Simple interest rate rules with a role for money

Michael Scharnagl
(Deutsche Bundesbank)

Christina Gerberding
(Deutsche Bundesbank)

Franz Seitz
(University of Applied Sciences Amberg-Weiden)

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Deutsche Bundesbank, Wilhelm-Epstein-Strasse 14, 60431 Frankfurt am Main,
Postfach 10 06 02, 60006 Frankfurt am Main

Tel +49 69 9566-1
Telex within Germany 41227, telex from abroad 414431

Please address all orders in writing to: Deutsche Bundesbank,
Press and Public Relations Division, at the above address or via fax +49 69 9566-3077

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Abstract:

The paper analyses the performance of simple interest rate rules which feature a response to noisy observations of inflation, output and money growth. The analysis is based on a small empirical model of the hybrid New Keynesian type which has been estimated on euro area data by Stracca (2007). To assess the magnitude of the measurement problems regarding the feedback variables, we draw upon the real-time data set for Germany compiled by Gerberding et al. (2004). We find that interest rate rules which include a response to money growth outperform both Taylor-type rules and speed limit policies once real-time output gap uncertainty is accounted for. One reason is that targeting money growth introduces history dependence into the policy rule which is desirable when private agents are forward-looking. The second reason is that money growth contains information on the "true" growth rate of output which can only be measured imperfectly.

Keywords: Monetary policy rules, euro area, data uncertainty

JEL-Classification: E43, E52, E58

Non-technical summary

In the predominant New Keynesian models, money is irrelevant for the determination of real output, inflation and the interest rate. One consequence of this is that money growth is assigned only a minor role in formulating the optimal monetary policy strategy. This dictum is, however, questioned by some authors in view of data and model uncertainty and the properties of robust optimal monetary policy rules. These doubts form the starting point of the current paper which investigates the role of money in simple interest rate rules given uncertainty regarding the level of and change in the output gap. The paper focuses on the issue of whether adding a money growth term (in addition to inflation and the output gap) yields any extra benefits. To this end, the relative performance of various interest rate rules is analysed in a small empirical model of the euro area economy.

Section 2 begins by taking a closer look at the problems associated with determining the output gap. We use data from the Bundesbank's real-time database to assess the likely extent of measurement error in real-time data on actual and potential output. The analysis of these data confirms evidence available for other countries, which shows that measurement errors in the level of the output gap are likely to be considerable and persistent. As a result of this persistence, the measurement problem regarding the change in the output gap is less severe. The statistical properties of the historical measurement errors are used to calibrate the extent of data uncertainty assumed in the model.

The simulations are based on a version of the standard New Keynesian model estimated on euro area data. The Phillips curve allows for backward-looking and forward-looking price setting. Aggregate demand (the IS curve) is, by contrast, specified as purely backward-looking for empirical reasons. In order to be able to investigate the role of money the model must be supplemented by a money demand equation. Money demand depends on the nominal interest rate and current output (as a proxy for the transaction volume). Five different variants of monetary policy rules are considered: an interest rate rule, whereby the central bank reacts to deviations in inflation from the target rate as well as to deviations in current output level from its potential (Taylor rule or TR); a variant whereby the central bank reacts to the change in the output gap rather than to the level of the output gap (speed limit rule or SPL); a combination of both of these rules (TR + SPL); and two variants of the Taylor rule and the speed limit rule which include an additional response to money growth (TRM, SPLM). The optimal feedback coefficients are derived using an objective function in which the central bank is assumed to

minimise the deviations of inflation and output from their respective target values and to avoid interest rate fluctuations.

In section 4 the feedback coefficients and the stabilisation properties of the various rules are compared under different assumptions about the extent of output gap uncertainty. In a situation of perfectly observable output gaps, the optimal Taylor rule shows a very low degree of inertia, whereas the optimal SPL is extremely persistent. The reaction to the level of or change in the output gap is stronger than the reaction to current inflation. Allowing for an additional response to money growth changes the results very little. If, by contrast, uncertainty regarding the "true" level of the output gap is permitted, this leads to important changes in the results. First, the optimal response to the (uncertain) output gap or the change in the output gap decreases as expected. Second, the optimal reaction to inflation increases with the degree of output gap uncertainty. Third, money now plays a more important role, which is reflected in a marked rise in the feedback coefficient of the money growth term. The speed limit rule augmented by money growth (SPLM) now yields the lowest losses. This result is robust to the weighting of central bank's objectives, variations of model parameters (degree of backward-lookingness in the Phillips curve and in the IS curve, interest rate elasticity of aggregate demand, standard deviations of cost-push shocks, IS-shocks and money demand shocks) and parameter uncertainty. Overall, our results suggest that a monetary orientation, as is pursued *inter alia* by the Eurosystem, is quite appropriate.

Nicht-technische Zusammenfassung

In den vorherrschenden neukeynesianischen Modellen ist die Geldmenge für die Bestimmung des Produktionsniveaus, der Inflationsrate und des Zinssatzes irrelevant. Dies hat zur Folge, dass die Geldmengenentwicklung auch für die Ausgestaltung der optimalen geldpolitischen Strategie nur von untergeordneter Bedeutung ist. Vor dem Hintergrund von Daten- und Modellunsicherheit und den Eigenschaften robuster optimaler geldpolitischer Regeln wird dieses Diktum allerdings von einigen Autoren angezweifelt. Diese Zweifel sind auch der Ausgangpunkt des vorliegenden Papiers, das die Rolle der Geldmenge in einfachen zinspolitischen Reaktionsfunktionen bei Unsicherheit über Niveau und Veränderung der Outputlücke untersucht. Im Mittelpunkt steht dabei die Frage, unter welchen Bedingungen die zusätzliche Berücksichtigung der Geldmenge (neben der Preisentwicklung und der Outputlücke) Vorteile bringt. Zu diesem Zweck werden die makroökonomischen Eigenschaften verschiedener Zinsregeln im Rahmen eines kleinen empirischen Modells für den Euro-Raum verglichen.

In Kapitel 2 werden zunächst die Probleme bei der zeitnahen Bestimmung der Outputlücke einer näheren Betrachtung unterzogen. Dabei wird auf Daten aus der Echtzeitdatenbank der Bundesbank zurückgegriffen, die für den Zeitraum von 1974 bis 1998 sowohl Echtzeitdaten für das deutsche Bruttoinlandsprodukt als auch Echtzeitschätzungen des Produktionspotenzials enthält. Die Analyse dieser Daten bestätigt die auch für andere Länder vorliegende Evidenz, wonach die Messfehler im Niveau der Outputlücke im Beobachtungszeitraum beträchtlich und persistent waren. Durch diese Persistenz ist das Messproblem bei Veränderungen der Outputlücke nur noch in abgeschwächter Form vorhanden. In der folgenden Modellanalyse werden die statistischen Eigenschaften der historischen Messfehler zur Kalibrierung des im Modell unterstellten Ausmaßes an Datenunsicherheit herangezogen.

