Some Thoughts on Monetary Targeting vs. Inflation Targeting

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Abstract. We offer some empirical evidence on the likely scale of control and indicator problems surrounding alternative monetary targets and a direct inflation target. The links between monetary policy actions and inflation are estimated in dynamic linear models using the Kalman filter. We compare alternative intermediate-target and final-target monetary strategies using German data from the end of the Bretton Woods system until 1997. The estimation results show that broad money dominates narrow money as an intermediate target, while control problems involved in targeting broad money are larger than for direct inflation targets.

1. INTRODUCTION

During its first months of existence, the European Central Bank (ECB) has often been under fire for the lack of clarity of its monetary policy strategy. Whereas the final goal of price stability has already been determined in the Maastricht Treaty, the underlying monetary policy strategy remains somewhat austere: as it stands, the ECB’s strategy rests on two pillars, combining elements of inflation targeting with the use of an intermediate monetary target. Yet, it lacks core elements of both strategies: the binding announcement of monetary growth rates on the one hand and the publication of inflation forecasts on the other.1 Since the crucial task for the ECB will be to establish credibility as quickly as possible it will have to choose one of the strategies as soon as its experience with the transmission of monetary policies in Euroland permits.

While the strategies of monetary targeting and direct inflation targeting are not mutually exclusive at the operative level, their respective merits concerning their impact on the central bank’s credibility differ sharply from a theoretical point of view as shown by Cukierman (1995, 1996) and Svensson (1997). The

1. Recently, however, the ECB has started publishing an inflation outlook for the euro zone (European Central Bank, 1999, pp. 22ff.).
main advantages of monetary targets are twofold. First, monetary growth rates are closely related to the instruments of monetary policy, whereas a direct inflation target is much less controllable due to the long time lags involved in the transmission of policy actions. Second, direct inflation targeting is less transparent to the public, because taking into consideration various indicators obscures the decision-making process. However, the main advantage of an inflation target lies in its visibility, i.e. a larger fraction of the public understands the meaning of inflation as opposed to monetary growth.

Yet, the recent experiences with monetary targeting, particularly in Germany, differ sharply from these theoretical considerations: the Bundesbank’s control over monetary growth seems to have been diminishing considerably over the past decade (cf. e.g. von Hagen, 1995). Recently, Clarida and Gertler (1996), Clarida et al. (1997) or Bernanke and Mihov (1997) have questioned whether the Bundesbank can be regarded as a monetary targeter at all. Growth rates have become much more volatile, resulting in increased efforts to explain the failure to reach targets. The Bundesbank claimed that ‘special factors’ or ‘distortions’ dominated growth rates in the short run. This strategy has been successful in Germany – inflation rates are close to all-time lows. However, the situation facing the newly created ECB differs substantially from that of the Bundesbank. While the Bundesbank has built up its reputation over a long period, the ECB has to adhere strictly to its announced targets in order to build up credibility.

This raises several questions. First, if a monetary target were to be taken literally, could it be reached with the instruments of the central bank? Second, if this can be accomplished, does stable monetary growth translate into stable inflation rates? Third, how does a direct inflation target compare to an intermediate monetary target in terms of controllability? We address these questions using the framework introduced by Belongia and Batten (1992) and Dueker (1995), comparing control and projection errors in a state–space model of monetary targeting. We present an ex-post horse-race comparing two alternative strategies of monetary targets involving broad and narrow monetary aggregates on the one hand and a direct inflation target on the other. The analysis is carried out with German data for the period 1974:1 to 1997:1. We proceed as follows: Section 2 gives some theoretical background for the specification of the empirical model. In Section 3 we introduce the econometric methodology. Estimation results are presented in Section 4; a final section concludes.

2. The policy of the Bundesbank has sometimes been described as ‘monetary targeting in words’ and ‘inflation targeting in practice’.
3. The idea behind our procedure is also described by von Hagen (1998).
2. THEORETICAL BACKGROUND

The hypothesis that, in the long run, monetary growth alone determines inflation is built upon the theoretical assumption of a stable money demand function. Furthermore, the demand for money is considered to be a real phenomenon, i.e. not dependent on monetary policy actions. Given these assumptions the central bank can control inflation by simply stabilizing the nominal money supply. This raises the two empirical questions whether money demand is stable and whether money supply can be controlled by the central bank.

