F. Seitz and A. Worms (2005b), 'How the Bundesbank Really Conducted Monetary Policy', *North American Journal of Economics and Finance*, 16, 277–92.

Gerdesmeier, D., and B. Roffia (2004), 'Taylor Rules for the Euro Area: The Issue of Real-Time Data', Deutsche Bundesbank Discussion Paper 37/2004.

Hansen, L., and T. Sargent (2003), 'Robust Control of Forward-Looking Models', *Journal of Monetary Economics*, 50, 581–604.

Kamada, K. (2004), 'Real-Time Estimation of the Output Gap in Japan and its Usefulness for Inflation Forecasting and Policymaking', Deutsche Bundesbank Discussion Paper Series 1, No 14/2004.

Leitemo, K., and I. Lonning (2006), 'Simple Monetary Policymaking Without the Output Gap', *Journal of Money, Credit and Banking*, 38, 1619–40.

Lippi, F., and S. Neri (2007), 'Information Variables for Monetary Policy in an Estimated Structural Model for the Euro Area', *Journal of Monetary Economics*, 54, 1256–70.

Nelson, E. (2008), 'Why Money Growth Determines Inflation in the Long Run: Answering the Woodford Critique', *Journal of Money, Credit and Banking*, 40, 1791–814.

Nelson, E., and K. Nikolov (2001), 'A Real-Time Output Gap Series for the United Kingdom, 1965–2000, Construction, Analysis and Implications for Inflation', CEPR Discussion Paper No. 2999.

Orphanides, A. (2001), 'Monetary Policy Rules Based on Real-Time Data', *American Economic Review*, 91, 964–85.

Orphanides, A. (2003a), 'The Quest for Prosperity Without Inflation', *Journal of Monetary Economics*, 50, 633–63.

Orphanides, A. (2003b), 'Historical Monetary Policy Analysis and the Taylor Rule', *Journal of Monetary Economics*, 50, 983–1022.

Orphanides, A. (2003c), 'Monetary Policy Evaluation with Noisy Information', *Journal of Monetary Economics*, 50, 605–31.

Orphanides, A., R. Porter, D. Reifschneider, R. Tetlow and F. Finan (2000), 'Errors in the Measurement of the Output Gap and the Design of Monetary Policy', *Journal of Economics and Business*, 52, 117–41.

Orphanides, A., and J. Williams (2002), 'Robust Monetary Policy Rules with Unknown Natural Rates', *Brookings Papers on Economic Activity*, 2, 63–118.

Rudebusch, G. (2001), 'Is the Fed Too Timid? Monetary Policy in an Uncertain World', *Review of Economics and Statistics*, 83, 203–7.

Rudebusch, G. (2002), 'Assessing Nominal Income Rules for Monetary Policy with Model and Data Uncertainty', *Economic Journal*, 112, 402–32.

Rudebusch, G., and L. Svensson (1999), 'Policy Rules for Inflation Targeting', in J. Taylor (ed.), *Monetary Policy Rules*, Chicago: The University of Chicago Press, Chicago, 203–46.

Rudebusch, G., and L. Svensson (2002), 'Eurosystem Monetary Targeting, Lessons from U.S. Data', *European Economic Review*, 46, 417–42.

Smets, F. (2002), 'Output Gap Uncertainty, Does It Matter for the Taylor Rule?', *Empirical Economics*, 27, 113–39.

Smets, F., and R. Wouters (2003), 'An Estimated Stochastic Dynamic General Equilibrium Model of the Euro Area', *Journal of the European Economic Association*, 1, 1123–75.

Söderström, U. (2005), 'Targeting Inflation with a Role for Money', *Economica*, 72, 577–96.

Stracca, L. (2007), 'A Speed Limit Monetary Policy Rule for the Euro Area', *International Finance*, 10(1), 21–41.

Svensson, L., and M. Woodford (2002), 'Indicator Variables for Optimal Policy Under Asymmetric Information', *Journal of Economic Dynamics and Control*, 28, 661–90.

Svensson, L., and M. Woodford (2003), 'Indicator Variables for Optimal Policy', *Journal of Monetary Economics*, 50, 691–720.

Swanson, E. (2004), 'On Signal Extraction and Non-Certainty-Equivalence in Optimal Monetary Policy Rules', *Macroeconomic Dynamics*, 8, 27–50.

Taylor, J. (ed.) (1999), *Monetary Policy Rules*. Chicago: The University of Chicago Press.

Walsh, C. (2003), 'Speed Limit Policies: The Output Gap and Optimal Monetary Policy', *American Economic Review*, 93, 265–278.

Walsh, C. (2004), 'Implications of a Changing Economic Structure for the Strategy of Monetary Policy', in *Monetary Policy and Uncertainty*, Jackson Hole Symposium 2003, Federal Reserve Bank of Kansas City, 297–348.

Williams, J. (2003), 'Simple Rules for Monetary Policy', Federal Reserve Bank of San Francisco Economic Review 2003.

Woodford, M. (2003), *Interest and Prices: Foundations of a Theory of Monetary Policy*. Princeton: Princeton University Press.

Woodford, M. (2008), 'How Important is Money in the Conduct of Monetary Policy?', *Journal of Money, Credit and Banking*, 40, 1561–98.