In Kapitel 3 wird das verwendete Modell näher beschrieben. Dabei handelt es sich um eine auf den Euroraum zugeschnittete Version des neukeynesianischen Standardmodells mit folgenden Eigenschaften: In der Phillipskurve wird sowohl ein vorausschauendes als auch ein vergangenheitsorientiertes Preissetzungsverhalten zugelassen. Die aggregierte Nachfrage (die IS-Kurve) wird dagegen aus empirischen Gründen rein vergangenheitsorientiert spezifiziert. Um die Rolle der Geldmenge untersuchen zu können, muss das Modell um eine Geldnachfragegleichung ergänzt werden. Die Geldnachfrage hängt dabei vom Nominalzins und dem aktuellen (tatsächlichen – im Unterschied zum gemessenen) Output (stellvertretend für das Transaktionsvolumen) ab. Es werden fünf verschiedene Varianten geldpolitischer Regeln betrachtet: Eine Zinsregel, bei der die Zentralbank auf Abweichungen der Inflation vom Zielwert sowie auf Abweichungen des aktuellen Produktionsniveaus vom Produktionspotential reagiert (eine sog. Taylor-Regel, TR), eine Variante, bei der Zentralbank nicht auf das Niveau der Produktionslücke, sondern auf deren Veränderung im Zeitablauf reagiert (eine sog. "speed limit rule", SPL), eine Kombination dieser beiden Regeln (TR+SPL) sowie zwei Varianten der Taylor-Regel und der Speed-Limit-Regel, die eine zusätzliche Reaktion auf Abweichungen des Geldmengenwachstums vom Geldmengenziel vorsehen (TRM, SPLM). Die optimale Höhe der jeweiligen Reaktionskoeffizienten wird mit Hilfe einer Zielfunktion der Zentralbank bestimmt, wobei unterstellt wird, dass die Inflationsrate in Höhe ihres Zielwerts und der Output auf Potenzialniveau stabilisiert sowie starke Zinsschwankungen vermieden werden sollen.

In Kapitel 4 werden die Reaktionskoeffizienten und die Stabilisierungseigenschaften der verschiedenen Regeln bei unterschiedlichen Annahmen über das Ausmaß der Outputgap-Unsicherheit verglichen. Herrscht vollkommene Sicherheit, so weist die optimale Taylor-Regel eine sehr geringe Persistenz von Zinsänderungen auf, während die optimale SPL äußerst persistent ist. Bei beiden Regeln ist die zinspolitische Reaktion auf das Niveau bzw. die Veränderung der Outputlücke zudem stärker als die Reaktion auf die Inflationslücke. Eine zusätzliche Reaktion auf Geldmengenentwicklungen ändert die Ergebnisse kaum. Lässt man dagegen Unsicherheit über das „wahre" Niveau der Outputlücke zu, so hat dies erheblichen Einfluss auf die Ergebnisse. Zum einen sinkt wie zu erwarten die Stärke der Reaktion auf die (unsichere) Outputlücke bzw. deren Veränderung. Zweitens erhöht sich die optimale Reaktion auf die Inflation mit dem Ausmaß des Messfehlers im Outputgap. Drittens kommt der Geldmenge jetzt eine bedeutendere Rolle zu, was sich in einem deutlichen Anstieg des Reaktionskoeffizienten niederschlägt. Am besten schneidet insgesamt die um Geldmengenentwicklungen ergänzte Speed-Limit-Regel (SPLM) ab. Dieses Ergebnis ist robust hinsichtlich der Gewichtung der Ziele der Zentralbank, Variationen der Modellparameter (vergangenheitsorientierte Elemente der Preisbestimmung und der IS-Kurve, Zinselastizität der aggregierten Nachfrage, Schwankungen der Angebots-, IS- und Geldnachfrage-Schocks) und Parameterunsicherheit. Demnach erscheint eine monetäre Orientierung, wie sie z. B. vom Eurosystem verfolgt wird, durchaus sinnvoll.

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Simple Interest Rate Rules with a Role for Money[*]

1. Introduction

In recent years, monetary targeting has received little support in the mainstream academic literature on optimal monetary policy. A prominent example is the paper by Rudebusch and Svensson (2002) which compares the relative performance of monetary targeting and inflation targeting in a small empirical model estimated on US data and concludes that monetary targeting is quite inefficient, yielding both higher inflation and output variability. More recently, when reviewing the case for assigning an important role to money in the conduct of monetary policy, Woodford (2006) has concluded that there is little to justify the Eurosystem's practice of paying continued attention to monetary aggregates.

One important reason for this largely negative verdict is the fact that in the canonical New Keynesian model which underlies much of the more recent literature on optimal monetary policy, money is irrelevant for the determination of real output, inflation and the interest rate. This property of the model has led the academic literature to focus on direct links between interest rate setting and objectives such as desired paths for inflation and real activity. Still, a number of authors have developed arguments for assigning a role to money even within the setup of the standard New Keynesian model. For instance, Söderström (2005) has shown that stabilising 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. Coenen et al. (2005) have demonstrated that monetary aggregates may have information content about the "true" level of aggregate output if the environment is characterised by (a) measurement errors in GDP data, (b) a contemporaneous linkage between money demand and real output and (c) a sufficiently low variability of money demand shocks. Beck and Wieland (2007) have shown that ECB-style monetary cross-checking can generate

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[*] Corresponding author: Michael Scharnagl, Deutsche Bundesbank, e-mail: michael.scharnagl@bundesbank.de. Christina Gerberding, Deutsche Bundesbank. Franz Seitz, University of Applied Sciences Amberg-Weiden. The views expressed in this paper are those of the authors and should not be interpreted as those of the Deutsche Bundesbank. We thank Heinz Herrmann, Petra Gerlach-Kirsten and participants of workshops at the Bundesbank, the Oesterreichische Nationalbank and the Schweizer Nationalbank for helpful comments.

substantial stabilisation benefits in the event of persistent policy misperceptions regarding potential output.

The present paper contributes to this literature by exploring the potential role of money in simple interest rate rules when policymakers face measurement problems with respect to both the level and the change in the output gap. Orphanides (2001, 2003a) was the first to point out that the good performance of the popular Taylor rule across a wide array of macroeconomic models (see Taylor, 1999) crucially depends upon the assumption that policymakers have reasonably accurate information about the "true" level of the output gap. In practice, however, this variable is unobservable and its estimation is complicated by controversies surrounding the appropriate definition and estimation method. Moreover, estimates of the output gap suffer from real-time data problems and have been shown to undergo major revisions over time. In order to avoid the policy errors which may result from reliance upon inaccurate estimates of this variable, Orphanides (2003b, c) has recommended the use of first difference rules which prescribe a change in the interest rate when inflation and/or output growth deviate from target. He has also pointed out that with a standard money demand relationship, money growth targeting can be reformulated as an interest rate rule of this type (Orphanides, 2003b, p. 990). Gerberding et al. (2007) have shown that this type of rule characterises the Bundesbank's monetary policy from 1979 to 1998 quite well.[1]

In the present paper, we take up this issue and look at it from a slightly different perspective. In particular, we ask whether adding a money growth term to an interest rate rule that already includes a response to both inflation and the output gap yields any extra benefits. On the one hand, augmenting a standard Taylor rule with a money growth target may be advantageous because it introduces inertia and history-dependence into the policy rule. On the other hand, this can also be achieved by including the lagged interest rate and output growth directly among the feedback variables (as in Stracca, 2007). However, even in this case, an additional response to money growth may be beneficial because money growth may have information content about the "true" rate of output growth which can only be measured imperfectly.

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[1] This result is robust to the use of real-time or ex post data.

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 Taylor rule and the speed limit rule which feature an additional response to money growth. We then go on to calculate the optimal feedback coefficients and to compare the performance of the optimised simple rules in a small estimated model of the euro-area economy. The model that we use is a version of the canonical New Keynesian model which has been proposed by Rudebusch (2002) and estimated on euro-area data by Stracca (2007). To capture the implications of output gap uncertainty, we assume that policymakers observe only noisy measures of the output gap and of the change in the output gap. Moreover, we assume that the observed uncertain variables enter the policy rule directly. In this respect, we follow the approach taken by Orphanides (2003c), Rudebusch (2001, 2002), or more recently, by Leitemo and Lonning (2006) as well as Beck and Wieland (2007). Alternatively, one could use the Kalman filter to derive optimal estimates of the variables in question. However, the optimal Kalman-filter estimates are complicated functions of past values of the observable variables and of the model parameters, which is at odds with the simple rules framework underlying our analysis.[2]

In order to assess the magnitude and the exact nature of the measurement errors, we draw on the Bundesbank's real-time data set for Germany which includes real-time data on actual output as well as on the Bundesbank's estimates of potential output (see Gerberding et al., 2004). The lessons to be learnt from the historical measurement errors in these data are described in Section 2 of the paper. In Section 3, we describe the aggregate demand, aggregate supply and money demand equations of the model, the set of policy rules that we consider and the details of the central bank objective function which we need to pin down the optimal values of the feedback coefficients. In Section 4.1, 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 growth significantly improves the performance of both the Taylor rule and the speed limit rule. In Section 4.2 and 4.3, we carry out a robustness analysis. Section 5 concludes.