Given the difficulties of the Bundesbank to reach its targets, the stability of money demand in Germany has received considerable attention recently.\(^4\) In the standard approach, money demand depends positively on the price level \((P)\) and the real volume of transactions \((Y)\), and negatively on the opportunity costs of holding money \((i^O)\). In equilibrium, money demand is homogeneous of degree one in prices so that the equation is formulated in real terms. We allow for deviations from homogeneity by adding a lagged price level to the right-hand side of the equation. Hence, (inverted) real money demand in our model is specified as

\[
\Delta(p - m)_t = \beta_1 \Delta p_{t-1} + \beta_2 \Delta y_t + \beta_3 i^O_t \]

where lowercase letters except interest rates denote logarithms; \(i^O\) stands for the interest differential between the higher yielding asset and M’s own rate. The role of money demand in the concept of monetary targeting lies mainly in its role of linking monetary growth to the inflation rate. Hence, in its purest version monetary targeting would imply to expand central bank money according to the target and let market interest rates adjust so as to equilibrate demand and supply. In practice, however, central banks wish to avoid the resulting volatility of interest rates and follow a strategy of smoothing rates. This means that, in the short run, they control interest rates rather than monetary growth. In the case of the German Bundesbank, for example, repo repurchase rates were only gradually adjusted in order to reach monetary targets.

Because of this, our model of the money supply process differs from the textbook money multiplier approach which views central bank money as the policy instrument and relies on a constant relationship between central bank money and money created in the banking sector. Instead, we consider the repo rate as the policy instrument which influences credit supply by the banking sector.\(^6\) Except for the fact that this seems appropriate from an operative viewpoint, it is also consistent with our aim to model the interaction of supply

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5. \(\Delta\) is the first difference operator, \(\Delta x_t = x_t - x_{t-1}\).
6. This is consistent with the findings by Clarida and Gertler (1996).
and demand factors in the transmission of policies because money demand of
the private sector determines the demand for central bank money by the
banking sector.

In a very simple model that neglects the net foreign position of banks as well
as credits to the government, credit supply equals money supply (see Bofinger
et al., 1999). Hence, we have to derive a credit supply function of the banking
sector. Banks behave as profit maximizers, so our model builds on the
determination of profits in the banking sector. Banks maximize their profits \( \Pi_t \)
generated by supplying credit \( M_t \). It is a function of the credit revenue \( R_t \) and
refinancing cost \( C_t \) on the one hand and expected costs of credit failure \( F_t \) on
the other.

\[
\Pi_t = f\left( \frac{R_t}{C_t} \right) \cdot M_t - F_t \cdot M_t^2
\]  

(2)

Starting with the last term on the right-hand side, we assume the risk of credit
failure to be increasing over-proportionately with the volume of credit
outstanding. Additionally, the share of credit failure in total credits is a
function of current and past economic performance which we operationalize
by the output gap. Hence

\[
F_t = \prod_{j=0}^{t} \left( \frac{1}{2} \frac{Y_j}{Y_j^p} \right)^{-\gamma}
\]

(3)

where \( Y^p \) stands for potential (real) output. Turning now to the first part
of equation (2), refinancing costs \( C_t \) are determined by the interest rate \( r \) that the
central bank charges for credits to the banking sector, so let the refinancing
costs associated with a given level of credits be \( C_t = (1 + r_t)^\delta \). Finally, credit
revenues increase with the differential between the interest paid to the banks
by their debtors and the interest rate paid on deposits. Since at any point of
time, banks have credits outstanding their revenue also depends on past values
of this interest differential. This leads to

\[
R_t = \prod_{j=0}^{t} \left( \frac{1 + i_t}{1 + r_t} \right)^{\alpha}
\]

Collecting terms, we may write profits as

\[
\Pi_t = \frac{\prod_{j=0}^{t} \left( \frac{1 + i_j}{1 + r_j} \right)^{\alpha}}{(1 + r_j)^{\delta}} \cdot M_t - \prod_{k=0}^{t} \left( \frac{1}{2} \frac{Y_k}{Y_k^p} \right)^{-\gamma} \cdot M_t^2
\]

(4)

Maximizing profits with respect to \( M_t \) and taking logarithms yields the
following optimal credit supply:
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\[ m_t^* = \sum_{j=0}^{t} \alpha(i_j - r_j) - \delta r_t + \sum_{k=0}^{t} \gamma(y_k - y_k^p) \]  

