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Money-based interest rate rules: lessons from German data

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Abstract:

The paper derives the monetary policy reaction function implied by money growth targeting. It consists of an interest rate response to deviations of the inflation rate from target, to the change in the output gap, to money demand shocks and to the lagged interest rate. In the second part, it is shown that this type of inertial interest rate rule characterises the Bundesbank's monetary policy from 1979 to 1998 quite well. This result is robust to the use of real-time or ex post data and to the consideration of serially correlated errors. The main lesson is that, in addition to anchoring long-term inflation expectations, monetary targeting introduces inertia and history-dependence into the monetary policy rule. This is advantageous when private agents have forward-looking expectations and when the level of the output gap is subject to persistent measurement errors.

Keywords: Monetary policy, Taylor rule, money growth targets, history dependence

JEL-Classification E43, E52, E58

Non technical summary

In recent years, it has become common practice to describe monetary policy via a feedback relation for short-term interest rates. Due to its simplicity and alleged robustness, the most popular of these monetary policy rules are those in the spirit of Taylor. According to Taylor rules, the short-term real interest rate should be raised above its equilibrium level if inflation increases above target and/or if the level of real output rises above potential. However, one shortcoming of these reaction functions is that they abstract from data uncertainty which policymakers face with respect to key variables entering the Taylor rule like the equilibrium level of the real interest rate and the level of the output gap. It has been shown, for example, that Taylor rules based on real-time data are not able to capture the Bundesbank's monetary policy adequately. For one thing, the Bundesbank did not respond to the level of the output gap, but to the change in it. Moreover, it was characterised by a high degree of interest rate inertia. Interestingly, both characteristics have recently been found to be desirable elements of robust monetary policy rules from a theoretic point of view.

In the present paper, we emphasise that the focus on output growth rather than on the level of real output (relative to potential) is a direct consequence of the use of money growth as an intermediate target and indicator variable. To demonstrate this, we formulate a simple model and derive the interest rate reaction function implied by monetary targeting. Such money-based interest rate rules feature a response to the lagged interest rate, to deviations of inflation from target, to the change in the output gap and possibly, but not necessarily, to short-run movements of money. In the third part of the paper, we show that this type of inertial interest rate rule characterises the Bundesbank's monetary policy from 1979 to 1998 quite well.

In section 4, we discuss the economic reasoning and consequences of the arguments incorporated in the interest rate rule. First, we show that the concentration on the change in the output gap drastically reduces the measurement problems and inaccuracies inherent in the level of the output gap. Secondly, we demonstrate that the interest rate reaction function implied by monetary targeting shares many features of the interest rate rule which characterizes optimal monetary policy under commitment in standard macroeconomic models with forward-looking private sector expectations. Thirdly, we show that the highly significant influence of the lagged interest rate in our estimated policy rule reflects "true" interest rate smoothing, and not – as it is sometimes claimed in the academic literature - measurement errors in the target interest rate or the influence of omitted variables. Furthermore, we argue that the forward-looking element in the interest rate policy of the Bundesbank may be explained by the fact that expected future inflation may be a better proxy for medium-term price developments than the current rate of inflation which is driven by temporary price shocks as well as longer-term trends.

The available empirical evidence suggests that the lessons from German data and the insights from recent research on optimal monetary policy under commitment are relevant for the euro area as well. Against the background of the increased uncertainty monetary policy makers in EMU are confronted with, the Eurosystem's prominent role for money seems to be a sensible approach.

Nicht-technische Zusammenfassung

Die Geldpolitik wird in Makromodellen üblicherweise über eine geldpolitische Reaktionsfunktion für die kurzfristigen Zinsen beschrieben. Besondere Popularität erlangte dabei wegen ihrer Einfachheit und ihrer angeblichen Robustheit die sog. Taylor-Regel. Danach soll der kurzfristige Realzins über sein Gleichgewichtsniveau hinaus erhöht werden, wenn die Inflation ihr Ziel überschreitet und/oder wenn das Niveau des realen Outputs über seinem Potenzialwert liegt. In jüngster Zeit wurden diese Regeln allerdings wegen der Nicht-Berücksichtigung von Datenunsicherheit kritisiert. So konnte z.B. gezeigt werden, dass die Bundesbankpolitik bei Verwendung derjenigen Daten, die den Entscheidungsträgern zum Zeitpunkt der Entscheidungen tatsächlich vorlagen (sog. Echtzeitdaten), durch eine Taylor-Regel nicht adäquat beschrieben werden kann. Vielmehr reagierte die Bundesbank, die als eine der erfolgreichsten Zentralbanken gilt, nicht auf das Niveau der Produktionslücke, sondern auf dessen Veränderung. Zudem war ihre Zinspolitik durch ein hohes Maß an Persistenz gekennzeichnet. Beide Charakteristika werden von der modernen makroökonomischen Theorie als wünschenswerte Eigenschaften robuster geldpolitischer Regeln angesehen.

In dem vorliegenden Papier zeigen wir zunächst, dass die Reaktion einer Zentralbank auf das Outputwachstum relativ zum Potenzial direkte Konsequenz einer Geldmengenorientierung ist, wie sie die Bundesbank von 1975 bis 1998 verfolgte. Um dies zu zeigen, formulieren wir ein kleines Modell und leiten die Zinsregel ab, die sich im Rahmen dieses Modells aus einer Geldmengenorientierung ergibt. Eine derartige geldmengenbasierte Zinsregel beinhaltet als weitere Feedback-Variablen den verzögerten Zins, Abweichungen der Inflation vom Inflationsziel und unter Umständen kurzfristige Geldmengenbewegungen. Aus dieser Ableitung folgt auch, dass die Geldmengenorientierung eine zusätzliche und wünschenswerte Abhängigkeit der Zinsentscheidungen von der wirtschaftlichen Entwicklung der Vorperioden („history dependence“) impliziert. Mit dieser Zinsregel kann die Bundesbankpolitik von 1979 bis 1998 gut nachvollzogen werden.

Im Anschluss an die Präsentation der Schätzergebnisse werden die Argumente der geschätzten Reaktionsfunktion einer näheren Untersuchung und Plausibilitätsprüfung unterzogen. Zum einen wird gezeigt, dass die Konzentration auf die Veränderung der Produktionslücke die Geldpolitik weniger anfällig für Messfehler und -ungenauigkeiten macht. Zweitens stellen wir fest, dass die für die Bundesbank geschätzte Zinsregel starke Ähnlichkeit mit der optimalen zeitinvarianten Zinsregel hat, die sich im Rahmen makroökonomischer Standardmodelle bei vorausschauendem Verhalten des Privatsektors ergibt. Drittens zeigen wir, dass der große Einfluss des verzögerten Zinssatzes auf die aktuellen Zinsentscheidungen tatsächlich ein Zinsglättungsmotiv reflektiert und nicht – wie in der Literatur manchmal unterstellt - Messfehler beim Zielzins oder die Nicht-Berücksichtigung wichtiger erklärender Variablen. Darüber hinaus können wir begründen, warum die Zinspolitik der Bundesbank vor dem Hintergrund der angelegten mittelfristigen Perspektive und dem Hauptziel der Preisstabilität vorausschauend war.

Die empirische Evidenz für Deutschland und neuere theoretische Erkenntnisse zur optimalen regelgebundenen Geldpolitik dürften auch für das Euro-Währungsgebiet relevant sein. Vor dem Hintergrund der erhöhten Unsicherheit seit Beginn der Währungsunion scheint die hervorgehobene Rolle der Geldmenge in der geldpolitischen Strategie des Eurosystems ein sinnvoller Ansatz zu sein.

