The Calvo Model of Price Setting and Inflation Dynamics in Germany

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Abstract: This paper tests the empirical fit of the forward-looking New-Keynesian Phillips Curve in Germany. The Calvo model of staggered price setting implies that inflation dynamics are driven by the present-value of future real marginal costs. We exploit forecasts of future real marginal costs generated by VAR models to assess the extent to which the model matches the behavior of actual inflation. The model replicates the overall dynamics of German inflation well at first sight. However, a set of bootstrapped confidence bands reveals that this seemingly favorable result is consistent with both a fitting and a failing model.

Keywords: Calvo contracts, New Keynesian Phillips Curve, present-value model, VAR, bootstrap

JEL classification: E31, E32

1 Introduction

Models with nominal rigidities and monopolistic competition have become the canonical framework to study inflation dynamics. The most widely used assumption in this New Keynesian environment to generate price stickiness is to let firms each period reset prices with a fixed probability. This price setting scheme that was proposed by Calvo (1983) implies that inflation dynamics are forward-looking. The resulting New Keynesian Phillips Curve (NKPC) relates current inflation to expected future inflation and a measure of current real activity. Furthermore, it can be shown that the inflation rate is given as the present-value of the entire expected path of future real marginal costs.

In this paper we assess the empirical fit of the present-value relation implied by the Calvo price setting scheme as it lends itself to a well-known empirical approach.[2] The forward-looking nature of inflation dynamics can be studied using the seminal approach proposed by Campbell and Shiller (1987). Although originally applied to the term structure of interest rates and the present-value formulations of stock and bond prices, this empirical approach is easily adopted to the purpose of this paper. Specifically, we can employ VAR based forecasts to generate a series of model-consistent or "fundamental" (Galí, Gertler, and López-Salido 2001) inflation that is supposed to match the behavior of actual inflation if the model is correct. Prominent contributions that exploit the present-value structure for U.S. data are Sbordone (2002, 2004) and Kurmann (2003). To date, the present-value implications have not been tested for Germany.

Coenen and Levin (2004) recently find that the Calvo model of staggered price setting provides a good description of the German inflation process. They estimate a truncated Calvo model augmented with real rigidities by means of a minimum-distance estimator. Here, in contrast, we utilize the present-value implications of the standard Calvo model. This paper assesses the model's explanatory power with quarterly German data from 1973 to 2004. Germany is a particularly well suited country to evaluate the Calvo model since the Bundesbank's high credibility over more than two decades is a supportive environment for the model's forward-looking character. If the model fails under these favorable circumstances, it is even more likely to do so in more adverse monetary environments that have gained less credibility.

We follow Kurmann (2003) and take account of estimation uncertainty. Since forecasts

[2] Galí, Gertler, and López-Salido (2001), Jondeau and Le Bihan (2001), and Benigno and López-Salido (2002) are the main contributions for evidence on the Calvo model with European data. These papers mainly use GMM techniques to estimate the New Keynesian Phillips Curve relation.

derived from VAR estimates are mere point estimates, plotting the implied inflation rate disguises the uncertainty involved in the estimation process. Hence, we assess whether the model indeed provides a reliable description of inflation dynamics. We find that the forward-looking Calvo model fits well at first sight only. Large confidence bands impair the model's explanatory power.

The present paper is organized as follows. The next section briefly sketches the Calvo model and the New Keynesian Phillips Curve as well as the present-value relation for inflation. Section 3 presents the estimation strategy, discusses estimation uncertainty and elaborates the bootstrap approach to calculate confidence intervals around standard measures of fit. Section 4 presents the results and discusses their robustness. Finally, section 5 concludes.

2 The Calvo model of inflation dynamics

In this section we use a stylized log-linear model to derive the basic present-value relation for inflation that is central to most specifications of the New Keynesian Phillips Curve.