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

2. 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 which are unobservable and can only be estimated with large margins of error. The problem is therefore especially acute for variables which are formulated in deviations from their equilibrium or "natural rate" levels. A well-known example are the measurement problems regarding the output gap, a variable which 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 which changes the assessment of past developments and (c) changes in the method used for estimating potential output. The problem is by no means new. However, in order to assess its implications for monetary policy, one needs to form a judgement on the magnitude and the exact nature of the measurement errors. Real-time data sets containing subsequent historical vintages of key macro variables constitute a valuable source for this kind of information.[3]

In this paper, we draw on real-time data sets for German GDP and for the Bundesbank's estimates of potential output described in Gerberding et al. (2004) to assess the likely extent of real-time uncertainty about the *level* of the output gap, the *change* in the output gap and its components, actual and potential output growth, prevailing in the euro area. Figure 1 illustrates the extent of revisions between the Bundesbank's 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) and Nelson and Nikolov (2001) for the US and the UK, 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

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[3] Such data sets are by now available for a number of countries, among them US, UK and Germany. See Croushore and Stark (2001), Orphanides (2001, 2003a) and Gerberding et al. (2004, 2005a).

amount of slack in the economy. When splitting up the overall measurement error 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 measurement errors suggest that monetary policymakers 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 measurement errors. 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.[4] As shown in the first graph of Figure 3, this is indeed the case. When splitting up the change in the output gap into its components (second graph), we find that the measurement errors in output growth and in the change in the output gap follow very similar patterns while the measurement errors regarding potential output growth are smaller, but more persistent. Finally, as illustrated by the third graph in Figure 3, revisions in consumer prices and in money growth were even smaller in size throughout the sample period, with money growth figures being hardly ever revised at all. 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.[5]

Table 1 provides some statistics on the extent and nature of the revisions which will later be used to calibrate the parameters of the measurement error processes of the model. In order to allow some time for revisions between the initial and the ex post observations, we shorten the sample period to 1974Q1 to 1995Q1 (which has the additional advantage of leaving us with West German data only). We report results for this sample period as well as for the - arguably more “normal” – sample period 1980Q1

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[4] 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.

[5] Coenen et al. (2005, p. 982) show that the ECB’s preferred measure of the broad money stock, M3, is subject to only small revisions after the first quarter and to negligible revisions in subsequent quarters.

to 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.[6]

To capture the potential persistence in the measurement errors, 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 in the revisions. Not surprisingly, the estimates of the persistence parameter ρ turn out to be highly significant and quite close to one for the measurement error in the level of the output gap. By contrast, the estimates of ρ for the measurement error in the change in the output gap as well as for real output growth are negative. On the other hand, the measurement errors in potential output growth are again quite persistent, but much smaller in size (with very low standard deviations).

Although the unconditional mean of the measurement error in the level of the output gap amounts to 3.10 for the sample period 1974Q1 to 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 measurement errors 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 measurement errors over time (see Figure 4), the parameter estimates of the measurement error processes are very similar.

3. Model specification

3.1. Aggregate demand, aggregate supply and money demand

The model that we use is a version of the canonical New Keynesian model which has been adapted by Rudebusch (2002) for empirical implementation with quarterly data. Specifically, the model contains a hybrid Phillips curve and a purely backward-looking specification of aggregate demand:

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

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

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

where y is a measure of the output gap, i is the short-term nominal interest rate, π is the annualised percentage change in the price level, $E_{t-1}\bar{\pi}_{t+3}$ 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 shocks.

The generalized Phillips curve described by equation (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 why inflation may depend on its own past values as well as on expected future inflation.[7] 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 lags in the transmission of monetary policy (from interest rates to the output gap and, again, 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 and finds coefficient values of γ=0.20, k=0.31, σ_π^2=0.94, α_1=1.47, α_2=-0.53, σ=0.17 and σ_y^2=0.20 (sample period: 1987Q1-2006Q2). The coefficient of particular interest is γ, or rather (1-γ), which measures the degree of explicitly forward-looking behaviour. With an estimated value of 0.80 for (1-γ), 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). By 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.

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[7] For instance, following Gali 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).

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 equation to the model. Following Rudebusch and Svensson (2002) and Coenen et al. (2005), we use a standard specification of the error correction type:

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

where $m_t^r = m_t - p_t$ is the real money stock, q_t is the 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 κ_m=0.15, κ_q=1.20, κ_i=0.80, $\kappa_{\Delta m}$=0.40, $\kappa_{\Delta q}$=0.10 and σ_m^2=0.20, which are in line with standard estimates for the euro area.

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:

$$y_t = q_t - q_t^*, \tag{4}$$

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:

$$q_t{*} = \rho_{q*} q_{t-1}{*} + \varepsilon_t^q \tag{5}$$

where ε_t^{q*} is a white noise shock.

3.2. Monetary policy rules

As noted in the introduction, our analysis takes place in a simple rules framework and focuses on the relative performance of several variants of the basic Taylor rule, taking into account that policymakers observe only a noisy measure of the output gap. These 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 minimise policymakers' expected loss (see Section 3.4). A potential advantage of simple rules is that they are easier to understand and monitor for the public 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 Taylor rule 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 the subscript $t|t$ 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 speed limit rule 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 which 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 Taylor rule and a variant of the speed limit rule with an additional response to money growth:

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

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

Our motivation for including money growth among the right-hand-side variables of the policy rule is twofold. First, Söderström (2005) has shown that in models with forward-looking expectations, stabilising money growth around a target can be a sensible strategy for a central bank acting under discretion because it introduces inertia and

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[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 normalised 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.

history-dependence into monetary policy. Augmenting the Taylor rule by a response to the money growth gap allows us to test the relevance of this argument in a simple rules framework. Secondly, Coenen et al. (2005) have demonstrated that monetary aggregates may have substantial information content about the "true" level of aggregate output if the environment is characterised by (a) significant measurement errors in GDP data, (b) a strong contemporaneous linkage between money demand and real output and (c) a low variability of money demand shocks.

3.3. Measurement errors in the feedback variables

Simple rules like the ones considered here typically model the interest rate in quarter *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 2, real-time data sets suggest that policymakers face substantial uncertainty about the "true" values of these variables, especially as regards 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 (see Section 2).

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 policymakers at the time the decisions are made (*t*) differ from the true series by a measurement error $\eta_{y,t}$:

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

According to this specification, the measurement error $\eta_{y,t}$ 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 assume that the central bank uses 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 have). Moreover, the "best" (model-consistent) estimate of unobservable variables like the output gap is a

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[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).

complicated function of past observable variables which is at odds with the simple rules framework used here.[11] This argument is reinforced by the fact that optimal filtering is even more intricate 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]

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

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

where $\varepsilon_t^{\eta y}$ is the measurement error shock. The measurement error $\eta_{y,t}$ 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 measurement error (ME) in the change in the output gap, $\eta_{\Delta y,t}$,[14] Here, we assume that this ME is approximately equal to the change in the ME of the level of gap, $\Delta\eta_{y,t}$:[15]

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

It can be shown that under these assumptions, 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 in the change is smaller than the error in the level. Estimates for the parameters of the ME process are obtained from the real-time data set presented in Section 2. As baseline values, we take

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[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 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 here (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 2, the historical measurement errors in the Bundesbank's estimates 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 noticeably from the initial estimate, $y_{t-1|t-1}$, which is a feature of the historical measurement errors described in Section 2.

the estimates for the shorter sample period 1980-1995 which excludes the large measurement errors of the 1970s. In addition, we consider a high-uncertainty scenario which is based on the estimates for the full sample period (1974-1995), and a low-uncertainty scenario which is characterised 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 in fact very close to the estimates reported by Orphanides et al. (2000) for the US.