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1 Introduction

There is an extensive literature on optimal and estimated monetary policy reaction functions. These range from the "classic" Taylor rule (Taylor, 1993) and numerous variants of it (e.g. Clarida et al., 1998; Mehra, 2001; Christiano and Rostagno, 2001; Gerlach-Kristen, 2003; Chadha et al., 2004) to nominal income rules (e.g. McCallum and Nelson, 1999; Rudebusch, 2002a) and different specifications of speed limit policies (Orphanides, 2003b; Walsh, 2004; Bernhardsen et al, 2005; Gerberding, Seitz and Worms, 2005). In the last decade, the most prominent monetary policy rules were those in the spirit of Taylor (1993). According to these rules, the short-term real interest rate should be raised if inflation increases above target and/or if the level of real output rises above trend. The popularity of such rules stems from their simplicity and their good performance across a wide array of macroeconomic models. In addition, the case for Taylor rules has been strengthened by the claim made by Clarida et al. (1998) and others that both the Fed's monetary policy under Paul Volcker and Alan Greenspan and the Bundesbank's monetary policy during the era of monetary targeting (1979-1998) can be well captured by a forward-looking variant of the Taylor rule.

However, one shortcoming of these studies is that they abstract from the measurement problems which policymakers face with respect to key variables entering the Taylor rule like the Equilibrium level of the real interest rate and the level of the output gap. For the US, Orphanides (2001, 2003b) has convincingly demonstrated that the use of real-time information can considerably change the outcome of an analysis of past monetary policy decisions. In particular, he finds that a Taylor rule based on real-time estimates of inflation and the output gap tracks the Fed's monetary policy in the 1970s quite closely and thus would not have been helpful in avoiding the policy mistakes of that era which can be identified today with the advantage of hindsight. In a

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similar vein, Gerberding et al. (2004, 2005) have shown that the use of real-time data for Germany considerably changes the assessment of the Bundesbank's monetary policy reaction function. According to that analysis, the Bundesbank did not respond to the level of the output gap as suggested by the Taylor rule, but rather to the change in the output gap as well as to deviations of (expected) inflation and money growth from their respective target values. Furthermore, the results suggest that the monetary policy of the Bundesbank was characterised by a high degree of interest rate inertia.

Interestingly, targeting the rate of change rather than the level of the output gap has recently been advocated by a number of authors, such as Orphanides (2003a) and Walsh (2003, 2004). One argument in favour of such an approach is that estimates of the level of the output gap are subject to much greater uncertainty than estimates of its change. Another advantage is that targeting the change in the output gap makes monetary policy more history-dependent, which is an important component of an optimal commitment policy in forward-looking models (Woodford, 1999). However, the latter argument has been put forward only recently, and thus does not answer the question why the Bundesbank might have looked more at changes than at the level of the output gap.

In the present paper, we argue that the Bundesbank's focus on output growth rather than on the level of real output (relative to potential) was a direct consequence of its use of money as an intermediate target and indicator variable. To demonstrate this, we first derive the interest rate reaction function implied by monetary targeting (part 2). In our model, money-based interest rate rules feature a response to the lagged interest rate, to deviations of inflation from target, to the change in the output gap and possibly, but not necessarily, to short-run movements of money in addition. In the third part of the paper, we show that this type of inertial interest rate rule characterises the Bundesbank's monetary policy from 1979 to 1998 quite well. Furthermore, we demonstrate that this result is robust to the use of ex post or real-time data. In section 4, we discuss the economic reasoning and consequences of all the arguments incorporated in the Bundesbank's interest rate rule. Here, we also consider the question whether the large weight of the lagged interest rate in the estimated policy rule represents a genuine feature of the Bundesbank's monetary policy or simply picks up the influence of serially correlated errors (Rudebusch, 2002b, 2005). Section 5 summarises and concludes.

2 Mapping monetary targeting into an interest rate reaction function

From 1975 to 1998, the Bundesbank announced annual targets for monetary growth and – at least according to its own descriptions – based monetary policy decisions on deviations of actual money growth from these targets. Contrasting this view, recent empirical studies argue that its interest rate decisions can be described sufficiently well by a standard forward-looking Taylor rule which relates the short-term nominal interest rate to deviations of expected future inflation from target, $E(\Delta p_{t+n} - \Delta p_{t+n}^{T})$, and of current from potential output, $(y_t - y_t^*)$. The latter is unobservable and therefore needs to be estimated:

$$i_t = (1-\rho)\cdot\left[i_t^* + \beta\cdot\left(E(\Delta p_{t+n}|\Omega_t) - \Delta p_{t+n}^{T}\right) + \gamma\cdot E\left((y_t - y_t^*)|\Omega_t\right)\right] + \rho\cdot i_{t-1} \qquad (1)$$

Here, it is a short-term nominal interest rate and it* is its long-run equilibrium level (which is equal to the sum of the long-run equilibrium real rate of interest plus the trend rate of inflation). The parameters ρ, β and γ capture the degree of interest rate smoothing and the strength of the interest rate response to the inflation gap and the output gap, respectively. E is the expectation operator and Ωt is the information available to the central bank at the time it sets interest rates (t). In order to test the relevance of money for the Bundesbank's interest rate decisions, these studies simply add a measure of the money gap (e.g. the deviation of money growth from target) to the list of explanatory variables:[1]

$$i_t = (1-\rho)\cdot\left[i_t^* + \beta\cdot\left(E(\Delta p_{t+n}|\Omega_t) - \Delta p_{t+n}^{T}\right) + \gamma\cdot E\left((y_t - y_t^*)|\Omega_t\right) + \delta\cdot(\Delta m - \Delta m^T)_t\right] + \rho\cdot i_{t-1} \qquad (1a)$$

If the money variable turns out to be insignificant, this is interpreted as indicating that *"the monetary aggregate just does not matter"* (Clarida et al., 1998, 1046).[2] In Gerberding et al. (2005) we have shown that the insignificance of the money growth gap in (1a) hinges critically on the use of ex post data and on the omission of another relevant explanatory variable, namely the *change* in the output gap. In this paper, we go

[1] See, e.g., Clarida et al. (1998) or Bernanke and Mihov (1997).

one step further and show that depending on the central bank's success in identifying shocks to money demand, the interest rate rule implied by monetary targeting need not include a monetary variable at all. To clarify this issue, it proves useful to reformulate monetary targeting in terms of an interest rate reaction function (see also Orphanides, 2003b, 990ff.). In fact, when explaining its strategy to the public, the Bundesbank always made the point that money growth did not serve as an instrument of monetary policy, but as an intermediate target and indicator variable in order to achieve the ultimate goal of price stability. Interpreted in this sense, "monetary targeting" can be represented by an interest rate reaction function of type (1) which links the short-term interest rate to deviations of money growth from the announced target value (all variables except interest rates are in logarithms):

$$i_t = (1-\rho)\cdot i_t^* + (1-\rho)\cdot \lambda \cdot \left(E(\Delta m_t | \Omega_t) - \Delta m_t^T\right) + \rho \cdot i_{t-1}, \qquad (2)$$

where λ captures the strength of the interest rate response to the money growth gap, $\left(E(\Delta m_t | \Omega_t) - \Delta m_t^T\right)$, and $E(\Delta m_t | \Omega_t)$ denotes policymakers' real-time estimate of current money growth which may deviate from the ex post (revised) value, Δm_t, by a measurement error η_t (that is, $E(\Delta m_t | \Omega_t) = \Delta m_t - \eta_t$). According to the quantity equation, money growth is by definition equal to nominal output growth, $(\Delta y_t + \Delta p_t)$, minus the rate of change of velocity Δv_t:

$$\Delta m_t = \Delta y_t + \Delta p_t - \Delta v_t \qquad (3)$$

Under the assumption that the long-run growth rates of output and velocity are exogenous to monetary policy, the trend rate of inflation moves one to one with the trend rate of money growth. Accordingly, the Bundesbank derived its monetary target, Δm_t^T, from its target value for the rate of change in prices (the so-called 'price assumption' or 'price norm'), Δp_t^T, plus the growth rate of the production potential, Δy_t^*, minus the trend rate of change in the velocity of circulation Δv_t^*. The latter two were unknown and hence had to be estimated:

$$\Delta m_t^T = \Delta p_t^T + \Delta y_t^{*,est} - \Delta v_t^{*,est} \qquad (4)$$

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[2] This procedure disregards the fact that a strategy of monetary targeting is only a means to reach the final goal of price stability.