Consider the case of staggered price setting put forward by Calvo (1983). We concentrate here on Calvo-style price setting behavior due to its parsimony and tractability.[3] According to the Calvo model, each firm adjusts its price during the current period with a fixed probability $1-\mu$ where $0<\mu<1$. Firms minimize the discounted future deviations of their price from the price they would set if prices were fully flexible. It can be shown that this problem results in an optimal reset price

$$p_t^* = (1-\phi\mu)\sum_{k=0}^{\infty}(\phi\mu)^k E_t\{nmc_{t+k}\} \tag{1}$$

with a subjective discount factor ϕ. The optimal reset price is set equal to a weighted average of the prices that it would have expected to set in the future if there were no price rigidities. In a frictionless market this price would equal a fixed markup (which we set to zero for expositional purposes) over marginal costs. In setting prices each firm takes the expected path of future nominal marginal costs, nmc_t, into account. The price level p_t is given as a convex combination of the lagged price level and the optimal reset price p_t^*

$$p_t = \mu p_{t-1} + (1-\mu)p_t^* \tag{2}$$

[3] Roberts (1995) shows that fixed length contracts proposed by Taylor (1980) result in similar inflation dynamics and Sbordone (2002) shows that both models of price setting imply a similar common trend restrictions.

Combining these two equations gives the aggregate price level as the present-value of expected future nominal marginal costs

$$p_t = \mu p_{t-1} + (1-\mu)(1-\phi\mu) \sum_{k=0}^{\infty} (\phi\mu)^k E_t \{nmc_{t+k}\} \tag{3}$$

The higher the probability μ, the more persistent is the price level. In the limiting case of perfectly flexible prices (i.e. $\mu \rightarrow 0$), the optimal reset price and, thus, the price level are determined only by the current level of marginal costs, $p_t = nmc_t$.
From this model we can derive the NKPC (see, e.g. Galí and Gertler, 1999)

$$\pi_t = \phi E_t \pi_{t+1} + \gamma rmc_t \tag{4}$$

Inflation (in deviation from the zero inflation steady state) is determined by expected future inflation and current real marginal costs, where $\pi_t = p_t - p_{t-1}$ is the inflation rate, rmc_t denotes a measure of real marginal costs and E_t is the expectations operator. The composite parameter γ is given by $(1-\mu)(1-\phi\mu)\mu^{-1}$. Repeated substitution yields

$$\pi_t = \gamma \sum_{k=0}^{\infty} \phi^k E_t rmc_{t+k} \tag{5}$$

Equation (5) posits that the inflation rate at time t is a fraction of the present-value of the expected path of future real marginal costs.
Real marginal costs are given by the ratio of the real wage rate to the marginal product of labor. Let's assume a simple production technology of the form $Y_t = A_t L_t$. Marginal costs are then given by $\frac{W_t}{P_t A_t} = \frac{W_t L_t}{P_t Y_t} = S_t$, where S_t is the labor share of income. Linearizing this expression gives a simple representation of deviations of real marginal costs from their mean in terms of the deviations of the labor share from the steady-state value

$$rmc_t = \hat{s}_t \tag{6}$$

The forward-looking Phillips curve is frequently criticized for its lack of inflation inertia. This has led many researchers to assume that some firms follow rule-of-thumb price setting behavior or index the price setting to past inflation. These ad-hoc assumptions give rise to lagged inflation entering the Phillips curve specification (4). However, Coenen and Levin (2004) argue that backward-looking behavior plays no role in the German inflation process and a forward-looking specification is justified "in the context of a stable policy regime with a transparent and credible inflation objective" (p. 5). Furthermore, recent results of Banerjee and Batini (2004) support the notion that backward-looking behavior does not apply in the case of Germany. Therefore, we abstain from including backward-looking behavior into the empirical model and restrict the analysis to the forward-looking Phillips curve. Since our sample period ends in 2003 and, hence, includes the start of European Monetary Union in 1999, which might imply a less credible policy regime, we will later check whether the model exhibits a better empirical fit when estimated through 1998.

3 Estimation strategy and data

Campbell and Shiller (1987) propose a well-known framework to assess the fit of forward-looking present-value models. As a clear advantage, this approach does not involve making assumption about the structure of the whole economy in the application of maximum likelihood methods or the choice of appropriate instruments in an instrumental variables estimation. In a first step, we derive the cointegration restriction implied by the forward-looking model. In a second step, we present the estimation strategy based upon VAR projections as a proxy for market expectations.