3.4. Central bank preferences

Deriving the optimal feedback coefficients requires an objective function, and we use a fairly standard one in which the central bank is assumed to minimize the variation in inflation around its target (which is normalized to zero), in the output gap, and in the change in the interest rate:[16]

$$L_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left[w_\pi (\pi_t - \pi^*)^2 + w_y y_t^2 + w_{\Delta i} (i_t - i_{t-1})^2 \right] \tag{4}$$

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 (see Rudebusch and Svensson, 1999):

$$E(L_t) = \omega_\pi Var(\pi_t) + \omega_y Var(y_t) + \omega_{\Delta i} Var(\Delta i_t) \tag{4a}$$

This specification has been widely used in the literature on monetary policy rules (see Ehrmann and Smets, 2003, or Coenen et al., 2005). In the initial exercise, we follow Coenen et al. 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 policymaker whose primary objective is to stabilise inflation around target, while also seeking to stabilize output and to avoid large interest rate volatility.[17] Alternatively, it is sometimes assumed that policymakers care about the deviation of the interest rate from its steady-state level (rather than about its change against the previous

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

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

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).

4. Performance of the rules

4.1 Results of model simulations with optimised feedback coefficients

As a first step, we use the model described in Section 3.1. and summarized in Table 3 to compare the relative performance of the five rules defined above under different degrees of output gap uncertainty (no uncertainty, low uncertainty, baseline uncertainty, high uncertainty). We assume that the central bank minimises Equation (4a) 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 optimised coefficients, the standard deviations of the variables which enter the loss function, and the values of the period loss function. In order to gain 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 Taylor rule (TR) and the speed limit rule (SPL) closely resemble the ones presented by Stracca (2007) despite the fact that we use a slightly different objective function. In particular, the optimal Taylor rule is found to have a very low degree of inertia, while the optimal speed limit rule is found to be very persistent (in fact, it is identical to a first difference rule). Stracca argues that the difference between the values of Φ_1 is likely to reflect the fact that the Taylor rule feeds back strongly from the highly persistent level of the output gap, while the SPL rule reacts (again strongly) to the less persistent change in the output gap. Another interesting result is that the reaction to the output variable is much stronger than the response to current inflation, especially as regards the SPL rule. Again, this makes sense, since in an environment characterised by transmission lags and a low degree of inflation inertia, demand shocks which affect

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[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.

current output are much more relevant for future inflation than cost-push shocks which matter only for current inflation. Allowing for an additional response to money growth somewhat changes the optimal coefficients of the Taylor rule, but the associated reduction in the overall loss is fairly limited. Augmenting the speed limit rule 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 measurement error 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. Secondly, the optimal reaction to inflation increases with the degree of output gap uncertainty. While this result is in line with the literature on 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 growth as a feedback variable. Allowing for output gap uncertainty significantly increases the optimal coefficient on money growth, Φ_5, in both the money-augmented Taylor rule and the money-augmented speed limit rule.[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

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[20] The parameterization of the measurement error process for the baseline and the high-uncertainty case is based on Table 2. For the low-uncertainty case, the standard deviation of the innovation is lowered to 0.60.

(1.20) in the SPLM rule. More importantly, even at a low degree of uncertainty, the additional response to money growth reduces the loss by 4.6% relative to the standard Taylor rule and by 3.9% relative to the standard speed limit rule (without money). Under baseline (worst case) assumptions about output gap uncertainty, the welfare gain increases to 6.4% (8.0%) for the Taylor rule and to 6.2% (6.4%) for the speed limit rule. One explanation for the welfare gain compared to 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 SPLM rule, thus enabling it to avoid inefficient reactions to cost push shocks. By contrast, augmenting the speed limit rule with a response to the output gap (TRSPL) reduces the loss relative to the standard SPL rule only marginally.

Figure 5 plots the optimised coefficients of the standard Taylor rule, the standard speed limit rule and its money-augmented variants for different levels of persistence (left) and of shock variability (right) in the measurement error process. It shows that the main insights to be gained from tables 4 and 5, 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 measurement error process.

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

4.2 Some sensitivity analysis

In this section, we carry out some robustness checks regarding the key results of the paper. In particular, we try to find out whether the superior performance of the money-augmented speed limit rule 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 Taylor rule, the speed limit rule and the money-augmented speed limit rule 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 speed limit rule 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. Hence, the ranking of the policy rules is robust to the choice of the relative weight on output gap versus inflation stabilisation.

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 like the degree of forward-lookingness of the Phillips curve. Depending on the details of the specification, on the estimation method and on the sample period, existing estimates of these parameters differ widely. Hence, it is important to analyse the robustness of the results to variations in the numerical values chosen for key coefficients. In this exercise, we assume that policymakers know the underlying model coefficients and optimise 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 each of the three policy rules for different values of (a) the degree of backward-lookingness of the Phillips curve, (b) the degree of backward-lookingness of the IS curve, (c) the interest rate elasticity σ, (d) the output-gap elasticity k, (e) the standard deviation of the cost-push shock, (f) the standard deviation of the IS-shock, and (g), the standard deviation of the money demand shock. Overall, the ranking of the policy rules is quite robust to reasonable changes in the model coefficients. However, some of the results deserve a closer look. First, increasing the degree of backward-lookingness in the Phillips curve to values above 0.4/ 0.5 strongly increases the losses for all rules, but particularly so for the simple speed limit rule. This makes sense as the benefits of a speed limit policy over a conventional Taylor rule rest on its ability to stabilise private sector inflation expectations. In a purely backward-looking model, this channel is absent, and hence, there is no role for inertia and history dependence. However, as described in Section 3.1, the available evidence

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

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.

Secondly, 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:

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

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 element into the IS curve does not change the overall ranking of the rules, but 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 policymakers 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. Rational agents will understand 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 Taylor rule will increase and the rules will become more similar.

Thirdly and not surprisingly, the performance of the money-augmented speed limit rule relative to the other two rules depends upon the prevalence of money demand shocks. 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 speed limit rule which gradually erodes the welfare gain present at baseline parameter values.

4.3. Robustness to parameter uncertainty

In the last section, we have examined the relative performance of the simple rules considered under different parameterisations of the hybrid New Keynesian model. However, as pointed out by Rudebusch (2002), exercises of this type do not capture the model uncertainty faced by monetary policymakers. In practice, policymakers 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 the policymaker's 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 to approaches which 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 7 shows the losses which result from applying the rules optimised for three different values of γ (0.0; 0.2; 0.4) in a range of models with varying values of γ. For example, the results in the middle column are relevant for the policymaker who perceives 0.2 to be the most likely value of γ and optimises the policy rule for that situation. However, the policymaker 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 optimised for γ=0.2 for different true values of γ, the money-augmented speed limit rule dominates the other two rules across all possible values of γ considered. The same holds for the rules optimised for γ=0 and γ=0.4. Therefore, we can conclude that the ranking of the rules under the baseline model parameterisation 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 speed limit rule, 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 to the case when policymakers 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 policymaker may prefer to adopt the rule which has been optimised for $\gamma = 0.4$. In this respect, our results are in line with those of Walsh (2004) who finds that overestimating the persistence in the inflation process results in a more robust rule than is obtained if the persistence is underestimated.