(5)

where, again, lowercase letters except interest rates denote logs. However, banks are unable to adjust their credit supply costlessly and hence face the quadratic loss function

\[ L_t = \lambda(m_t - m^*)^2 + (1 - \lambda)(m_t - m_{t-1})^2 \]  

(6)

which we minimize with respect to \( m_t \). Renaming parameters for clarity, we may write in first differences of logs

\[ \Delta m_t = \beta_1 \Delta m_{t-1} + \beta_2 \Delta r_t + \beta_3 (i - r)_t + \beta_4 (y - y^p)_t \]  

(7)

where \( \beta_1 = 1 - \lambda, \beta_2 = -\delta \lambda, \beta_3 = \alpha \lambda \) and \( \beta_4 = \gamma \lambda \). Note that \( i \) represents an overall indicator for the prevailing level of interest rates rather than a specific rate.

In sharp contrast to the idea of monetary targeting, which stems from theoretical assumptions about the monetary transmission mechanism, stands the idea of targeting inflation direct. Most countries that are following direct inflation targets have – among other things – chosen them because empirical money demand was considered too unstable.7

Because of the well-known lags in the transmission mechanism of monetary policy it is impossible for the central bank to control inflation directly. Therefore ‘inflation targeting’ in practice means ‘inflation forecast targeting’ (Svensson, 1997). Recognition of this need for forecasts immediately raises the practical difficulty to specify the forecasting process. In the empirical section below we will use an augmented output gap model whose precise specification will be an empirical matter.

3. METHODOLOGY

After the above dose of preliminaries, let us now turn to the econometric issues involved. Any fruitful empirical procedure analysing the performance of alternative monetary strategies has to take into account the short-run risks and forecast errors associated with alternative monetary policy strategies. We compare the prediction errors that would have been incurred in the past under M3 targeting, used by the Bundesbank since 1988, M1 targeting and direct inflation targeting. In order to deal with the instability caused by changes in monetary policy, one can use time-varying parameter models which are less prone than fixed-effect models to break down as time passes. In order to assess the monetary policy forecast errors, we therefore consider a time-varying parameter model and German quarterly data over the period 1974:1 to 1997:1 to conduct an \textit{ex-post} horse-race among the alternative strategies.

Considering a target variable $y_{t+k}$ and a vector of weakly exogenous variables $x_t$ we allow the parameters $\beta_t$ to vary over time:

$$y_{t+k} = x'_t \beta_t + \epsilon_t$$  \hspace{1cm} (8)$$

where $\epsilon \sim N(0, \Sigma)$ and $k \in \mathcal{N}$ is the forecast horizon. Since we cannot observe the parameters directly, we use the Kalman filter to gain information about the time-varying parameters. Assuming that new information has a strong impact on the change in the parameters, we let the parameters move according to a random walk:

$$\beta_t = \beta_{t-1} + u_t$$ \hspace{1cm} (9)$$

where $u \sim N(0, \Sigma_u)$. From these equations, we can calculate the predictions for $\beta_{t|t-1}$ and $y_{t+k|t-1}$ as\(^8\)

$$\beta_{t|t-1} = \beta_{t-1}$$ \hspace{1cm} (10)$$

and

$$y_{t+k|t-1} = x'_t \beta_{t|t-1}$$ \hspace{1cm} (11)$$

The prediction error $y_{t+k} - y_{t+k|t-1}$ will serve as our measure of controllability of the dependent variable.\(^9\)

4. EMPIRICAL RESULTS

Consider a monetary targeting framework first. If the Bundesbank targets inflation via a monetary aggregate, its policy is subject to two types of errors. The first stems from the instability of money demand, the second from the insecurity of controlling the monetary aggregate with the bank’s instruments:

$$\Delta p_{t+k} - \Delta r_t = \Delta p_{t+k} - \Delta m_{t+k} + \epsilon_{\text{Instab},t} + \Delta m_{t+k} - \Delta r_t + \epsilon_{\text{Contr},t+k}$$ \hspace{1cm} (12)$$