3.1 The cointegration restriction

The Calvo model imposes a testable restriction on the long-run dynamics of the price level and the level of nominal marginal cost. To see this, subtract nmc_t from both sides of (3) and rearrange. We obtain

$$rmc_t = nmc_t - p_t = \left(\frac{\mu}{1-\mu}\right)\Delta p_t - \sum_{i=1}^{\infty}(\phi\mu)^i E_t\left\{\Delta nmc_{t+i}\right\} \qquad (7)$$

with the difference operator given by Δ. Equation (7) specifies real marginal cost, rmc_t, as the present-value of the path of changes in nominal marginal costs. This expression imposes a restriction on the joint behavior of the price level and the level of nominal marginal costs. If nmc_t and p_t are nonstationary, their first differences must by definition be stationary. Assume a linear combination $\boldsymbol{\beta}'\mathbf{x}_t$ with a (1×2) vector $\boldsymbol{\beta}$ and the data vector $\mathbf{x}_t' = (nmc_t, p_t)$. The testable implication is that $\boldsymbol{\beta}' = (1, -1)$. In other words, nominal marginal costs and the price level are cointegrated.

3.2 Inflation forecasts from VAR projections

To assess the explanatory power of the Calvo model of staggered price setting, we construct an implied series for the forward-looking terms and contrast model-consistent inflation rates with actually observed inflation rates. We assume that the information contained in a small atheoretical bivariate VAR is a subset of the market's full information set. The virtue of this approach originally proposed by Campbell and Shiller (1987) is its robustness to omitted information.

Let $\mathbf{Z}_t = [rmc_t, ..., rmc_{t-q+1}, \pi_t, ..., \pi_{t-q+1}]'$ be an approximation to agents' information set. Hence, market information can be described by current and past realizations of inflation and real marginal costs. We will later check for the robustness of the results and will use the alternative forecasting VAR with $\mathbf{Z}_t = [rmc_t, ..., rmc_{t-q+1}, \Delta nmc_t, ..., \Delta nmc_{t-q+1}]'$ and a three-variable VAR $\mathbf{Z}_t = [rmc_t, ..., rmc_{t-q+1}, \Delta nmc_t, ..., \Delta nmc_{t-q+1}, i_t, ...i_{t-q+1}]'$, where i_t denotes the short-term interest rate. The vector $\mathbf{Z}_t$ follows a VAR(q) in companion form

$$\mathbf{Z}_{t+1} = \mathbf{A}\mathbf{Z}_t + \mathbf{\Gamma}_{Z_{t+1}} \tag{8}$$

where $\mathbf{\Gamma}_{Z_{t+1}} = [u_{1t}, 0, ..., 0, u_{2t}, 0, ...0]'$ represent innovations to agents' information sets and $\mathbf{A}$ is the $2q \times 2q$ companion matrix. We know that forecasts based on the econometrician's information set $\mathcal{H}_t$, which includes only current and lagged values of the variables in $\mathbf{Z}_t$, is given by the multi-period forecasting formula

$$E_t [\mathbf{Z}_{t+k} | \mathcal{H}_t] = \mathbf{A}^k \mathbf{Z}_t \tag{9}$$

The vector of the discounted future paths of the variables can be calculated as

$$\sum_{k=0}^{\infty} \phi^k E_t \mathbf{Z}_{t+k} = (\mathbf{I} - \phi \mathbf{A})^{-1} \mathbf{Z}_t \tag{10}$$

We map these forecasts into the present-value representation of the Calvo pricing model to obtain an expression for the model-consistent inflation rate. This "fundamental" (Galí and Gertler 1999, p. 217) inflation rate is given by

$$\pi_t^{fund} = \gamma \mathbf{h}'_{rmc} (\mathbf{I} - \phi \mathbf{A})^{-1} \mathbf{Z}_t \tag{11}$$

where $\mathbf{h}'_{rmc}$ denotes a selection vector that singles out the forecast of real marginal costs, i.e. the first element of $(\mathbf{I} - \phi \mathbf{A})^{-1} \mathbf{Z}_t$. The NKPC thus predicts that inflation at time t should be a scalar multiple of the first entry in the vector $(\mathbf{I} - \phi \mathbf{A})^{-1} \mathbf{Z}_t$, which is observable. We follow Rudd and Whelan (2003), who propose to infer the coefficient γ from a regression of actual inflation on the present-value of future real marginal cost $\mathbf{h}'_{rmc} (\mathbf{I} - \phi \mathbf{A})^{-1} \mathbf{Z}_t$. The fit of the Calvo model will then be assessed by comparing actual inflation with fundamental inflation. If the model provides an accurate description of inflation, these two series must coincide.