Combining Eq. (3) and (4), we can decompose the money growth gap $\left(\Delta m_t - \Delta m_t^T\right)$ into an inflation gap $\left(\Delta p_t - \Delta p_t^T\right)$, a real output growth gap $\left(\Delta y_t - \Delta y_t^{*,est}\right)$, which is equivalent to the change in the output gap, and a velocity growth gap $\left(\Delta v_t - \Delta v_t^{*,est}\right)$:

$$\Delta m_t - \Delta m_t^T = \left(\Delta p_t - \Delta p_t^T\right) + \left(\Delta y_t - \Delta y_t^{*,est}\right) - \left(\Delta v_t - \Delta v_t^{*,est}\right) \qquad (5)$$

Finally, we can replace Δv_t with the help of a standard money demand function that relates real money holdings $\left(m_t - p_t\right)$ to output y_t (transactions variable) and the interest rate i_t (opportunity cost variable) in a stable and predictable way:[3]

$$\left(m_t - p_t\right) = \gamma_1 \cdot y_t - \gamma_2 \cdot i_t + \varepsilon_t \qquad (6)$$

The term ε captures all deviations of actual money holdings from the level explained by fundamentals, especially short-run dynamics and money demand shocks. Taking first differences of (6) and inserting in (3) yields

$$\Delta v_t = (1 - \gamma_1) \cdot \Delta y_t + \gamma_2 \cdot \Delta i_t - \Delta \varepsilon_t \qquad (7)$$

In the long-run, output growth equals potential output growth and $\Delta\varepsilon = 0$, so that the trend change in velocity is a function of potential output growth, Δy^*, and the trend change in the steady-state (equilibrium) nominal interest rate, Δi^*:

$$\Delta v_t^* = (1 - \gamma_1) \cdot \Delta y_t^* + \gamma_2 \Delta i_t^* \qquad (8)$$

In order to estimate the magnitude of Δv^*, the central bank has to estimate the parameters γ_1 and γ_2, as well as Δy^*, and Δi^*:

$$\Delta v_t^{*,est} = (1 - \hat{\gamma}_1) \cdot \Delta y_t^{*,est} + \hat{\gamma}_2 \Delta i_t^{*,est} \qquad (8a)$$

According to the Fisher equation, the long-run nominal interest rate can be decomposed into the long-run (natural) real rate of interest and the long-run rate of inflation, that is $i_t^* = r_t^* + \Delta p_t^{tr}$, so that any trend change in i^* must be due to an upward or downward trend in the real rate of interest and/or to a change in trend inflation. While it may be argued that the successive lowering of the Bundesbank's price norm from 5 %

[3] The money demand function in (6) is a very standard one to concentrate on the main arguments. A more sophisticated forward-looking specification within a similar spirit may be found in Kajanoja (2003)

in 1975 to 2 % in 1985 did in fact lead to a decrease in the trend rate of inflation, the Bundesbank did not take this into account when deriving its money growth targets but assumed that the nominal interest rate is constant in the long-run.[4] Setting $\Delta i^{*,est}$ equal to zero and substituting (7) and (8a) into (5) yields:

$$\Delta m_t - \Delta m_t^T = \left(\Delta p_t - \Delta p_t^T\right) + \gamma_1\left(\Delta y_t - \Delta y_t^{*,est}\right) + (\gamma_1 - \hat{\gamma}_1)\Delta y_t^{*,est} - \gamma_2 \cdot \Delta i_t + \Delta\varepsilon_t \qquad (5a)$$

Eq. (5a) can now be used to rewrite Eq. (2) in a way that facilitates comparison with the class of Taylor rules described by Eq. (1). Provided that the central bank's estimate of γ_1 is unbiased, the term $(\gamma_1 - \hat{\gamma}_1)\Delta y_t^{*,est}$ can be subsumed into the error term, which leaves us with:

$$i_t = (1-\rho')\cdot\left(i_t^* + \lambda\cdot\left(\Delta p_t - \Delta p_t^T\right) + \lambda\cdot\gamma_1\cdot\left(\Delta y_t - \Delta y_t^{*,est}\right) + \lambda\cdot\Delta\varepsilon_t - \lambda\cdot\eta_t\right) + \rho'\cdot i_{t-1} + \nu_t \qquad (9)$$

with $\rho' = \dfrac{\rho + (1-\rho)\cdot\lambda\cdot\gamma_2}{1 + (1-\rho)\cdot\lambda\cdot\gamma_2} \geq \rho$

At first sight, Eq. (9) looks rather similar to the Taylor rule (1) in that it includes the rate of inflation, the output gap and the lagged interest rate as feedback variables. However, a closer inspection reveals some important differences:

(a) Monetary targeting as expressed by (9) implies a policy response to the difference between the *growth rate* of actual output and the (estimated) growth rate of potential output growth whereas the Taylor rule (1) includes a response to the estimated *level* of the output gap. Hence, monetary targeting introduces history dependence into the policy rule which is an important component of an optimal commitment policy when agents have forward-looking expectations (see Woodford 1999).[5]

(b) Monetary targeting implies a response to the "true" values of Δp and Δy (which determine money demand) while at the same time introducing measurement errors in money growth, η_t, into the policy rule. By contrast, interest rate rules with a direct feedback from prices and output - such as Taylor-type rules or nominal income targeting - are vulnerable to measurement errors in these variables, but do not suffer from measurement errors in money growth. The relative performance of these rules

[4] See Deutsche Bundesbank (1992, p. 27f). One reason for ignoring an expected downward trend in the nominal interest rate due to a trend decline in inflation is that it would imply an upward correction of the money growth target which would in turn decrease the speed at which the trend rate of inflation is brought down.

compared to monetary targeting therefore crucially depends on the magnitude of the respective measurement errors. We will come back to this point below.

(c) Monetary targeting introduces additional inertia into the policy rule. This can easily be seen from the expression for ρ' in Eq. (9). Even if there is no interest rate smoothing in the initial interest rate rule (that is, $\rho=0$), ρ' will still be positive as long as the interest rate response to the money growth gap, λ, and the interest elasticity of money demand, γ_2, differ from zero.

(d) According to (9), monetary targeting implies a response to the contemporaneous rate of inflation whereas the forward-looking variant of the Taylor rule described by (1) allows for values of *n* greater than zero. This issue is discussed further in section 4.3.

(e) Eq. (9) implies a policy response to $\Delta\varepsilon_t$ which captures short-run dynamics and fluctuations of money demand.

The latter is usually seen as the principal drawback of monetary targeting. However, the Bundesbank was aware of this problem and tried to identify and filter out “special factors” ("Sonderfaktoren") which only influence money demand in the short run but do not have any repercussions on the long-run relationships, especially on trend inflation and on inflation expectations (see, e.g. Baltensperger, 1998; Deutsche Bundesbank, 1998, 36f.).[6] In terms of Eq. (9), this practice of filtering actual money growth figures implies that the coefficient on $\Delta\varepsilon$ should be smaller than λ or may even be zero:

$$i_t = (1-\rho')\cdot\left(i_t^* + \lambda_1\cdot\left(\Delta p_t - \Delta p_t^T\right) + \lambda_1\cdot\gamma_1\cdot\left(\Delta y_t - \Delta y_t^{*,est}\right) + \lambda_2\cdot\Delta\varepsilon_t - \lambda_1\cdot\eta_t\right) + \rho' i_{t-1} + \nu_t \qquad (10)$$

with $\lambda_1 > \lambda_2 \geq 0$. A positive value of λ_2 would either indicate that the staff made systematic mistakes in estimating the long-run relationships or that, despite the medium-term orientation of their approach, policymakers still showed some response to short-run fluctuations in money demand (even if these were correctly identified).

5 A similar point has been made by Söderström (2005).

6 Long-run money demand for M3 in Germany showed a stable pattern over the whole monetary targeting period, even after German unification (see, inter alia, Hubrich, 1999; Scharnagl, 1998; Wolters et al., 1998).