We can separate this equation and rearrange terms to yield an equation for the inverted real money demand as in equation (1):

$$\Delta p_{t+k} - \Delta m_{t+k} = \beta_0 + \beta_1 \Delta p_{t+k-1} + \beta_2 \Delta m_{t+k-1} + \beta_3 \hat{h}_{t+k-1} + \epsilon_{\text{Instab},t+k}$$ \hspace{1cm} (13)$$

and the credit supply function as in equation (7):

$$\Delta m_{t+k} = \beta_1 \Delta m_t + \beta_2 \Delta r_t + \beta_3 (i - r)_t + \beta_4 (y - y^*)_t + \epsilon_{\text{Contr},t+k}$$ \hspace{1cm} (14)$$

8. Let $\xi_t$ be all information available at time $t$; we use $x_{t|s}$ as a shorthand for $E(x_t|\xi_s)$.

9. Since we assume a direct influence of $x_t$ on $y_{t+k}$ we cannot simply do iterative one-step forecasts as usual (e.g. Hamilton, 1994, pp. 384f.). Therefore, we have adapted the filter for longer forecast horizons. Since the mathematics is tedious it is relegated to Appendix A.

10. If banks do not adjust credits instantaneously $k$ will be larger than one. As this is a realistic setting we allowed for a longer forecast horizon in equation (7). See the discussion below.
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The relevant interest rate in the money demand function should capture the opportunity costs of holding money, which equals the difference between a long-run rate and the monetary aggregate’s own rate. Since we are not aware of a satisfying way to measure the latter, it is captured by the constant. Note that we estimate an inverse demand function, so the expected signs of the coefficients have all been multiplied by minus one. To avoid problems of endogeneity we used lagged right-hand variables as instruments.

As opposed to this framework, direct inflation targeting carries only one error, which combines the difficulty to control inflation with the insecurity to predict it. Since there exists no closed-form theoretical framework for direct inflation targeting, we use the same information set as in the monetary targeting case so as to keep the horse-race a fair one. Hence, we perceive inflation targeting as described in the following augmented output gap model:\(^\text{(15)}\)

\[
\Delta p_{t+k} = \beta_1 \Delta r_t + \beta_2 i_t + \beta_3 (y - y^p)_t + \beta_4 \Delta y_{t+k-1} + \epsilon_{\text{Contr.Inst.}t+k}
\]

The sign for the long-run interest rate is ambiguous since it may represent the investment environment beyond the central bank’s influence. A high interest rate restrains firms from investing and thus keeps inflation low, resulting in a negative sign for \(\beta_2\). However, the long-term interest rate could also serve as an indicator of inflation expectations. In this case the rate would be positively correlated with future inflation, and \(\beta_2\) would be positive. Because of the long lag we expect this to be the dominating effect.

Owing to the long forecast horizon the Bundesbank incurs two types of systematic errors: it has to project GDP and the output gap when forecasting inflation in \(t\), and it only learns about the long-run influences when inflation is realized in \(t + k\). We simplify the first problem and use current GDP and the output gap as rough proxies. The second problem leads to a modification of the Kalman filter which we derive in Appendix A.

As noted above, our aim is to model the decision-making process of the central bank at each point in time. Hence, we only use the information available at time \(t\). This implies that we filter only once and initialize the Kalman filter using prior information rather than smooth and optimize over the complete information set.\(^\text{(12)}\) In particular, we used the signs for the coefficients given below equations (13) to (15). The coefficients’ size was estimated using the first five years of data. Because volatile data contain much

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11. It is generally accepted that inflation is closely related to the pace of economic activity. The most common formation of the gap model is that there is a level of output potential that is consistent with a stable rate of inflation. There is considerable empirical support for the gap model from a large number of studies (cf. e.g. International Monetary Fund, 1991; OECD, 1994).

12. Alternatively, we maximized the likelihood and smoothed the parameters (see e.g. Lütkepohl, 1993; Hamilton, 1994). However, the relative forecasting properties of the two frameworks remained unchanged.
noise in a signal extracting setting we associate small parameters with volatile data. Second, at longer forecast horizons noise will blur the information contained in the data, which again leads to smaller prior parameters. Denoting the first five years of data by $\tilde{x}$ we set the coefficients’ prior mean to $\mu_\beta = 0.01(1/2\sigma_\tilde{x}k)$.

In order to allow for incorrect assumptions about the parameters’ signs we chose a conservative confidence level of 90 per cent and set prior variances accordingly. One difference compared with ‘true’ ex-ante forecasts is, however, that the data used in the paper are the latest revised estimates available, whereas the ‘true’ ex-ante forecasts have to use data available at the time of the forecast, data that are often subsequently revised.