We plot actual inflation against fundamental inflation and compute standard measures of fit. Following the literature on present-value models, Campbell and Shiller (1987) propose two measures that indicate the extent to which the model is able to replicate actual inflation. The first measure is the ratio of standard deviations. A perfect fit would result in a standard deviations ratio of unity. In that case the Calvo model would explain all the variation in actual inflation. The second measure is the correlation coefficient between fundamental and actual inflation.

Note that these measures of fit do not reflect the degree of uncertainty about the model's fit. Most previous applications of the empirical approach sketched above to the New Keynesian model of inflation dynamics neglect this issue. Kurmann (2003), on the contrary, provide evidence on the uncertain fit of the NKPC for U.S. data. In this paper we follow his approach and compute confidence bands around the measures of fit.

3.3 The role of estimation uncertainty

The crucial motivation of the empirical analysis in this paper is the fact that using VAR projections disguises the degree of estimation uncertainty. This uncertainty possibly stems from various sources. Among them, the forecasting properties of the VAR process, the approximation of marginal costs by the labor share, and the parameter values for γ and ϕ. To assess the accuracy of the model's fit, we employ a bootstrap approach that infers the distribution of our measures of fit from estimating the model with artificial data. We will also check whether changes of the VAR specification, i.e. with respect to the information set, the lag order and the calibration of the discount factor, will affect the distribution of the measures of fit.

We obtain confidence intervals by drawing from the residuals of the estimated model and generating new observations for the data vector using the estimated companion matrix. The VAR model is estimated again and a new coefficient matrix is computed. From this we compute the series of expected real marginal costs and regress actual inflation on the present value of future real marginal costs to infer the slope coefficient. Finally, the ratio of standard deviations and the correlation coefficient are computed. Repeating this procedure 10000 times provides us with an empirical distribution for the ratio of standard deviations and the correlation coefficient. The 90% confidence intervals lie between the 5% and 95% percentile endpoints of this distribution.[4]

However, Kilian (1998) shows that this standard bootstrap algorithm performs poorly when it is used to compute distributions of statistics that are nonlinear functions of

[4] This bootstrap approach has the advantage of respecting the boundedness of the correlation coefficient $-1 < \rho < 1$ and the ratio of standard deviations $\sigma(\pi_t^{fund})/\sigma\left(\pi_t^{actual}\right) > 0$, and allowing for skewness because it does not impose symmetry.

VAR parameters. Note that both the ratio of standard deviations and the correlation coefficient are highly nonlinear functions of the estimated VAR coefficients. Therefore, we follow Kurmann (2003) and apply Kilian's bias-corrected bootstrap algorithm. Basically, he proposes to replace the estimated VAR coefficients by bias-corrected estimates before running the bootstrap to compute the measures of fit. Details about this bias-correction can be found in Kilian (1998). The algorithm also includes a procedure for shrinking the bias estimates in case the bias-corrected VAR estimates imply that the resulting VAR becomes nonstationary. Moreover, Kilian (1998) proposes a second bias-correction because the OLS estimates are themselves biased away from their population values. Thus, the approach amounts to a bootstrap-after-bootstrap technique.

3.4 The data set

We use quarterly data for Germany obtained from the OECD's Economic Outlook database. The sample covers 1973:4 through 2004:1. The inflation rate is measured as the annualized quarterly change of the (log) GDP deflator p_t (in percentage points), i.e. $\pi_t = 400\,(p_t - p_{t-1})$. To control for an obvious outlier due to German reunification, we set the inflation rate in 1991:1 equal to the average of the observations in 1990:4 and 1991:2. Real marginal costs are proportional to labor's share of income and are approximated by the (log) ratio of compensation to employees to nominal GDP. The short-term interest rate (call money rate) is taken from the IMF's International Financial Statistics database.

To account for the downward trend in inflation and real marginal costs over the sample period, we linearily detrend both series prior to estimation. This downward trend can be interpreted as a proxy to the Bundesbank's medium-run inflation objective.[5] To ensure that the results are not driven by this detrending procedure, we also report results from a specification estimated in (demeaned) levels.