Eq. (10) shows that simply amending the Taylor rule (1) by a money (growth) gap in order to check whether monetary policy actually reacted to monetary aggregates does not do justice to the medium-term nature of monetary targeting. To see this more clearly, we can use Eq. (5a) to substitute for $\Delta\varepsilon_t$:

$$i_t = (1-\rho'')\cdot\begin{pmatrix} i_t^* + (\lambda_1-\lambda_2)\cdot\left(\Delta p_t - \Delta p_t^T - \eta_t\right) + (\lambda_1-\lambda_2)\cdot\gamma_1\cdot\left(\Delta y_t - \Delta y_t^{*,est}\right) \\ +\lambda_2\cdot\left(E(\Delta m_t|\Omega_t) - \Delta m_t^*\right) \end{pmatrix} + \rho''\cdot i_{t-1} + \nu_t \quad (10a)$$

with $\rho'' = (\rho' - \gamma_2)/(1-\gamma_2)$. Note that Eq. (10a) only corresponds to our initial representation of monetary targeting, Eq. (2), if λ_1 equals λ_2, i.e., if policymakers do not filter actual money growth figures but react to any deviation of money growth from target (which is at odds with the Bundesbank's own explanations of its approach). If, however, λ_2 is smaller than λ_1, the interest rate rule implied by monetary targeting bears some resemblance to the variants of nominal income growth targeting or "natural" growth targeting advocated, among others, by McCallum and Nelson (1999) and Orphanides (2004). However, one potential advantage of money growth targeting over these two monetary policy strategies is that money growth may contain useful information on the unobserved "true" value of current output growth whereas central banks which target output growth directly have to rely on noisy estimates of this variable. Of course, this advantage hinges critically on the relative magnitude of the measurement errors in money and output data as well as on the central bank's ability to identify money demand shocks in real time and to separate short-run from long-run influences on money demand (see Coenen et al., 2005).

The crucial difference between (10) and a Taylor rule is whether monetary policy reacts to the *change* or to the *level* of the output gap. But whether monetary policy indeed reacted to one or the other (or to both) can obviously only be tested empirically by estimating a reaction function which contains both arguments. More generally, nesting the ingredients of the forward-looking Taylor rule (Eq. (1)) and the feedback variables implied by Eq. (10a) into one model leads to the following interest-rate rule ($n \geq 1$):

$$i_t = (1-\rho)\cdot\left(i_t^* + \phi_{p1}\cdot\left(E(\Delta p_{t+n}\,|\Omega_t) - \Delta p_{t+n}^T\right) + \phi_y\cdot E((y_t - y_t^*)\,|\Omega_t)\right. \tag{11}$$

$$\left. + \phi_{p2}\cdot\left(\Delta p_t - \Delta p_t^T - \eta_t\right) + \phi_{\Delta y}\cdot\left(\Delta y_t - \Delta y_t^{*,est}\right) + \phi_m\cdot\left(E(\Delta m_t\,|\Omega_t) - \Delta m_t^*\right)\right) + \rho\cdot i_{t-1} + \nu_t$$

with $\phi_{p2} = (\lambda_1 - \lambda_2), \phi_{\Delta y} = \gamma_1(\lambda_1 - \lambda_2), \phi_m = \lambda_2$

If the estimated values of ϕ_{p1} and ϕ_y were significantly positive and ϕ_{p2}, $\phi_{\Delta y}$ as well as ϕ_m turn out to be insignificant, then this would be evidence in favour of the claim made by Clarida et al. (1998) that the Bundesbank preached monetary targeting, but in fact followed a forward-looking Taylor rule. If, however, the estimated values of ϕ_{p2} and $\phi_{\Delta y}$ are significantly positive and ϕ_{p1} as well as ϕ_y turn out to be insignificant, then this would be evidence in favour of a money-based interest-rate rule such as (10).

3 Estimating the reaction function of the Bundesbank

Following the approach taken by Taylor (1993), the first generation of empirical studies on monetary policy reaction functions were based on finally revised data. Influential examples include Clarida and Gertler (1997) or Clarida et al. (1998, 2000). However, Orphanides (2001, 2003c) has pointed out that ex post data on key macro variables may differ considerably from the information available to policymakers at the time the decisions are made. This so-called real-time data problem stems from the fact that some potential determinants of monetary policy suffer from considerable measurement problems and are often substantially revised over time. Indeed, with the advantage of hindsight we now know that measurement problems are particularly pronounced for the level of the output gap, which plays a prominent role in interest rate rules of the Taylor type. Interestingly, this is not specific to the US but seems to be an international phenomenon (see Gerberding et al. (2005) for Germany, Gerdesmeier and Roffia (2005) for the Euro Area, Kamada (2004) for Japan, Nelson and Nikolov (2001) for the UK and Orphanides (2001) for the USA). For the purpose of practical monetary policy, estimating reaction functions on revised data is hence inappropriate *a priori* since this ignores serious measurement errors, leading to biased estimates (and test statistics).

However, more recently, the argument has been put forward that the available real-time data sets do not fully reflect the information set available to policymakers when they took decisions. For instance, the analysis of a broad set of indicators may have enabled policymakers to implicitly circumvent the measurement problems underlying real-time estimates. If this were true, policymakers' own (implicit) estimates of key macro variables may differ from those contained in real-time data sets (which are usually based on published data and staff estimates).

As the outcome of this debate is still open, our approach is to use ex post data as well as real-time data to estimate the Bundesbank's reaction function. Looking at both sets of results seems particularly appropriate in our context since the interest rate representation of monetary targeting derived in Section 2 includes a response to the "true" rate of inflation and the "true" growth rate of output. As our benchmark ex post series, we match the last available vintage of official Bundesbank estimates of the production potential (dating from Jan. 1999) with the March 1999 vintages of all other data.[7] By allowing the horizon of the inflation gap, *n*, to vary from zero to six, the two variables measuring current and future price pressure can be subsumed into one term and we are left with the following version of Eq. (11):

$$\begin{aligned} i_t = (1-\rho')\Big(\alpha + \Delta p_{t+n}^T + \phi_p \cdot E((\Delta p_{t+n} - \Delta p_{t+n}^T)\big|\Omega_t) + \phi_y \cdot E((y_t - y_t^*)\big|\Omega_t) \\ + \phi_{\Delta y} \cdot E((\Delta y_t - \Delta y_t^*)\big|\Omega_t) + \phi_m \cdot E((\Delta m_t - \Delta m_t^*)\big|\Omega_t\Big) + \rho' i_{t-1} + \mu_t \end{aligned} \tag{12}$$

where the measurement error in money growth, η_t, has been set equal to zero, and the superscript "*a*" indicates rates of change over the previous four quarters. Furthermore, i_t* has been replaced by the sum of a constant and the price target, Δp_{t+n}^T. An important issue is the method used to generate the forecasts. Since we do not know policymakers' "true" forecasts of inflation, the output gap and the change in the output gap, we follow the standard practice of using the realized values as proxies. Therefore, the error term μ_t is a linear combination of the forecast errors of inflation and output and the exogenous disturbance term v_t. In order to avoid simultaneity problems, the RHS-variables are instrumented by a vector of variables I_t which belong to the central bank's information set at the time it sets interest rates and which are orthogonal to μ_t. As we

[7] See Gerberding et al (2004), p. 7 ff and footnote 9.

use end-of-quarter values of the dependent variable, we include the contemporary values of those RHS variables which were known to policymakers at the end of quarter *t* (that is, inflation, the price assumption, the money growth target and money growth in the first two months of the quarter) as well as two lags of each RHS variable in the instrument set.[8]

Table 1a summarizes the results of estimating (12) on ex post data for different forecast horizons *n*. Several observations are in order. First, in all cases, the J-statistic confirms the validity of the over-identifying restrictions. Second, the coefficient of the inflation gap, ϕ_p, is significantly positive for all values of *n*. Third, the coefficient of the level of the output gap, ϕ_y, is significant only for $n=0$, suggesting that in this case, the output gap acts as an indicator of future inflation rather than as an independent feedback variable. Fourth, the coefficients of the output growth gap, $\phi_{\Delta y}$, and of the money growth gap, ϕ_m, are significantly positive for all values of *n*. However, for the specification with the lowest standard error, $n=3$, the interest rate response to the money growth gap is significant only at the 10% level, while the response to both the inflation gap and the output growth gap are significant at the 1% level. Fifth, with estimated values of ρ between 0.80 and 0.91, the rule exhibits a high degree of interest rate smoothing. Finally, dropping the insignificant output gap leaves the results unchanged with the only exception that ϕ_p increases somewhat for forecast horizons $n = 0, 1, 2$ (see Table 1b). As a consequence, the response to inflation becomes significantly larger than one for all values of *n*.