We also face the problem of estimating an optimal lag for the effects of monetary policy in both frameworks. With respect to the direct targeting case, empirical findings indicate that monetary policy has strongest real effects about eight quarters ahead (Romer and Romer, 1989; Loungani and Rush, 1995), implying that price rigidities have an impact at shorter horizons. Assuming that inflation is rather closely related to output fluctuations we can expect the strongest effect of monetary policy on inflation at a horizon of about two years. New Zealand adopted a time frame for its initial inflation target of two years (Mishkin and Posen, 1997, p. 39), and the Bank of England publishes inflation forecasts of up to eight quarters (Bofinger et al., 1996, p. 368). Hence, we tried forecast horizons of six to 12 quarters. Anything between seven and 12 quarters yields the predicted signs for the parameters. To save space, we report results for a lag of eight quarters.

In the monetary framework, we used the forecast horizon applied by the Bundesbank, who – with the exception of 1998/99 – announced monetary targets for one year ahead. Hence, we chose the forecast horizon of four quarters in equation (14) in correspondence with the horizon implied by the Bundesbank. Note that in terms of policy-making the two frameworks of monetary and inflation targeting function with forecast horizons of four and eight quarters, respectively. Representing reality adequately, however, this comparison is unsatisfying from a statistical point of view, because it draws on different policies and different horizons at the same time. Therefore, we compare forecast errors from both strategies at both horizons.

We use quarterly data for M1, M3, the call money rate, GDP, the output gap, the CPI and a long-term interest rate (Umlaufrendite) for the period 1974:1 until 1997:1. Where applicable, we use annualized quarterly growth rates. Monetary aggregates, inflation and GDP were seasonally adjusted and the effects of German unification on M1, M3 and GDP were removed by an impulse dummy. Exact definitions are given in Appendix C.

Running the Kalman filter we get forecast errors from equations (13) to (15) as well as time paths for the coefficients. Table 1 gives some statistics for serial independence of the residuals from the estimation. Since residuals are

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13. The prior parameters are reproduced in Appendix C.
14. We are grateful to the anonymous referee for drawing our attention to this point.
stationary, our model seemingly captures long-run relationships as well as short-run dynamics among the variables involved. Therefore, we do not misspecify the equations when we do not include levels of the I(1) variables. However, in this setting we cannot interpret the coefficients’ sizes.15

The estimation yields the time paths of the coefficients depicted in Appendix B.16 Over the whole period, most parameters have the signs we anticipated. To construct confidence intervals we exploit our theoretical prejudices about the influence of the right-hand variables on the dependent variable. Since we want to test $H_0: |\beta| > 0$ we drew 90 per cent error bands, which is equivalent to a 5 per cent significance level in a one-sided test. It turns out that not all coefficients are significantly different from zero, which we attribute to the size of our sample. Furthermore, we find that several parameters appear to be varying, whereas others may be constant over the whole period.

Unfortunately, we are unable to resolve the controversial question whether M3 demand is stable. However, looking at Figures 5 and 6, it seems that parameters in the M3 demand equation vary much less than in the M1 demand equation. Hence by eyeball econometrics, money demand for M3 is more stable than M1 money demand. Looking at credit supply, the output gap has a highly varying influence on both monetary aggregates. In contrast, the link between the central bank’s instrument and money varies little over time. This may provide a rationale for targeting a monetary aggregate.

As a measure for the Bundesbank’s ability to control the targeted variable and predict inflation in the various settings we use the forecast errors from the two frameworks. As a first measure, Table 2 shows the root mean squared forecast error (RMSE). The table demonstrates that, on the one hand, M3 targeting would have involved a smaller RMSE than the one incurred using a narrow monetary aggregate. On the other hand, direct inflation targeting carries even smaller errors than M3 targeting. Since the Bundesbank has not followed a rigorous monetary target in the past, we use the sum of the errors
from the credit supply and the money demand functions to permit temporary escapes of the monetary aggregate. Since the errors are negatively correlated (with a correlation coefficient of $-0.89 [-0.82]$ for M1 [M3] targeting) the compound errors are smaller than the sum of the control and instability errors.