Standard unit root tests suffer from severe power problems in the presence of structural breaks. In this sample structural breaks due to German unification are a very likely to distort the results of conventionally used tests. Therefore, we apply a set of unit root tests proposed by Zivot and Andrews (1992) that are robust to a single structural break in the series at unknown time. The results are presented in table (1). We find that we cannot reject the null of nonstationarity in the price level and the level of marginal costs. However, we can easily reject the null for inflation, nominal marginal

[5] See Coenen and Levin (2004) for a similar transformation of the data series.

cost growth, and for real marginal costs.[6]

4 Results

The Campbell-Shiller approach requires the price level and the level of nominal marginal cost to be cointegrated with a vector $\boldsymbol{\beta}' = (1, -1)$. Table (2) reports the results from a Johansen test applied to a bivariate VECM with five lags.[7] We find that we cannot reject the cointegrating vector $(1, -1)'$ that was implied by the stylized Calvo model of price setting. Thus, we find a stable long-run equilibrium relationship between the aggregate price level and the level of nominal marginal costs.

We proceed by estimating the forecasting VAR model with five lags and calculating fundamental inflation according to the model laid out before. We will later also report results for a VAR with three lags only. Following Rudd and Whelan (2003), actual inflation is regressed on a constant and the present-value of future real marginal costs in order to infer the parameter γ. We then compare the series of fundamental inflation with actual inflation by means of the ratio of their standard deviations and their correlation coefficient. Under the null hypothesis, $\pi_t^{actual} = \pi_t^{fund}$; hence $\rho\left(\pi_t^{actual}, \pi_t^{fund}\right) = 1$ and $\sigma\left(\pi_t^{fund}\right)/\sigma\left(\pi_t^{actual}\right) = 1$, where $\rho(.)$ is the correlation coefficient and $\sigma(.)$ is the standard deviation. To derive a series of fundamental inflation, one has to fix the discount factor. In accordance to the literature, we set the discount factor to $\phi = 0.99$, but will also report results for a specification with $\phi = 0.98$.

Figure (1) depicts the time series of actual and model-consistent or fundamental inflation for Germany. We find that the Calvo model broadly tracks the behavior of the actual inflation rate. Table (3) reports the main estimated measures of fit together with the bootstrapped confidence bands.

In specification I, the baseline model, the ratio of standard deviations of fundamental and actual inflation is 0.57 and the correlation between both series is 0.59. These numbers confirm the visual impression from the beforementioned figure and seem to indicate a reasonable fit of the New Keynesian Phillips Curve. However, these results are mere point estimates. Confidence bands, whose derivation is explained above, reveal that both measures of fit are surrounded by a large degree of uncertainty. The

[6] Note that the entire literature assumes the existence of a steady state of inflation. Consequently, a stationary inflation rate is the prerequisite for any empirical evaluation of these models of staggered price setting, i.e. for GMM approaches, maximum likelihood techniques, as well as for the present-value model in this paper.

[7] The lag order was chosen such that standard information criteria are minimized and specification tests indicate no autocorrelation in the residuals.

90% confidence band around the standard deviations ratio covers values between 0.20 and 1.61 in the first specification. In other words, the point estimates are consistent with both a nicely fitting model that explains all variation in actual inflation, but also with a badly performing model that explains roughly one fifth of the variation or is far more volatile than actual inflation. The confidence bands around the correlation coefficient cover negative correlations as well as high positive correlations. Hence, this measure of fit also indicates that we cannot safely conclude whether the model fits or fails.

To check the robustness of these results, we modify the baseline model in various respects. The results of these experiments are also reported in table (3). In specification II we estimate the model in levels and find even more alarming results. The alternative forecasting VAR with current and lagged realizations of $[rmc_t, \Delta nmc_t]'$ (specification III) also generates similar results. In specification IV, we arbitrarily truncate the lag order to $q = 3$, motivated by the fact the forecasting VAR model contains some insignificant lags of the endogenous variables. Interestingly, the width of the confidence band around the relative volatility shrinks somewhat but, still, both confidence bands remain wide. In specification V, the series of fundamental inflation is derived under a slightly lower discount factor. The results barely change. Specification VI amends the forecasting VAR with the short-term interest rate as a third variable. Note that this specification exhibits the smallest confidence band around the volatility ratio, which covers values between 0.18 and 0.73. Nevertheless, this is far too wide to lend support to the model's explanatory power. Finally, the sample in specification VII is restricted to the Bundesbank's period of targeting monetary aggregates from 1975:1 through 1998:4.[8] While the point estimates suggest that this specification has the best empirical fit and the interval around the correlation is remarkably narrow, the confidence band around the ratio of standard deviations remains large.