Another important aspect is whether the optimised rules are robust to misperceptions about the true level of output-gap uncertainty. Table 8 shows the losses under different assumptions regarding the true and perceived parameters of the measurement error process. Consider first the case where the rules have been optimised for baseline model coefficients and baseline uncertainty. Again, we find that the money-augmented speed limit rule dominates the other two rules across all possible degrees of output gap uncertainty considered here. The same is true when the policy rules are optimised for a low or a high degree of uncertainty. However, when policymakers use the optimised no-uncertainty rules, the results are somewhat different. In that case, the Taylor rule dominates the speed limit rules 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 optimised no-uncertainty Taylor rule results in a much higher loss than either variant of the speed limit rule.

The fact that strongly underestimating the true degree of output gap uncertainty leads to substantial losses, especially in the case where policymakers do not account for uncertainty, suggests that it may again be better to overestimate the level of output gap uncertainty rather than to underestimate it. In fact, a policymaker who follows a strategy of minimising the worst-case loss will always choose the money-augmented speed limit rule, with the coefficients optimised 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 over-emphasising the problem of data uncertainty and measurement errors.

5. Conclusions and outlook

In the present paper, we have extended the analysis of simple monetary policy rules for the euro area conducted by Stracca (2007) to the case where policymakers face measurement problems with respect to both actual and potential output. To sum up, we have found that a speed limit rule which includes an additional response to money growth outperforms both the standard speed limit rule and more conventional Taylor rules (with and without money) once we account for a realistic degree of output gap uncertainty. The main reason for the welfare gain is that the information on current output growth contained in money growth data allows the central bank to reduce its response to current inflation, thus enabling it to avoid inefficient reactions to cost push shocks.

One reason why we consider these results to be interesting is that they differ from those of Rudebusch (2002) who concludes that augmenting the Taylor rule with a response to output growth does little to improve its performance even with plausible data measurement errors. Moreover, they also differ from the findings of Coenen et al. (2005) as well as Lippi and Neri (2007) who conclude that money has fairly limited information content as an indicator of contemporaneous aggregate demand 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 in the simple New Keynesian model underlying our analysis, money has no causal role in influencing output or inflation, but 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 which captures the empirically well-established role of money as a leading indicator of changes in trend inflation. This is an important task for future research.

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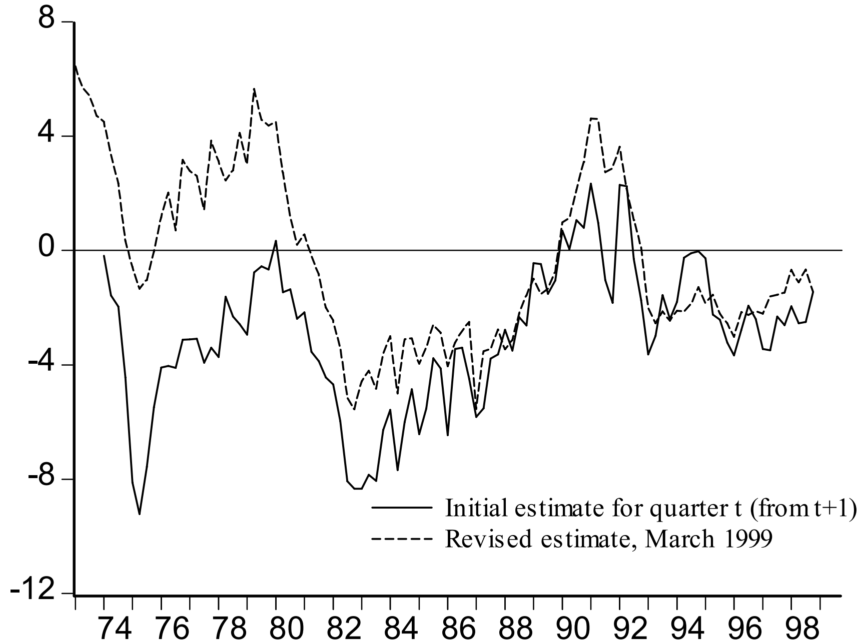
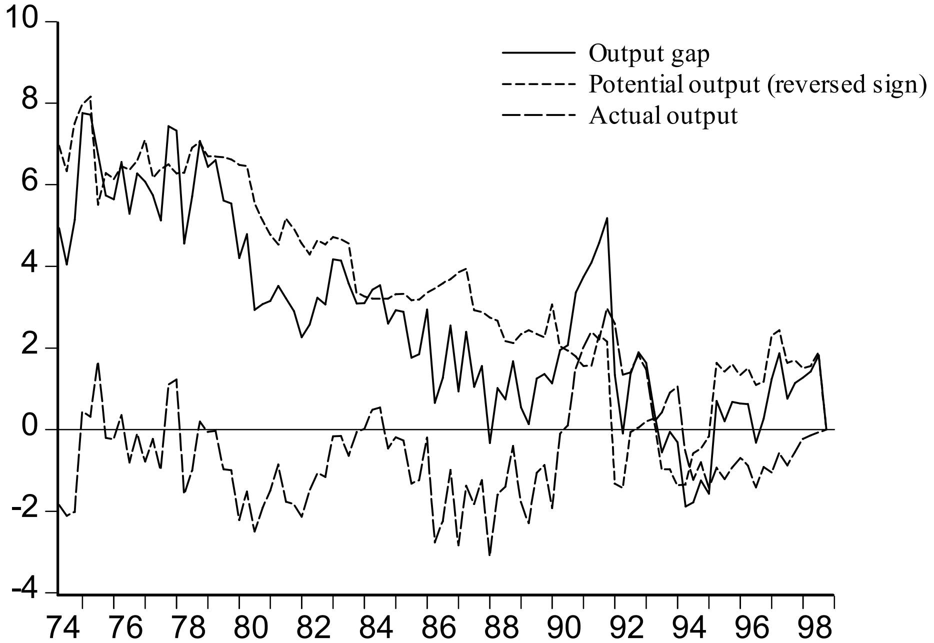
Figure 1: Initial and ex post estimates of the output gap, Germany 1974-1998*



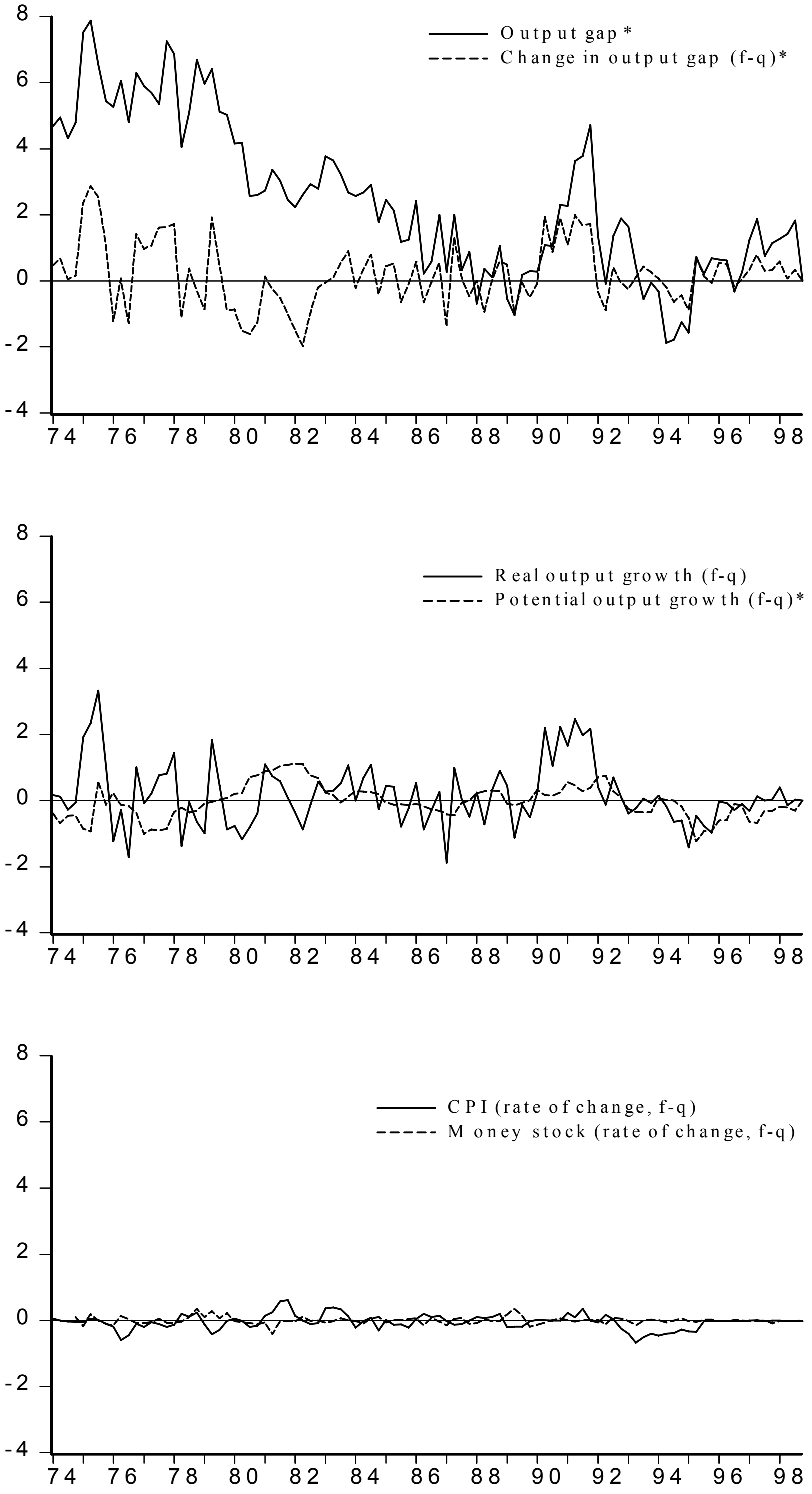
*The calculation is based on Bundesbank estimates of potential output.