Before turning to the interpretation of these results, we check whether using real-time data instead of ex post data makes any difference. For that purpose, we re-estimate Eq. (12) using the real-time data set compiled by Gerberding et al. (2004). We find that all real-time estimates reveal a significant reaction to the inflation gap, to the *change* of the output gap and to the money growth gap, while the feedback from the *level* of the output gap turns out to be insignificant. Again, the response to the money growth gap is weakest for an inflation forecast horizon *n* of three quarters which is the specification with the lowest standard error. The rule also exhibits a high degree of interest rate

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[8] Compared to the approach taken by Gerberding et al. (2005), we have reduced the number of instruments from 29 to 17. We do this to avoid the potential biases associated with using too many instruments, but the results are largely unchanged.

smoothing. Moreover, the parameters of the change in the output gap and the inflation gap are not too far apart from each other.[9] In fact, for $n=0$, the point estimate of $\phi_{\Delta y}$ is even slightly above ϕ_p, which is perfectly in line with the parameter restrictions implied by monetary targeting in the case of $\gamma_1 > 1$ (see Eqs. (9) and (10)).[10]

These results prove to be quite robust to changes in the forecast horizon n ($1 \leq n \leq 6$), the exact timing of the inflation and output variables, the concrete specification of the money gap (annual growth rates, annualised 6-month growth rates, level specifications), and to the choice of alternative proxies for the unobserved forecasts of inflation (consumer prices, output deflator, consensus forecasts).[11]

However, what is perhaps most surprising is that the results based on real-time data differ only slightly from the results in the ex-post setting. An obvious explanation for this congruence is that (in contrast to other central banks) policymakers at the Bundesbank focussed their attention on indicator variables which were exposed to measurement error only to a comparatively small extent. Figure 1 illustrates that this is indeed the case. First of all, as shown in Figure 1(a), the measurement errors regarding the *change* in the output gap were much smaller and much less persistent than the measurement errors regarding the *level* of the output gap. Second, when splitting up the change in the output gap into actual output growth and potential output growth (Figure 1(b)), we find that the measurement errors in output growth and 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 Figure 1(c), 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 be true for other countries over different sample periods, Coenen et al. (2005) reach very similar conclusions with respect to euro-area data since 1999.

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9 Rudebusch (2002a) shows that nominal income targeting performs well when inflation is forward-looking.

10 The income elasticity of broad money demand is generally estimated to be greater than one in the case of the euro area and in Germany, see e.g., Bruggemann et al. (2003) and Scharnagl (1998).

11 See Table 2 in Gerberding et al. (2004) and further calculations which are available upon request.

4 Interpretation of the interest rate rule

Obviously, the Bundesbank did not follow a Taylor rule since the level of the output gap turns out to be insignificant in almost all regressions. Instead, the significant and sizable response to both, inflation and the output growth gap as well as the high degree of interest rate smoothing suggest that the Bundesbank took its money growth targets seriously. However, there are also two aspects in which the results deviate from the money based interest rate rule derived in Section 2. First, by responding to expected future inflation rather than to current inflation, policymakers at the Bundesbank seem to have taken a more forward-looking approach than implied by the interest rate rules (9) and (10). Second, beyond the feedback from the variables implied by monetary targeting, there seems to have been an additional, independent response to money growth. We will discuss each of these results in turn.

4.1 Role of the Output Gap

The strong and robust influence of the *change* in the output gap on interest rate decisions points to an omitted variables bias in *standard* Taylor rule specifications of the Bundesbank reaction function like the one estimated by Clarida et al. (1998). In this sense, our results throw serious doubt on the widespread practice of using the Taylor rule – even if it does not accurately describe central banks' real-time behaviour – as a reasonably accurate ex-post description of monetary policy which may be exploited, for instance, in the estimation of DSGE models based on ex-post data.

From a normative point of view, targeting the change rather than the level of the output gap can be advantageous for two different reasons. First, as demonstrated by Orphanides et al. (2000), there may be a case for responding to the *change* in the output gap rather than to its *level* if the measurement errors in the level of the output gap are large and highly persistent.[12] The measurement errors in the level of the output gap are defined as (the tilde refers to real-time values):

$$(y_t - y_t^*) - (\tilde{y}_t - \tilde{y}_t^*) = (y_t - \tilde{y}_t) - (y_t^* - \tilde{y}_t^*) \qquad (13)$$

As shown in Figure 1, the measurement errors in the Bundesbank's estimates of the output gap were sizable and quite persistent, as was the case not only in Germany.

[12] See Orphanides et al. (2000) or Walsh (2004).

This high degree of persistence implies that, e.g., high positive errors in period *t* usually follow high positive measurement errors in *t-1*. However, given this high degree of persistence, the measurement errors of the *change* of the output gap

$$(\Delta y_t - \Delta y_t^*) - (\Delta \tilde{y}_t - \Delta \tilde{y}_t^*) = [(y_t - \tilde{y}_t) - (y_t^* - \tilde{y}_t^*)] - [(y_{t-1} - \tilde{y}_{t-1}) - (y_{t-1}^* - \tilde{y}_{t-1}^*)] \quad (14)$$

are much smaller than that of the level. Therefore, in normative terms, it may be preferable to focus on output growth (relative to trend growth) rather than on the level of the output gap. Orphanides (2003a), Orphanides et al. (2000) and Walsh (2004) show that in the presence of imperfect information about the level of potential output, monetary policy strategies such as inflation and output growth targeting, difference rules or speed limit policies outperform simple Taylor-type rules.

Second, responding to the change in the output gap may be welfare-improving since it introduces history-dependence into the policy rule, thereby stabilising inflation expectations and, via the expectations channel, stabilising also actual inflation. To fully understand the argument, consider the following example.[13] Assume that policymakers care about stabilising inflation, output and the interest rate around target values. In this case, the central bank's period loss function takes the form[14]

$$L_t = (\Delta p_t - \Delta p_t^T)^2 + \alpha_y (y_t - y^*)^2 + \alpha_i (i_t - i^*)^2, \quad (15)$$

where α_y and α_i are the relative weights attached to output and interest rate stabilization and y^* is assumed to be consistent with the steady-state level of output. Assume further that the aggregate demand and supply equations are of the standard New-Keynesian type.[15] Under these assumptions, the first order conditions which characterize optimal monetary policy under *discretion* can be transformed into

$$i_t = i^* + \phi_p (\Delta p_t - \Delta p_t^T) + \phi_y (y_t - y^*) \quad (16)$$

Eq. (16) can easily be interpreted as a policy rule of the Taylor type. However, with forward-looking price setting and a short-run output inflation trade-off, there are gains from commitment to a policy rule. Under commitment, the central bank takes the effects of its own actions on private sector expectations into account. As a consequence,

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[13] See Kara (2003) and Giannoni and Woodford (2003)

[14] This loss function can also be given a welfare-theoretic justification, see Woodford (2003, Chapter 6).

optimal policy is not purely forward-looking, but history-dependent in the sense that it implies systematic responses to the lagged interest rate, to the lagged change in the interest rate and to the lagged output gap. Choosing the commitment solution that is optimal from a timeless perspective, the interest rate rule takes the form:[16]

$$i_t = (1-\rho_1)i^* + \rho_1 i_{t-1} + \rho_2 \Delta i_{t-1} + \phi_p(\Delta p_t - \Delta p_t^T) + \phi_{\Delta y}(\Delta y_t - \Delta y_t^*) \qquad (17)$$

Comparing Eq. (17) with Eqs. (9) and (10), we find that the optimal time-invariant policy rule under commitment shares many features with the interest rate representation of flexible monetary targeting derived in Section 2.