Figure (2) shows, as a prototype for all specifications, the density of the ratio of standard deviations of fundamental and actual inflation and the correlation coefficients across bootstrap replications for the baseline model. The results of all specification and robustness tests suggest the same interpretation: the basic Calvo model replicates German inflation well, but based on highly unreliable point estimates.

The estimated slope coefficient $\hat{\gamma} = (1-\mu)(1-\phi\mu)\mu^{-1}$ in conjunction with a fixed discount factor β allows us to infer the degree of price rigidity μ and the average

[8] The Bundesbank started monetary targeting by announcing a money growth target for the year 1975. See Neumann (1997) and von Hagen (1999) for a detailed analysis of the Bundesbank's policy of monetary targeting.

duration of sticky-price contracts under the Calvo price setting scheme which is equal to $\frac{1}{1-\mu}$. Table (3) reports the average duration (in quarters) of fixed-price Calvo contracts. We obtain an average duration of fixed prices of 3.63 quarters in the baseline specification. In all specifications, the duration of sticky prices lies between three and six quarters. This is plausible and consistent with the results of other studies. Two recent studies conducted under the Eurosystems' Inflation Persistence Network find comparable numbers for the price setting behavior of German firms. Hoffmann and Kurz-Kim (2004) find that prices for consumer goods at the retail level are fixed for two years on average. Stahl (2004) uses individual price data and shows that the prices of consumer goods are fixed for three to four quarters and those of investment goods for three quarters. The difference between these mean durations of price spells might be explained by the fact that the latter study covers 20 years of data while the first study explicitly covers the recent phase of low inflation only.

5 Conclusions

In this paper we assessed the ability of the standard Calvo model of staggered price setting to replicate German inflation dynamics. To that purpose, we exploited the forward-looking nature of inflation that is implied by Calvo contracts and used VAR forecasts to proxy expectations of the future path of real marginal cost. We compared the series of model-consistent inflation rates with actually observed inflation in the post-Bretton Woods era.

At first sight, the model explains the overall dynamics of German inflation well. The drawback, however, is the fact that conventionally used measures of fit are surrounded by large confidence bands that cover almost the entire range of volatility ratios and correlation coefficients between actual and fundamental inflation. Note that the model's failure to replicate the relative volatility of both inflation series is of particular relevance, since most investigations into optimal monetary policy focus on inflation volatility as one argument of the policy maker's loss function. This type of analysis relies on the Phillips curve as an accurate building block for the description of inflation volatility.

The results stand in contrast to the findings of Coenen and Levin (2004), who recently argue that the Calvo model provides a good description of German inflation. They augment the model and find that real rigidities play an important role for German inflation dynamics.

Finally, two notes of caution seem to be warranted. First, the estimation period

in this paper includes a shift in the monetary policy regime from the Bundesbank's monetary targeting to a single monetary policy for the aggregate Euro area. Therefore, a deeper analysis of the model's stability over time might offer interesting insights on the reliability of forward-looking models across regime changes.
Second, the results of this paper are based on the present-value implications of the Calvo model. This present-value approach is intuitively appealing and certainly has many virtues. However, Nason and Rogers (2005) recently employ this framework to investigate the sources of the empirical failure of the intertemporal model of the current account. They find that the present-value approach tends to not reject the model even though the data are generated by a model that lies in the rejection region. A similar line of reasoning might apply in this paper and should motivate further research.

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Table 1: Unit root tests

series	Zivot-Andrews test		
	test statistic	critical value (5%)	break date
break in intercept			
p_t	-3.30	-4.80	1995:4
Δp_t	-5.94	-4.80	1989:3
nmc_t	-3.97	-4.80	1996:2
Δnmc_t	-12.85	-4.80	1990:2
rmc_t	-5.00	-4.80	1991:1
break in intercept and trend			
p_t	-3.78	-5.08	1992:2
Δp_t	-5.91	-5.08	1989:3
nmc_t	-4.59	-5.08	1992:2
Δnmc_t	-12.79	-5.08	1990:2
rmc_t	-5.43	-5.08	1991:1

Notes: Unit root tests that allows for a single break proposed by Zivot and Andrews (1992). All variables in logs. Sample: 1973:4 - 2004:1.