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



1) Measurement error defined as difference between ex post and initial figures

Figure 3: Measurement errors in key monetary policy indicators, 1975-1998[1)]



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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.

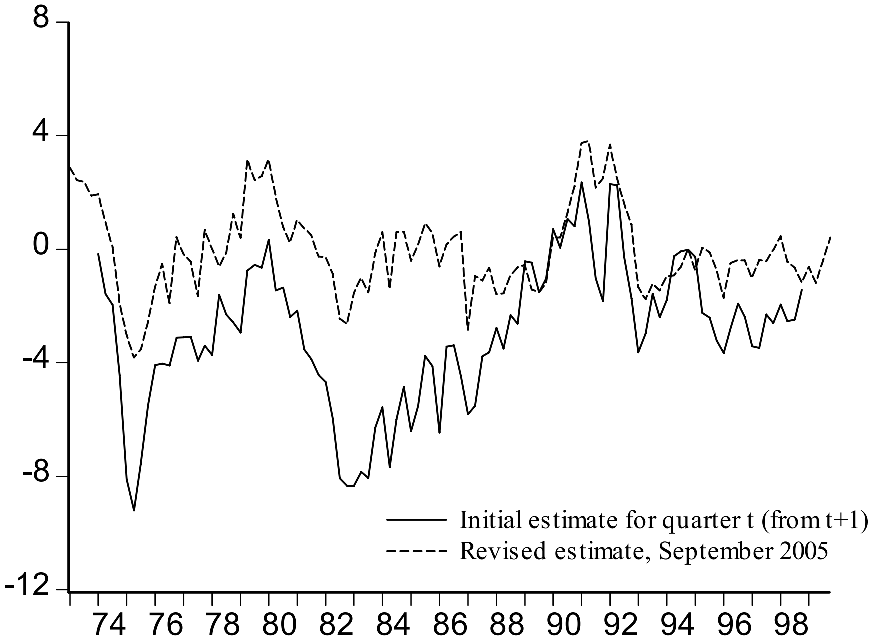
Table 1: Statistics on historical errors in the measurement of key macro variables

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

Measurement error for	*Uncond. mean of η_t*	*Uncond. st. dev. of η_t*	μ_η	ρ_η	*St. Dev. 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: Sept. 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: Sept. 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: Sept. 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: Sept. 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

*The series is calculated by detrending the September 2005 vintage of GDP data with an 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).

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.

Table 2: Alternative estimates for the degree of output gap uncertainty

Assumed model: $\eta_t = \rho_n \eta_{t-1} + \varepsilon_t^\eta$	$\hat{\rho}_n$	sd(ε_t^η) (in %)
***Based on real-time data for Germany*[1]**		
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
***… for the US*[2]**		
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 utilisation revisions 1980:Q1 – 1994:Q4	0.80	0.51
1) Based on real-time GDP data and Bundesbank estimates of potential output for Germany. 2) Source: Orphanides et al. (2000).		

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 σ=0.17; σ_y^2=0.20
(2) Aggregate supply	$\pi_t = \gamma\pi_{t-1} + (1-\gamma)E_{t-1}\bar{\pi}_{t+3} + k\,y_{t-1} + \varepsilon_t^{\pi}$ benchmark values: γ=0.20; k=0.31; σ_π^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: κ_m=0.15; κ_q=1.20; κ_i=0.80; κ_1=0.40; $\kappa_{\Delta q}$=0.10; σ_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: ρ=0.95; σ_{q*}^2=0.13
(5) Policy rules	$\hat{i}_t = \phi_1 \cdot \hat{i}_{t-1} + \phi_2(\pi_{t\|t} - \pi_t^*) + \phi_3 \cdot y_{t\|t}$ (TR) $\hat{i}_t = \phi_1 \cdot \hat{i}_{t-1} + \phi_2(\pi_{t\|t} - \pi_t^*) + \phi_4 \cdot (y_{t\|t} - y_{t-1\|t})$ (SPL) $\hat{i}_t = \phi_1 \cdot \hat{i}_{t-1} + \phi_2(\pi_{t\|t} - \pi_t^*) + \phi_3 \cdot y_{t\|t} + \phi_4 \cdot (y_{t\|t} - y_{t-1\|t})$ (TRSPL) $\hat{i}_t = \phi_1 \cdot \hat{i}_{t-1} + \phi_2(\pi_{t\|t} - \pi_t^*) + \phi_3 \cdot y_{t\|t} + \phi_5(\Delta m_{t\|t} - \Delta m_t^*)$ (TRM) $\hat{i}_t = \phi_1 \cdot \hat{i}_{t-1} + \phi_2(\pi_{t\|t} - \pi_t^*) + \phi_4(y_{t\|t} - y_{t-1\|t}) + \phi_5(\Delta m_{t\|t} - \Delta m_t^*)$ (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: ρ_η=0.89; σ_η^2=0.98

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(di_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					
	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(di_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

Table 4: Performance of policy rules under different degrees of output gap uncertainty, cntd

	Baseline Uncertainty					
	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(di_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					
	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
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(di_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

Table 5: Expected losses for different degrees of output gap uncertainty

E(L)	***TR***	***TRM***	***SPL***	***SPLM***	***TRSPL***	***OC***
No uncertainty	2.08	2.06	1.71	1.71	1.70	1.65
Low uncertainty	4.11	3.92	3.33	3.20	3.31	-
Baseline uncertainty	4.52	4.23	4.04	3.79	4.01	-
High uncertainty	4.78	4.40	4.21	3.94	4.21	-

Figure 5: Optimised coefficients for different forms and degrees of output gap uncertainty – Taylor rule