4.2 Interest Rate Smoothing – Spurious or Real?

The estimated Bundesbank reaction function implies a high degree of interest rate smoothing, as measured by the persistence parameter ρ. Recently, some authors have questioned whether the significance of the lagged interest rate in estimated policy rules reflects "true" interest rate smoothing, arguing that it may be caused either by measurement error in the target interest rate (Lansing, 2002; Apel and Jansson, 2005) or by the omission of variables from the reaction function to which policymakers actually did respond (e.g. Rudebusch, 2002b). If this were true, efforts to identify the monetary policy rule would create the illusion of interest rate smoothing behaviour when, in fact, there is none.

In order to investigate these two potential sources of misspecification, it proves useful to re-write the central bank's reaction function as:

$$i_t = (1-\rho)\cdot \hat{i}_t + \rho \cdot i_{t-1} + \mu_t\,, \qquad (18)$$

where $\hat{i}$ is the target interest rate determined by the policy rule. If $\hat{i}$ is measured with error, one might expect the coefficient *(1-ρ)* to be biased downwards, thus creating the impression of partial adjustment. One plausible reason why $\hat{i}$ might be subject to a measurement error is the use of data that were not available to policymakers at the time of their policy decisions (that is, ex post data). In our setup, we can easily investigate this possibility by comparing the estimates of ρ based on ex post data with the

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[15] To ensure long-run neutrality, the inflation variable entering the Phillips curve and the output equation should be defined as inflation relative to its steady-state value. See McCallum and Nelson (2004), p. 44, footnote 3.

corresponding estimates based on real-time data. Since we do not find any significant differences in the estimates of ρ, the high degree of partial adjustment found in our estimates of the Bundesbank's policy rule obviously is not driven by measurement error in the data entering the reaction function.

However, a number of other considerations could give rise to the impression of interest rate smoothing were in fact there is none. For instance, Rudebusch has repeatedly made the point that the lagged interest rate may simply pick up the influence of serially correlated errors which may be caused, for instance, by serially correlated omitted variables (see Rudebusch (2002, 2005)). English et al. (2003) have demonstrated that this hypothesis can be tested empirically by estimating a model which combines the partial adjustment model of Eq. (18) with an AR(1)-model for the error term (19): [17]

$$\mu_t = \varphi \cdot \mu_{t-1} + \omega_t \tag{19}$$

Rewriting (18) in first differences (Δi), lagging it once, multiplying it by φ and subtracting it from its current-period counterpart yields

$$\Delta i_t = (1-\hat{\rho}) \cdot \Delta \hat{i}_t + (1-\hat{\rho}) \cdot (1-\varphi) \cdot (\hat{i}_{t-1} - i_{t-1}) + \hat{\rho} \cdot \varphi \cdot \Delta i_{t-1} + \omega_t \tag{20}$$

Estimating Eq. (20) for our preferred specification of the reaction function (12) yields direct estimates of the interest rate smoothing parameter $\hat{\rho}$ and of the AR-parameter φ. As shown in Table 3, we cannot reject the hypothesis $\varphi = 0$ for all forward-looking specifications ranging from $n = 0$ to 6.[18] In contrast, the estimated values of the other coefficients, including $\hat{\rho}$, remain largely unchanged compared to the baseline specification. Hence, we conclude that the Bundesbank's monetary policy rule is characterized by a high degree of "true" interest rate smoothing. This result is in line with our finding from Section 2 that monetary targeting introduces additional inertia

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[16] The advantages of focussing on this solution are explained in Woodford (2003, p. 464ff)

[17] The critique of Welz and Österholm (2005) on size distortions of this test is not justified in our case, as we should have taken into account all relevant *systematic* influences on German monetary policy in our sample. The exchange rate, one often mentioned variable in this direction, should be captured by the other variables in our setting.

[18] $n = 0$ is already forward-looking as a first estimate of the output gap in t is only available in $t+1$. The cases n = 2, 3 are not shown in the table as the coefficients are nearly the same as for the other forecast horizons. They are available upon request.

into the policy rule, and it matches the Bundesbank professed preference for conducting a “steady-as-she-goes” interest-rate policy ("Politik der ruhigen Hand").

4.3 Role of the Forecast Horizon and the Money Growth Gap

Taken literally, our theoretical model of monetary targeting derived in Section 2 implies an interest rate response to deviations of current inflation from target (see Eqs. (9) and (10)). And in fact, for $n=0$, our estimates of the feedback coefficients correspond well with the predictions of the theoretical model, particularly in the real-time setup. However, increasing the forecast horizon of the inflation gap lowers the standard error of the regression even further until it reaches its minimum at a forecast horizon of three quarters.

In order to better understand this result, recall that the Bundesbank tried to identify and filter out short-run fluctuations in money demand which did not have any repercussions on the long-run relationships, especially on trend inflation and on inflation expectations. Such fluctuations might not only be caused by shocks to real money demand (as captured by the variable $\Delta\varepsilon_t$ in Eq. (9)), but also by the effects of price shocks on nominal money demand. Viewed from this perspective, increasing the time horizon of the inflation variable may improve the fit of the model because expected future inflation is a better proxy for medium-term price developments than the current rate of inflation which is driven by temporary price shocks as well as longer-term trends.

Finally, we still have to explain the role of the explicit money growth gap in the Bundesbank’s reaction function. First of all, note that increasing the horizon of the inflation gap from zero to three quarters (in the case of $\phi_y = 0$) lowers the coefficient of the money growth gap from 0.98 to 0.29 in the ex post setup and from 1.05 to 0.30 in the real-time setup just to increase again for $n > 3$. As regards the estimates based on real-time data, the remaining response to the money growth gap at $n=3$ might be explained by its role as an indicator of the "true" growth rate of real output.[19] More generally, the significant reaction to money growth in both scenarios may reflect an insurance scheme to policymakers against measurement errors in output growth of unknown size at the time decisions were made. Apart from that, ϕ_m may capture a remaining influence of short-run dynamics and money demand shocks on the Bundesbank's interest rate decisions. This may simply reflect mistakes, possibly due to difficulties in identifying the shocks in real time. This may also reflect a conscious decision by policymakers to show some response to obvious deviations of money growth from target, even if they were believed to be caused by shocks and therefore not to feed into prices in the medium to long run (e.g. for credibility reasons).[20]

5 Conclusions

In the present paper, we have taken up the question raised by Gerberding et al. (2005) of why the Bundesbank might have looked more at changes than at the level of the output gap. To shed light on this issue, we have shown that monetary targeting taken seriously implies an interest rate response to deviations of inflation from target, to the *change* in the output gap, to the lagged interest rate and to deviations of money demand from long-run equilibrium. The latter is usually seen as the principal drawback of monetary targeting. However, we have argued that a central bank with a focus on money will be aware of this problem and, depending on the staff's success in identifying shocks to money demand, the interest rate response to such shocks will be muted or even non-existent.

With their implied response to the lagged interest rate and to the change in the output gap, money growth targets introduce inertia and history-dependence into monetary policy. As shown by Giannoni and Woodford (2003), both features are important components of optimal monetary policy in standard New-Keynesian models with forward-looking expectations. In addition, responding to the change in the output gap rather than to its level may be advantageous when the latter is subject to large and persistent measurement errors as has historically been the case. Furthermore, as pointed out by Nelson (2003), beyond the stabilisation concerns captured by short-run models, central banks have to be concerned with pinning down the steady-state rate of inflation, and this was certainly the main motivation behind the Bundesbank's commitment to a money growth target.

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[19] See for analysis in the same spirit Kajanoja (2003).

[20] Additional reasons why it might be helpful for policymakers to look at money are discussed in Gerberding et al. (2004), section 5.

Therefore, the lessons to be drawn from the Bundesbank's experience differ from those provided by Rudebusch and Svensson (2002) who compare the relative performance of inflation targeting and monetary targeting in a small empirical model estimated on US data. In contrast to our analysis, they conclude that the reaction function resulting from monetary targeting is quite unsuitable for stabilizing inflation and the output gap, even if there are no shocks to money demand. One reason for this negative verdict is that there are no expectation channels and consequently, no gains from commitment in their purely backward-looking model. While this may or may not be an adequate model for the US economy, Galí et al. (2001), Smets and Wouters (2003), ECB (2005), and most recently Stracca (2006) present evidence that inflation in the euro area is characterized by a relatively low degree of intrinsic inertia.[21] Moreover, Woodford (2005) has shown that commitment continues to be important for optimal policy even if the assumption of model-consistent expectations is replaced by the weaker assumption of near-rational expectations.