Table 3 compares RMSEs when $M_t^8$ is used as an intermediate target. This case does not differ much from the first case. Comparing across the tables, it is also evident that monetary targeting with a forecast horizon of four quarters induces a larger RMSE than inflation targeting over eight quarters.

Continuing with the last case we now look at the errors’ development over time. Figure 1 shows that the prediction using M1 (solid line) is over the whole period worse than the one from any of the other two policies. To see whether the difference between M3 and direct targeting is significant, we calculated confidence intervals by bootstrap. Figure 2 shows that the RMSE is significantly larger for M3 targeting than for inflation targeting at least since the early 1990s, although we accounted for the unification shock in the monetary aggregates in 1990.

The assumption underlying the RMSE is a quadratic loss function for the Bundesbank. We now drop this assumption and compare the size of the forecast errors on a more general level. To this end, we apply two non-parametric tests described in Diebold and Mariano (1994) as a second measure. As opposed to the RMSE these tests do not assume an explicit loss function. The Wilcoxon signed-rank and Diebold–Mariano sign tests confirm at least at the

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<th>Table 2</th>
<th>RMSE of four-quarter forecasts</th>
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<td></td>
<td>Control error</td>
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<tr>
<td>M1</td>
<td>0.0122</td>
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<tr>
<td>M3</td>
<td>0.0075</td>
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<td>Inflation direct</td>
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<tr>
<th>Table 3</th>
<th>RMSE of eight-quarter forecasts</th>
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<tr>
<td></td>
<td>Control error</td>
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<tr>
<td>M1</td>
<td>0.0120</td>
</tr>
<tr>
<td>M3</td>
<td>0.0074</td>
</tr>
<tr>
<td>Inflation direct</td>
<td>–</td>
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17. Our results are robust if we compare the two frameworks at the same horizon $k = 4$. They are even enforced if $k = 8$ is used for both equations.
18. It is obvious that confidence bands may be asymmetric if we bootstrap from the sample. In periods where forecast errors are small (large) compared to the whole sample period RMSEs are in the lower (upper) part of the confidence band, in extreme cases even outside.
Figure 1  Root mean squared errors from different targeting policies

Note: Root mean squared prediction errors from M1 targeting (solid line), M3 targeting (dashed line) over a forecast horizon of four quarters and direct targeting (dotted line) over eight quarters.

Figure 2  RMSEs from two different targeting policies

Note: Root mean squared prediction errors with 90 per cent confidence bands from M3 targeting (thin solid with confidence bands in short dashes) and direct targeting (thick solid with dotted bands).
10 per cent level that over the whole period forecast errors from direct targeting have been smaller than errors incurred using M3 targeting.\textsuperscript{19}

As a last indicator, we consider the usefulness of the forecasts. Looking at Figure 3 it becomes clear that direct targeting in our framework generates meaningful forecasts. In contrast, M3 targeting leads to forecasts that tend to follow inflation rather than leading it. Whereas the direct prognosis predicts structural breaks as in 1983 or 1993, the forecast using M3 does not. Also, the direct forecast predicts the correct sign of inflation growth in over 70 per cent of the cases whereas the monetary aggregate leads to correct forecasts of direction in less than half of the observations. Note that forecasts from direct targeting overshoot in the early 1990s, a period of large disturbances induced by German reunification. These disturbances are identified as information by the filter. Yet, it is noteworthy that direct targeting returns to highly precise forecasts directly afterwards. During this period, forecasts from M3 targeting are smoother than those from direct targeting because we used knowledge outside

\textsuperscript{19} Test results (and $p$-values) were $-2.27$ (0.985) and $-1.33$ (0.907), respectively. Comparing the frameworks at $k = 4$, both tests reject at the 1 per cent level. Using $k = 8$, however, only the Wilcoxon test rejects at the 5 per cent level.
the model to create dummies which remove these disturbances from the monetary aggregate.

5. CONCLUSIONS

What we are offering in the paper is a thought experiment. The paper’s purpose is to investigate at the operational level the performance of alternative monetary policy frameworks in a case study using German data. All things considered, our forward-looking framework offers two tentative conclusions. First, when comparing different monetary aggregates broader intermediate targets dominate narrow ones at least with respect to controllability of the ultimate objective of monetary policy. Thus the paper offers some evidence illustrating why the Bundesbank preferred targeting M3 over M1. Second, the uncertainty involved in targeting inflation directly is lower than it is for any of the intermediate targets considered. In other words, to the extent that the German evidence can be taken as indicative for the situation prevailing in the newly created EMU, the ECB would be well advised to consider an inflation-targeting framework.