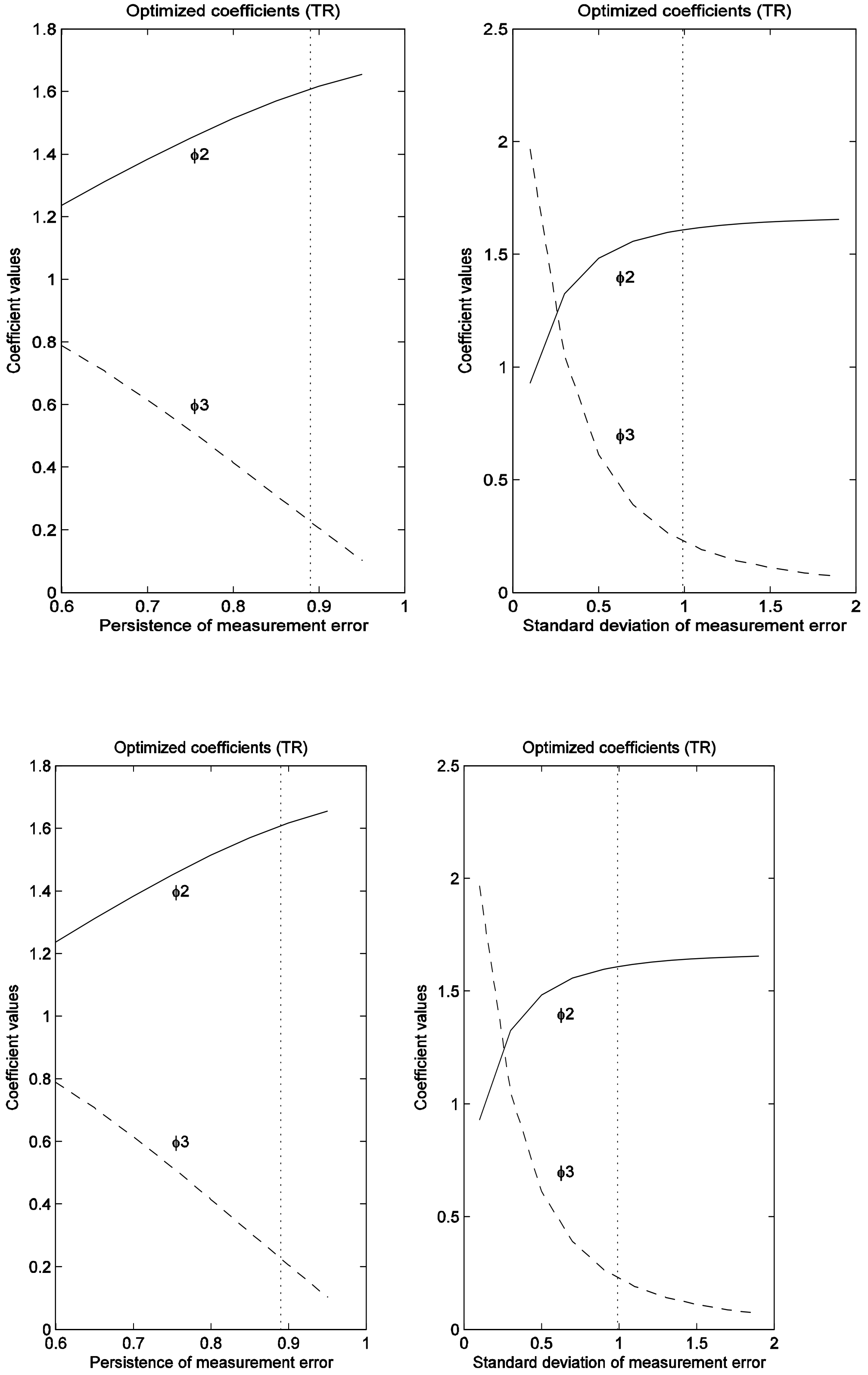


Figure 5: Optimised coefficients for different forms and degrees of output gap uncertainty – speed limit policy

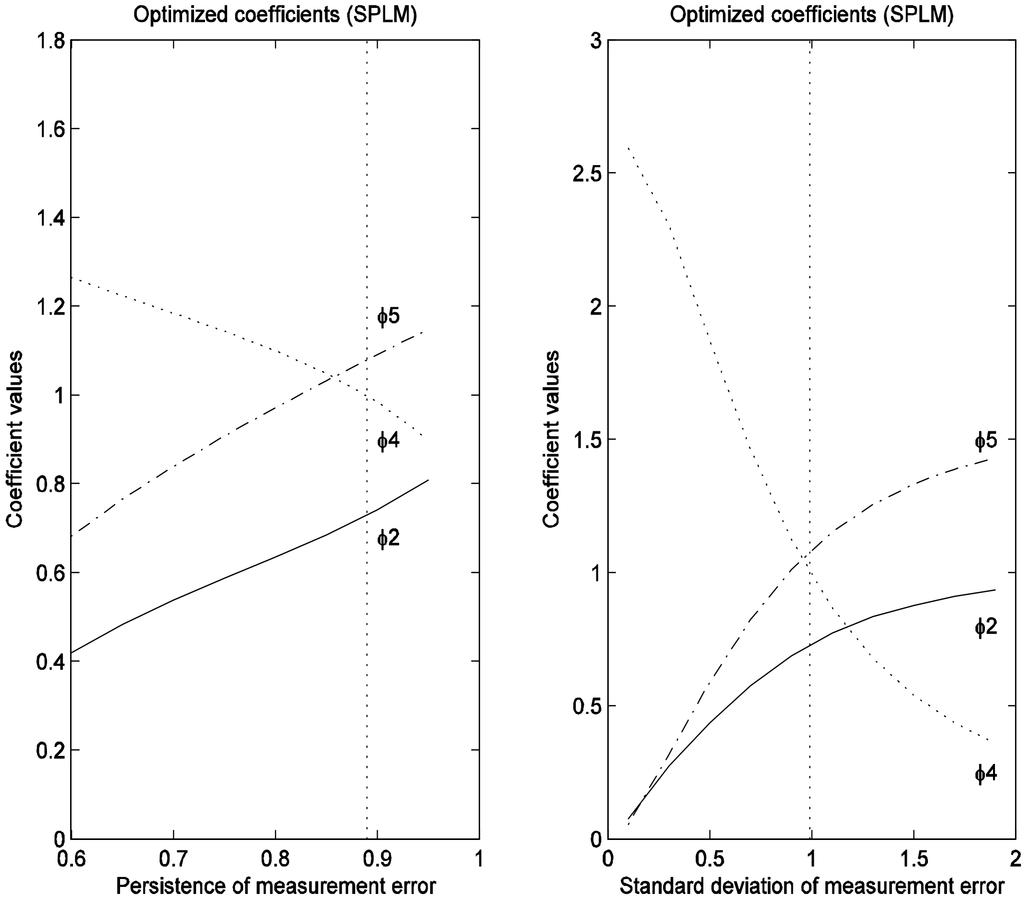


Figure 6: Comparing the central bank losses under different forms and degrees of output gap uncertainty