A second reason for Rudebusch and Svensson's negative verdict on monetary targeting is that their analysis abstracts from the problem of data uncertainty. In fact, they argue that it is not obvious that monetary targeting would be favoured under such uncertainty since money data are also subject to important revisions.[22] Again, while this may be true for the US (see Amato and Swanson, 1999), Coenen et al. (2005, 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.

Hence, the available empirical evidence suggests that the lessons from German data, together with the insights from recent research on optimal monetary policy under commitment, are more relevant for the euro area than the lessons from US data presented by Rudebusch and Svensson. Having said this and against the background of the increased uncertainty monetary policy makers in EMU are confronted with, the Eurosystem's prominent role for money seems to be a sensible approach. Taken seriously, this orientation introduces the necessary ingredients of a robust and inertial monetary policy rule. However, in order to arrive at more definite conclusions, the present analysis needs to be complemented by further studies which take account of the

[21] Benigno and López-Salido (2006) have shown that this is also true for Germany

[22] See Rudebusch and Svensson (2002), footnote 26

structural relationships as well as of the degree of model and data uncertainty currently prevailing in the euro area. This is an important task for future research.

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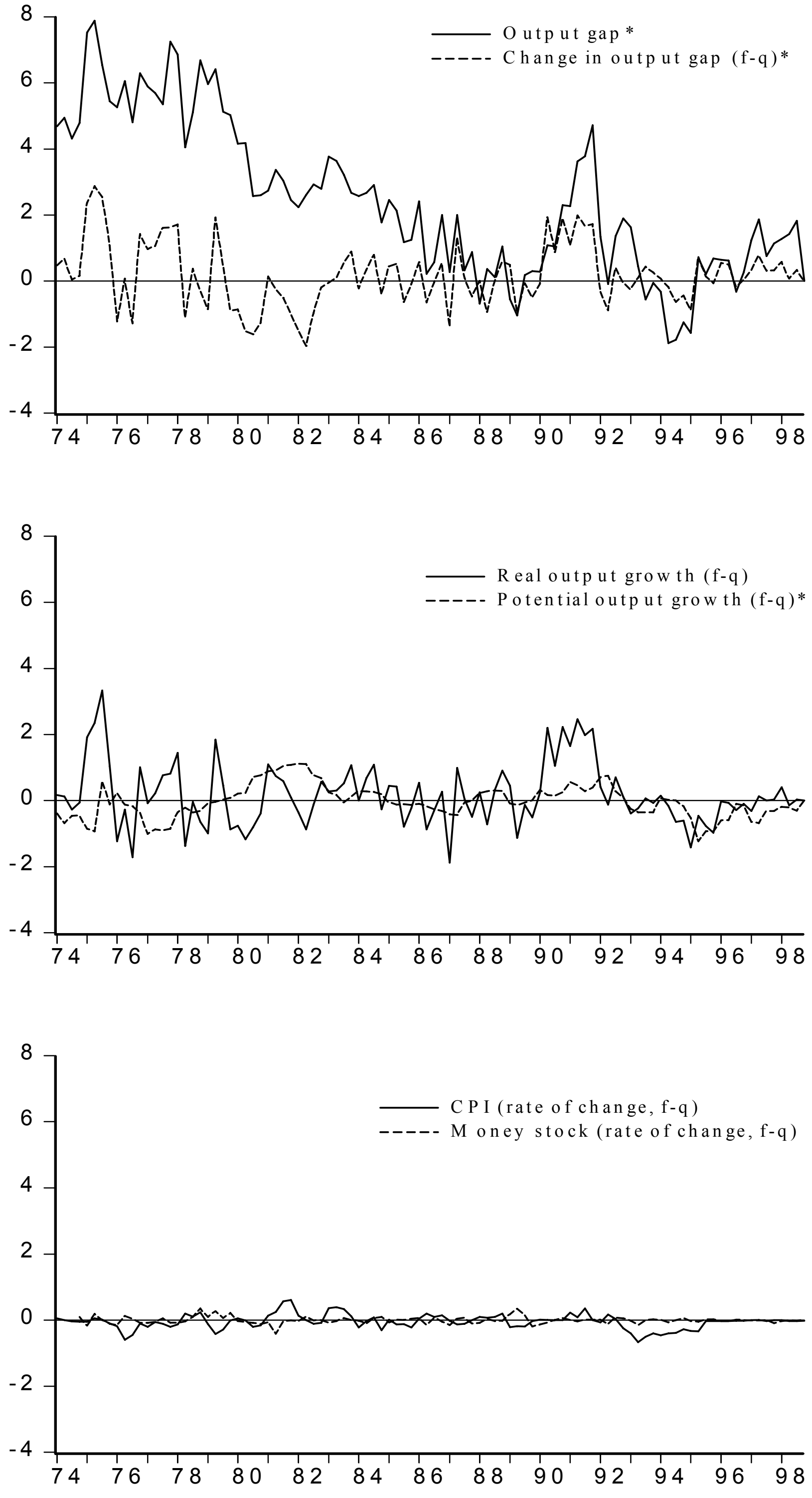
Figure 1: Measurement error in key monetary policy indicators, 1975-1998[1)]



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 1a: Ex-post estimates of Equation (12)

	n=0	n=1	n=2	n=3	n=4	n=5	n=6
ϕ_p	1.03**	1.43***	1.71***	2.92***	2.37**	2.41**	2.99**
	(0.41)	(0.42)	(0.60)	(0.77)	(1.02)	(1.17)	(1.39)
ϕ_y	0.55**	0.30	0.24	-0.14	0.19	0.41	0.44
	(0.23)	(0.18)	(0.30)	(0.27)	(0.38)	(0.44)	(0.46)
$\phi_{\Delta y}$	1.25**	1.04**	1.34**	1.33***	1.74**	2.08**	2.33**
	(0.53)	(0.40)	(0.54)	(0.41)	(0.68)	(0.92)	(1.06)
ϕ_m	0.54***	0.46***	0.49**	0.25*	0.40**	0.52**	0.61**
	(0.19)	(0.16)	(0.20)	(0.15)	(0.18)	(0.23)	(0.27)
$\hat{\rho}$	0.83***	0.80***	0.84***	0.85***	0.88***	0.90***	0.91***
	(0.04)	(0.05)	(0.05)	(0.03)	(0.03)	(0.03)	(0.03)
R²	0.94	0.95	0.95	0.96	0.95	0.95	0.95
SEE	0.61	0.60	0.57	0.53	0.57	0.57	0.56
JB	0.00	0.01	0.28	0.32	0.87	0.39	0.09
J-stat	0.51	0.61	0.56	0.65	0.72	0.59	0.53

***(**/*) denotes significance at the 1% (5%/10%) level. Estimation period: 1979Q1 to 1998Q4,: estimation method: GMM; HAC-robust standard errors in parentheses; for further notes see table 1. Ex-post series as of March 1999.
Variables: left-hand-side variable: 3-month money market rate (end-of-quarter); right -hand-side variables: inflation gap according to cpi; level and change in the output gap with Bundesbank's own estimates of production potential. For further details on the data see Gerberding et al (2004)
To correct for extreme outliers in the residuals, it proved necessary to include a dummy variable in the estimations which is one in the first quarter of 1981 and zero otherwise. The dummy captures the jump in money market rates which occurred in February 1981 when the Bundesbank replaced its "normal" lombard loans by a new special lombard facility which cost 3 percentage points more. The instrument set includes the contemporary values of inflation and the price assumption (which were known to policy makers at the end of each quarter) as well as two lags of each explanatory variable. Pretesting suggests that this instrument structure is sufficient.
R^2: adjusted coefficient of determination; SEE: standard error of the regression; J-stat: p-value of the J-statistic on the validity of overidentifying restrictions ; JB: p-value of the Jarque Bera test of the normality of residuals.