APPENDIX A: THE KALMAN FILTER FOR A LONGER TIME HORIZON

The usual Kalman filter model is captured in equations (8) and (9) with $k = 0$. The updating step can be calculated given $\beta_t$'s prior distribution

$$ P(\beta_t|\xi_t) = \frac{1}{N_1} \exp \{-\frac{1}{2} (\beta_t - \beta_t_{t-1})' \Sigma_\beta(t|t-1)^{-1} (\beta_t - \beta_t_{t-1}) \} $$

where $\xi_t$ is all information available at time $t$ and defining $x_t|\xi_t := E(x_t|\xi_t)$. Combining with equation (8) this yields the posterior probability density for $\beta_t$:

$$ P(\beta_t|\xi_t) = \frac{1}{N_2} \exp \{-\frac{1}{2} (\beta_t - \beta_t_{t-1})' \Sigma_\beta(t|t-1)^{-1} (\beta_t - \beta_t_{t-1}) \} $$$$ \cdot \exp \{-\frac{1}{2} (y_t - x_t\beta_t)' \Sigma_\epsilon^{-1} (y_t - x_t\beta_t) \} $$

Taking logarithms and evaluating the function in terms quadratic and linear in $\beta_t$ yields the second and first moments of $\beta_t$'s posterior distribution

$$ \Sigma_\beta(t|t)^{-1} = \Sigma_\beta(t|t-1)^{-1} + x_t' \Sigma_\epsilon^{-1} x_t $$

and

$$ \beta_{t|t} = \Sigma_\beta(t|t)(\Sigma_\beta(t|t-1)^{-1} \beta_{t|t-1} + x_t' \Sigma_\epsilon^{-1} y_t) $$
Consider now a modified version of the model, where some variables influence the dependent variable only with a lag, whereas others have immediate influence. We can split $x$ and $\beta$ in an upper and a lower part so that

$$y_t = \bar{x}_t \bar{\beta} + \epsilon_t = \begin{bmatrix} x_t^{\mu} \\ x_{t-k}^{\mu} \end{bmatrix} \begin{bmatrix} \beta_t^{\mu} \\ \beta_{t-k}^{\mu} \end{bmatrix} + \epsilon_t \quad \text{with } \epsilon \sim N(0, \Sigma) \quad (20)$$

where we use bars over variables to keep in mind that the time index represents the most recent part of the respective vector. Collecting information at time $t$, we now have the log-likelihood

$$\ell(\bar{\beta}_t | y_t) = c - \frac{1}{2} \left\{ (\bar{\beta}_t - \bar{\beta}_{t|t-1}) \Sigma_{\beta} (t|t-1)^{-1} (\bar{\beta}_t - \bar{\beta}_{t|t-1}) + (y_t - \bar{x}_t \bar{\beta}_t) \Sigma_{\epsilon}^{-1} (y_t - \bar{x}_t \bar{\beta}_t) \right\} \quad (21)$$

where

$$\bar{\beta}_{t|t-1} = \begin{bmatrix} \beta_{t|t-1}^{\mu} \\ \beta_{t-k|t-k-1}^{\mu} \end{bmatrix} \quad (22)$$

Evaluating this as in (18) and (19) the posterior $\beta_{t|t}$ now has variance

$$\Sigma_{\beta}(t|t) = \Sigma_{\beta}(t|t-1)^{-1} + \begin{bmatrix} x_t^{\mu} \\ 0_{x^l} \end{bmatrix} \Sigma_{\epsilon}^{-1} \begin{bmatrix} x_t^{\mu} \\ 0_{x^l} \end{bmatrix} \quad (23)$$

and mean

$$\beta_{t|t} = \Sigma_{\beta}(t|t) \left( \Sigma_{\beta}(t|t-1)^{-1} \beta_{t|t-1} + \begin{bmatrix} x_t^{\mu} \\ 0_{x^l} \end{bmatrix} \Sigma_{\epsilon}^{-1} y_t \right) \quad (24)$$

where $0_{x^l}$ is a matrix of zeros with the dimensions of $x^l$.