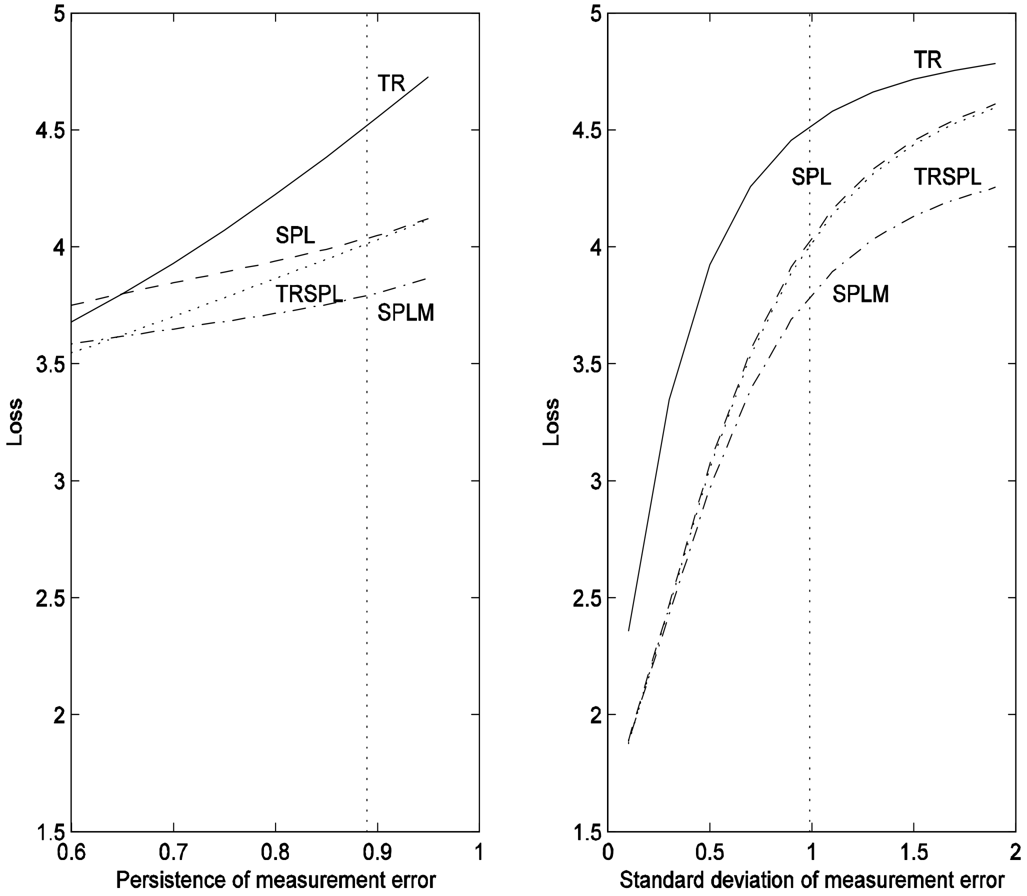


Figure 7: Efficiency frontiers

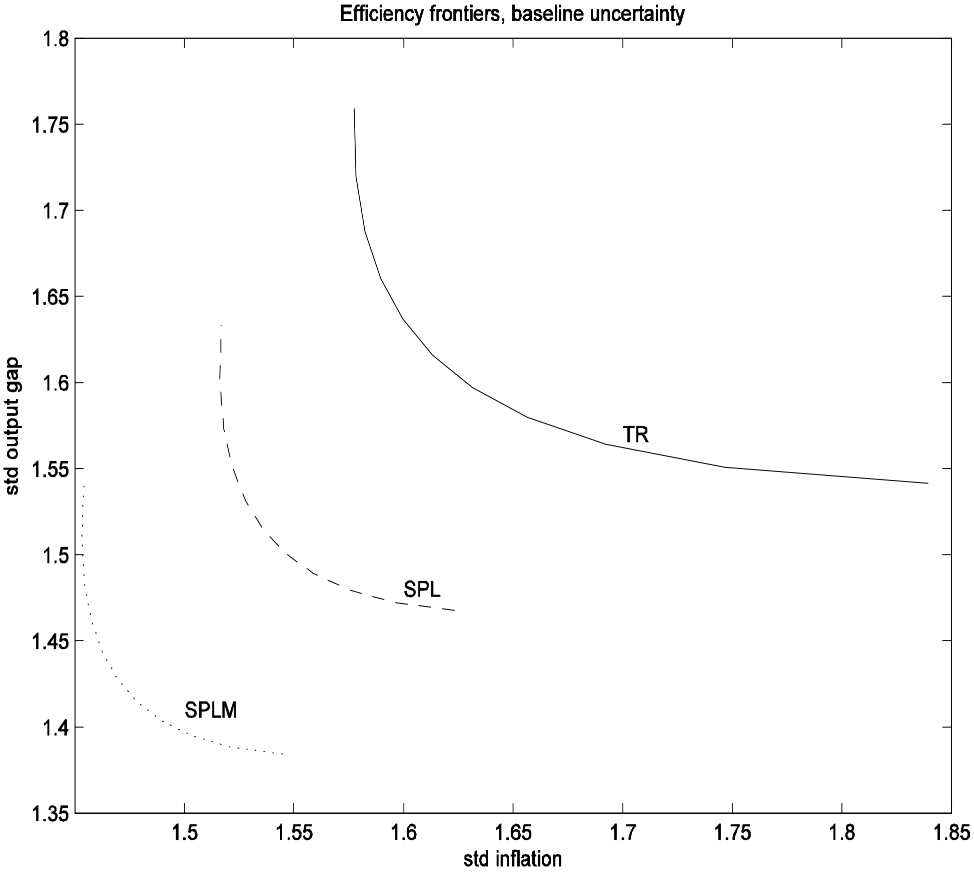


Figure 8: Comparing the central bank losses under different parameters

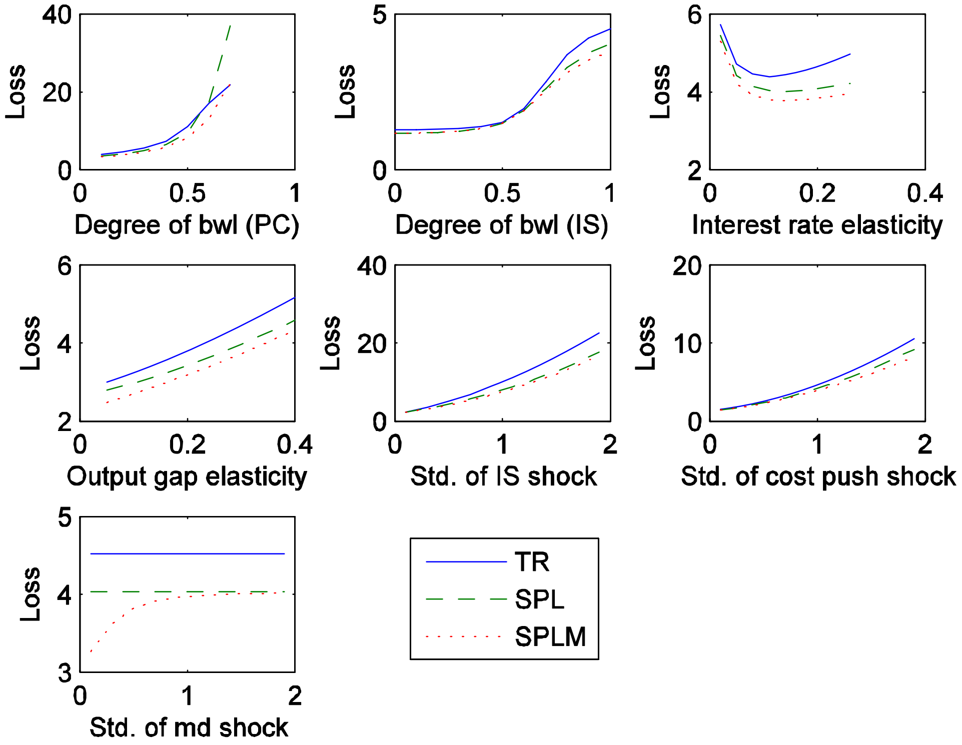


Table 6: Losses for different assumptions about true and perceived degree of backward-lookingness of the Phillips curve

Taylor rule (TR)

True value of gamma	Most likely value of gamma 0.0	0.2	0.4
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 (SPL)

True value of gamma	Most likely value of gamma 0.0	0.2	0.4
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 (SPLM)

True value Of gamma	Most likely value of gamma 0.0	0.2	0.4
0.0	3.04	3.11	3.64
0.2	3.91	3.79	4.11
0.4	8.72	6.60	5.82

Table 7: Losses for different assumptions about output gap uncertainty

Taylor rule (TR)

True uncertainty	Perceived uncertainty no	low	baseline	high
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 (SPL)

True Uncertainty	Perceived uncertainty no	low	baseline	high
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 (SPLM)

True Uncertainty	Perceived uncertainty no	low	baseline	high
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

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