Table 1b: Ex-post estimates of Equation (12) with $\phi_y = 0$

	n=0	n=1	n=2	n=3	n=4	n=5	n=6
ϕ_p	1.91***	2.03***	2.15***	2.69***	2.73***	3.17***	3.45***
	(0.41)	(0.29)	(0.33)	(0.52)	(0.68)	(0.95)	(1.08)
$\phi_{\Delta y}$	2.22**	1.18***	1.30***	1.37***	1.78***	2.20**	2.07**
	(0.92)	(0.43)	(0.45)	(0.45)	(0.65)	(0.83)	(0.83)
ϕ_m	0.98***	0.53***	0.48**	0.29**	0.38**	0.50**	0.60**
	(0.36)	(0.20)	(0.18)	(0.14)	(0.15)	(0.20)	(0.24)
$\hat{\rho}$	0.86***	0.79***	0.81***	0.85***	0.87***	0.89***	0.90***
	(0.05)	(0.06)	(0.05)	(0.03)	(0.03)	(0.03)	(0.03)
R²	0.89	0.93	0.94	0.96	0.95	0.94	0.95
SEE	0.87	0.68	0.61	0.52	0.57	0.60	0.56
JB	0.00	0.00	0.17	0.41	0.90	0.67	0.10
J-stat	0.67	0.74	0.63	0.71	0.79	0.64	0.57

***(**/*) denotes significance at the 1% (5%/10%) level. Estimation period: 1979Q1 to 1998Q4,: estimation method: GMM; HAC-robust standard errors in parentheses; for further notes see table 1. Ex-post series as of March 1999. For further notes see Table 1a.

Table 2a: Real-time estimates of Equation (12)

	n=0	n=1	n=2	n=3	n=4	n=5	n=6
ϕ_p	2.17***	2.19***	2.43***	3.05***	2.64***	2.73***	3.56***
	(0.48)	(0.36)	(0.33)	(0.45)	(0.71)	(0.81)	(1.07)
ϕ_y	0.06	0.01	-0.09	-0.31**	0.00	0.04	-0.16
	(0.18)	(0.14)	(0.11)	(0.15)	(0.23)	(0.25)	(0.31)
$\phi_{\Delta y}$	2.41***	1.79***	1.53***	1.72***	2.57***	3.01***	3.57***
	(0.77)	(0.53)	(0.43)	(0.48)	(0.87)	(1.11)	(1.19)
ϕ_m	0.98***	0.61***	0.39**	0.17	0.60**	0.80***	0.91***
	(0.31)	(0.21)	(0.16)	(0.15)	(0.23)	(0.30)	(0.34)
$\hat{\rho}$	0.84***	0.82***	0.82***	0.85***	0.89***	0.91***	0.92***
	(0.04)	(0.04)	(0.04)	(0.03)	(0.02)	(0.02)	(0.02)
R^2	0.90	0.93	0.95	0.96	0.95	0.95	0.94
SEE	0.82	0.66	0.56	0.53	0.57	0.60	0.61
JB	0.00	0.14	0.67	0.45	0.91	0.58	0.04
J-stat	0.68	0.67	0.68	0.74	0.49	0.48	0.44

***(**/*) denotes significance at the 1% (5%/10%) level. Estimation period: 1979Q1 to 1998Q4,: estimation method: GMM; HAC-robust standard errors in parentheses.
Variables: left-hand-side variable: 3-month money market rate (end-of-quarter); right -hand-side variables: inflation gap according to cpi; level and change in the output gap with Bundesbank's own estimates of production potential. For further details on the data see Gerberding et al (2004)
To correct for extreme outliers in the residuals, it proved necessary to include a dummy variable in the estimations which is one in the first quarter of 1981 and zero otherwise. The dummy captures the jump in money market rates which occurred in February 1981 when the Bundesbank replaced its "normal" lombard loans by a new special lombard facility which cost 3 percentage points more. The instrument set includes the contemporary values of inflation and the price assumption (which were known to policy makers at the end of each quarter) as well as two lags of each explanatory variable. Pretesting suggests that this instrument structure is sufficient.
R^2: adjusted coefficient of determination; SEE: standard error of the regression; J-stat: p-value of the J-statistic on the validity of overidentifying restrictions ; JB: p-value of the Jarque Bera test of the normality of residuals.

Table 2b: Real-time estimates of Equation (12) with $\phi_y = 0$

	n=0	n=1	n=2	n=3	n=4	n=5	n=6
ϕ_p	2.30***	2.21***	2.26***	2.57***	2.64***	2.81***	3.07***
	(0.33)	(0.25)	(0.25)	(0.39)	(0.58)	(0.71)	(0.88)
$\phi_{\Delta y}$	2.57***	1.82***	1.47***	1.74***	2.57***	3.07***	3.44***
	(0.71)	(0.49)	(0.39)	(0.49)	(0.86)	(1.09)	(1.25)
ϕ_m	1.05***	0.61***	0.39***	0.30**	0.60**	0.78**	1.04***
	(0.30)	(0.21)	(0.14)	(0.14)	(0.23)	(0.30)	(0.39)
$\hat{\rho}$	0.85***	0.82***	0.82***	0.86***	0.89***	0.91***	0.92***
	(0.04)	(0.04)	(0.04)	(0.03)	(0.02)	(0.02)	(0.02)
R^2	0.90	0.93	0.95	0.96	0.95	0.95	0.94
SEE	0.82	0.66	0.56	0.52	0.56	0.59	0.60
JB	0.00	0.15	0.78	0.49	0.91	0.61	0.06
J-stat	0.76	0.75	0.77	0.77	0.58	0.57	0.53

***(**/*) denotes significance at the 1% (5%/10%) level. Estimation period: 1979Q1 to 1998Q4,: estimation method: GMM; HAC-robust standard errors in parentheses; for further notes see table 2a.

Table 3: Partial adjustment versus serial correlation in a real-time setting

	n=0	n=1	n=4	n=5	n=6
ϕ_p	2.12*** (0.33)	2.15*** (0.28)	2.35*** (0.43)	2.29*** (0.35)	2.51*** (0.35)
$\phi_{\Delta y}$	2.53*** (0.69)	1.74*** (0.53)	1.49* (0.81)	1.14* (0.67)	0.63 (0.46)
ϕ_m	0.93*** (0.30)	0.56** (0.22)	0.37* (0.22)	0.33* (0.18)	0.25** (0.11)
ρ'	0.84*** (0.04)	0.81*** (0.05)	0.85*** (0.05)	0.83*** (0.05)	0.80*** (0.06)
φ	0.12 (0.09)	0.12 (0.12)	0.12 (0.11)	0.14 (0.10)	0.13 (0.12)
R^2	0.20	0.24	0.47	0.46	0.44
SEE	0.67	0.65	0.55	0.56	0.57
JB	0.06	0.34	0.86	0.27	0.03
J-stat	0.68	0.62	0.47	0.41	0.73

***(**/*) denotes significance at the 1% (5%/10%) level. Estimation period: 1979Q1 to 1998Q4,: estimation method: GMM; HAC-robust standard errors in parentheses.
Variables: left-hand-side variable: 3-month money market rate (end-of-quarter); right - hand-side variables: inflation gap according to cpi; growth of the output gap with Bundesbank's own estimates of production potential; money gap: annual growth rates relative to target. For further details on the data see Gerberding et al (2004)
To correct for extreme outliers in the residuals, it proved necessary to include a dummy variable in the estimations which is one in the first quarter of 1981 and zero otherwise. The dummy captures the jump in money market rates which occurred in February 1981 when the Bundesbank replaced its "normal" lombard loans by a new special lombard facility which cost 3 percentage points more. The instrument set includes the contemporary values of inflation, the monetary target and the price assumption (which were known to policy makers at the end of each quarter) as well as two lags of each explanatory variable (except the monetary target). Pretesting suggests that this instrument structure is sufficient.
R^2: adjusted coefficient of determination; SEE: standard error of the regression; J-stat: p-value of the J-statistic on the validity of overidentifying restrictions ; JB: p-value of the Jarque Bera test of the normality of residuals.

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