Table 2: Results of Johansen cointegration test and test of restrictions

H_0	$\lambda^{\max}$	trace test		$\lambda^{\max}$ test	
$rank = r$		statistic	5% cv	statistic	5% cv
$r = 0$	0.18	33.16	19.96	24.00	15.67
$r \leq 1$	0.07	9.15	9.24	9.15	9.24

cointegrating relation:

$$\boldsymbol{\alpha}(\boldsymbol{\beta}'\mathbf{x}_{t-1} + c) = \begin{pmatrix} -0.03 \\ 0.06 \end{pmatrix} \left[\begin{pmatrix} 1.00 & -1.06 \end{pmatrix} \begin{pmatrix} nmc_{t-1} \\ p_{t-1} \end{pmatrix} + 0.65 \right]$$

restrictions:

$H_0 : \beta_p = -1$	LR $(\chi^2) = 1.81$	$p = 0.18$
$H_0 : \alpha_{nmc} = 0$	LR $(\chi^2) = 0.50$	$p = 0.48$
$H_0 : \alpha_p = 0$	LR $(\chi^2) = 11.18$	$p = 0.00$

Notes: Johansen (1991) test for five lag (in levels) and a restricted constant based on a vector error-correction model (VECM) of order q for $x_t = (nmc_t, p_t)'$.The stationary long-run equilibrium relation is given by $\boldsymbol{\beta}'\mathbf{x}_t$ with the adjustment towards the equilibrium driven by the vector of loadings $\boldsymbol{\alpha}$. $\lambda^{\max}$ denotes the maximum eigenvalue. The Likelihood Ratio (LR) test statistic of the hypothesis of weak exogeneity is asymptotically χ^2 distributed. The marginal significance level is given by p.

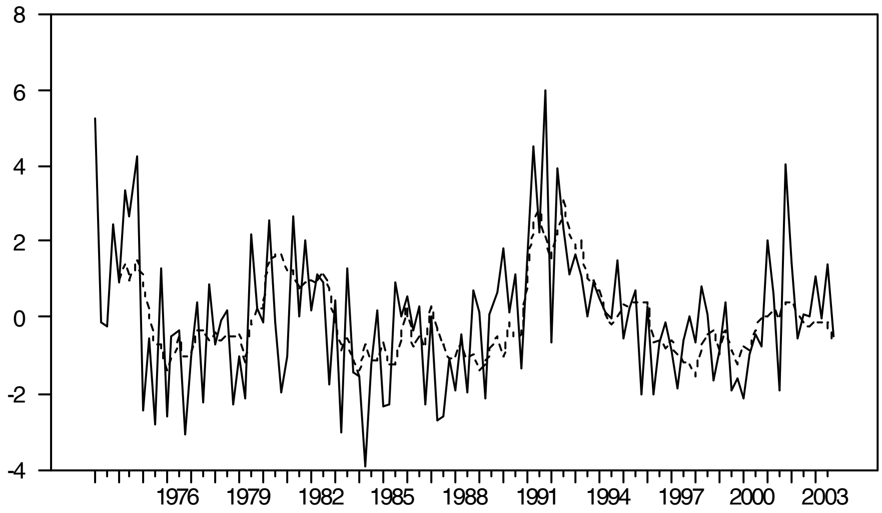

Figure 1: Actual (bold line) and fundamental (dotted line) inflation (detrended) in Germany (in % p.a.) from baseline model