At time $t - k$ the filter now forecasts $y_t$ as $y_{t|t-k} = \bar{x}_{t|t-k} \bar{\beta}_{t|t-k}$. However, this projection carries the inflated error term $\epsilon_t + x_t^{\mu} \beta_t - x_{t|t-k}^{\mu} \beta_{t|t-k}^{\mu}$. This is part of the cost for using a longer horizon for the forecast. The other cost is incurred when at time $t$ we receive information about $y_t$, and can use this to update the estimation of $\beta_t^{\mu}$ but only to update $\beta_{t-k}^{\mu}$ rather than $\beta_t^{\mu}$. Using (22), we can also estimate $\ell(\beta_{t-k}^{\mu} | y_t)$, and hence the posterior’s parameters

$$\Sigma_{\beta}(t-k|t-k) = \Sigma_{\beta}(t-k|t-k-1)^{-1} + \begin{bmatrix} 0_{x^u} \\ x_{t-k}^{\mu} \end{bmatrix} \Sigma_{\epsilon}^{-1} \begin{bmatrix} 0_{x^u} \\ x_{t-k}^{\mu} \end{bmatrix} \quad (25)$$

and

$$\beta_{t-k|t-k} = \Sigma_{\beta}(t-k|t-k) \left( \Sigma_{\beta}(t-k|t-k-1)^{-1} \beta_{t-k|t-k-1} + \begin{bmatrix} 0_{x^u} \\ x_{t-k}^{\mu} \end{bmatrix} \Sigma_{\epsilon}^{-1} y_t \right) \quad (27)$$

20. The last step is obvious considering that $\xi_{t-k} \ldots \xi_{t-1}$ add no information that is relevant to $\gamma_{t-k}$.
Assuming this posterior as $\beta_{t+1}'$’s prior we get the following steps for the modified filtering procedure:

1. Prediction step

   $$\tilde{\beta}_{t|t-1} = \eta \tilde{\beta}_{t-1|t-1}$$
   $$\Sigma_{\beta}(t|t - 1) = \eta \Sigma_{\beta}(t - 1|t - 1)\eta' + \Sigma_u$$

2. Correction step

   $$\Sigma_{\beta}(t|t) = \left\{ \Sigma_{\beta}(t|t - 1)^{-1} + \bar{x}_t'\Sigma_{\epsilon}^{-1}\bar{x}_t \right\}^{-1}$$
   $$\tilde{\beta}_{t|t} = \Sigma_{\beta}(t|t) \left( \Sigma_{\beta}(t|t - 1)^{-1} \tilde{\beta}_{t|t-1} + \bar{x}_t\Sigma_{\epsilon}^{-1}y_t \right)$$

3. Forecasting step

   $$y_{t+k|t-1} = \bar{x}_{t+k|t} \begin{bmatrix} \beta_{t+k|t-1} \\ \beta_{t|t-1} \end{bmatrix}$$

This procedure includes the usual Kalman filter as a special case.

**APPENDIX B: FIGURES**

![Figure 4](image.png)

**Figure 4**  Time paths of coefficients for direct inflation targeting

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Figure 5  Time paths of coefficients for M1 demand (upper four panels) and supply (lower four panels)
Figure 6  Time paths of coefficients for M3 demand (upper four panels) and supply (lower four panels)
APPENDIX C: DATA

We use quarterly data for M1, M3, the overnight interest rate, GDP, the output gap, the CPI and the yield on obligations with a maturity of ten years (*Umlaufsrendite*) from 1974:1 until 1997:1, totalling 93 observations. All data except for the output gap are drawn from the Bundesbank database. The output gap is published by the Ifo Institute based on survey data. The monetary aggregates M3 and M1, inflation and GDP were adjusted for seasonal effects using multiplicative X11. We removed the effects of German unification in 1990:2 and 1990:3 on the monetary aggregates by an impulse dummy. The same was achieved for the GDP series in 1991:1 since at this point we switch from West German data to GDP data for the unified Germany. Quarterly growth rates measured by first differences of logs were annualized.

**Table 4** Prior parameters

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<td>$r$</td>
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<tr>
<td>$y$</td>
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<td>$y^p$</td>
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<table>
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<td>(intermediate target)</td>
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<tr>
<td>(M3)</td>
<td>(M1)</td>
<td>(M3)</td>
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REFERENCES