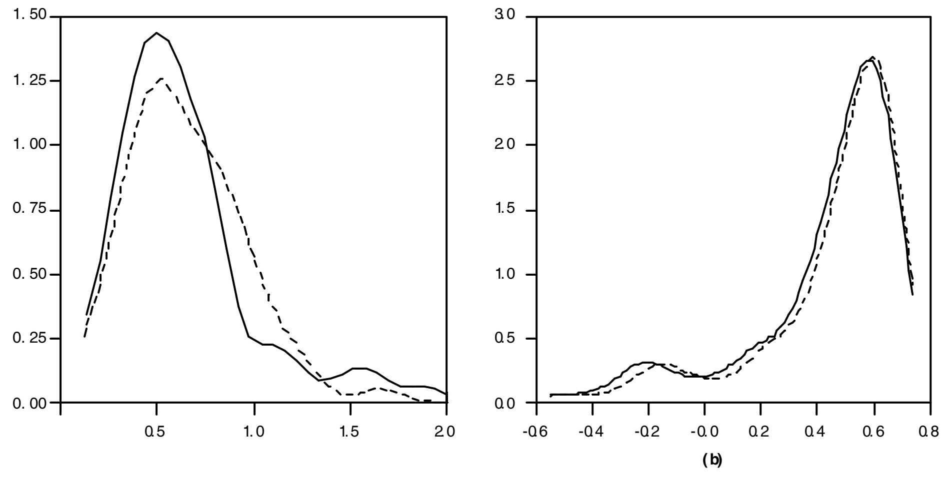

Figure 2: Distribution of (a) ratio of standard deviations and (b) correlation coefficient across bias-corrected (solid line) and uncorrected (dotted line) bootstrap replications from baseline model

Table 3: The uncertain fit of the forward-looking NKPC

Specification			Results			
	VAR	ϕ	measure of fit	estimate	90% conf. band	duration
I	$[rmc_t, \pi_t]'$		$\frac{std.dev.(\pi^{fund})}{std.dev.(\pi^{act})}$	0.57	$\begin{bmatrix} 0.20 & 1.61 \end{bmatrix}$	3.63
	$q = 5$	0.99				
	detrended		$corr\left(\pi^{fund}, \pi^{act}\right)$	0.59	$\begin{bmatrix} -0.18 & 0.69 \end{bmatrix}$	
II	$[rmc_t, \pi_t]'$		$\frac{std.dev.(\pi^{fund})}{std.dev.(\pi^{act})}$	0.62	$\begin{bmatrix} 0.10 & 2.21 \end{bmatrix}$	5.85
	$q = 5$	0.99				
	in levels		$corr\left(\pi^{fund}, \pi^{act}\right)$	0.66	$\begin{bmatrix} -0.69 & 0.80 \end{bmatrix}$	
III	$[rmc_t, \Delta nmc_t]'$		$\frac{std.dev.(\pi^{fund})}{std.dev.(\pi^{act})}$	0.36	$\begin{bmatrix} 0.21 & 1.25 \end{bmatrix}$	5.05
	$q = 5$	0.99				
	detrended		$corr\left(\pi^{fund}, \pi^{act}\right)$	0.37	$\begin{bmatrix} -0.68 & 0.76 \end{bmatrix}$	
IV	$[rmc_t, \pi_t]'$		$\frac{std.dev.(\pi^{fund})}{std.dev.(\pi^{act})}$	0.29	$\begin{bmatrix} 0.08 & 0.64 \end{bmatrix}$	4.79
	$q = 3$	0.99				
	detrended		$corr\left(\pi^{fund}, \pi^{act}\right)$	0.29	$\begin{bmatrix} -0.07 & 0.44 \end{bmatrix}$	
V	$[rmc_t, \pi_t]'$		$\frac{std.dev.(\pi^{fund})}{std.dev.(\pi^{act})}$	0.56	$\begin{bmatrix} 0.20 & 1.48 \end{bmatrix}$	3.66
	$q = 5$	0.98				
	detrended		$corr\left(\pi^{fund}, \pi^{act}\right)$	0.57	$\begin{bmatrix} -0.17 & 0.69 \end{bmatrix}$	
VI	$[rmc_t, \pi_t, i_t]'$		$\frac{std.dev.(\pi^{fund})}{std.dev.(\pi^{act})}$	0.36	$\begin{bmatrix} 0.18 & 0.73 \end{bmatrix}$	5.02
	$q = 3$	0.99				
	detrended		$corr\left(\pi^{fund}, \pi^{act}\right)$	0.36	$\begin{bmatrix} -0.16 & 0.44 \end{bmatrix}$	
VII	$[rmc_t, \pi_t]'$		$\frac{std.dev.(\pi^{fund})}{std.dev.(\pi^{act})}$	0.66	$\begin{bmatrix} 0.39 & 1.18 \end{bmatrix}$	3.45
	$q = 5$	0.99				
	detrended		$corr\left(\pi^{fund}, \pi^{act}\right)$	0.69	$\begin{bmatrix} 0.57 & 0.73 \end{bmatrix}$	
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