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The mechanics of a reasonably fitted quarterly New Keynesian macro model

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The Mechanics of a Reasonably Fitted Quarterly New Keynesian Macro Model

by

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Abstract

Within this paper we estimate key parameters of a New Keynesian Macromodel in order to evaluate the mechanics of the model. Similar approaches have been taken by Castelnovo (2003), Dennis (2001) and Söderlind et.al (2002). Based on matching moments the paper presents evidence that hybrid specifications of New Keynesian macromodels are characterised by approximately 60 percent of backward looking economic agents. The predominant goal of monetary policy is price stability and financial market stability. Output gap stabilisation only plays a minor role as an independent goal if a central bank faces a flat Phillips curve.

Keywords: New Keynesian Macromodel, hybrid Phillips curve, hybrid IS curve, forward looking behaviour, rule-of-thumb behaviour.

JEL Classification: C51, E52, E58.

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The Mechanics of a Reasonably Fitted Quarterly New Keynesian Macro Model

Abstract

Within this paper we estimate key parameters of a New Keynesian Macromodel in order to evaluate the mechanics of the model. Similar approaches have been taken by Castelnuovo (2003), Dennis (2001) and Söderlind et.al (2002). Based on matching moments the paper presents evidence that hybrid specifications of a New Keynesian macromodel are characterised by approximately 60 percent of backward looking economic agents. The predominant goal of monetary policy is price stability and financial market stability. Output gap stabilisation only plays a minor role as an independent goal if a central bank faces a flat Phillips curve.

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1 Introduction

The last years have witnessed a sharp increase of interest in evaluating monetary policy strategies (see Taylor (1999)). This normative branch of monetary economics tries to evaluate the performance of alternative strategies in terms of associated monetary policy outcomes. The basic rationale for this approach is the insight that the central bank faces a stable choice menu in terms second moments of the target variables (e.g., Taylor (1979)). This exercise is crucially based on the assumption that key parameters of the model, in particular the degree of forward-lookingness in the intertemporal IS-equation and the New Keynesian Phillips Curve (NKPC), as well as the preference vector of monetary policy which trades off the different goal variables are correctly specified. This paper targets at proposing a strategy that simultaneously identifies these key parameters by matching moments. Similar approaches have been taken by Castelnuovo (2003) and Söderlind et.al (2002). We construct for each variable (the inflation rate, the output gap, the interest rate and the first difference of each variable) a separate criterion, which measures the sum of squared percentage deviations of the individual moments from its historical counterparts. The estimated vector of key parameters minimises the distance between the moments of the model and those nested in the data. As a toolkit to analyse the plausibility of the identified key parameters we proceed along the following lines. First, we compute the impulse response functions as a cross cheque for the embedded transmission structure. Second, we test for stability and uniqueness along the lines as proposed by Blanchard et. al. (1980) by computing the regions of determinacy. Third and most importantly we evaluate the mechanics of the model in detail by performing a battery of baseline evaluations.

The following results stand out: Approximately 60 percent of all pricing and consumption decisions are made by rule of thumb setters which simply centre their pricing decisions on heuristics. Additionally we present evidence that the dominant goal of monetary policy

besides stabilizing the inflation rate is interest rate smoothing. The stabilization of the output gap only seems to play a minor role for the conduct of monetary policy as an independent goal variable. The presence of forward looking economic agents seems to facilitate the conduct of monetary policy once the central bank implements a unique and stable rational expectations equilibrium.

2 The Structure of New Keynesian Macro Models

Standard New Keynesian Macro Models share a simple structure that is centred around three building blocs:

- A new Keynesian Phillips curve as inflation adjustment line.
- An intertemporal IS-equation describing the optimal consumption behaviour of households.
- And an optimal or simple monetary policy rule depicting the way according to which monetary policy is conducted

We will shortly discuss each of these building blocks in term.

2.1 The New Keynesian Phillips Curve

A cornerstone of New Keynesian macromodels is the New Keynesian Phillips Curve (NKPC) (e.g., Jondeau et al, 2001, Roberts, 1995; Sbordone, 1999; Woodford 1996). The NKPC curve relates the inflation rate to some measure of economic activity. Hence it gives a description of the supply side of the economy. The standard NKPC can be summarized as follows:

$$p_t = \beta p_{t+1} + g y_t + e_t, \quad (1)$$

where β depicts the discount factor of households. Note that γ is a function of the underlying deeper structural parameters of a New Keynesian macromodel. In particular it will depend on the fraction of firms that receive each period a signal to reset prices optimally (Calvo-pricing) and on the assumptions made on the production technology of firms (e.g., Walsh (2003), chapter 5). In applied work it has prevailed that purely forward-looking specification of the NKPC do not replicate the hump-shaped response embedded in impulse response functions as documented by VAR studies (e.g., Christiano J. et al., (1998). Therefore some degree of backward lookingness is necessary to introduce persistence in the inflation rate. A popular approach to endogenize persistence was proposed by Altig et al. (2002). They introduce rule of thumb behaviour on some part of price setters. Hence besides Calvo-pricing some price setters update their prices following a rule of thumb. In particular one may assume that some price setters simply update their prices by yesterday's aggregate price level. Note that the degree of indexation may be partial (e.g., Smets et al (2003)). This rule of thumb behavior can be rationalized as follows (e.g., Amato et. al., (2003)):

- Rule of thumb behaviour does not produce any computational costs.
- The fraction of price setters that updates by rule of thumb implicitly learns as p_{t-1} incorporates the pricing decisions of those agents that have optimised in period $t-1$.

- In steady state rule of thumb setters will set prices equal to those who do Calvo (1983) pricing.

Based on this notion the NKPC in its most general form at a quarterly frequency can be written as follows:

$$p_t = m_p E_{t-1} \bar{p}_{t+k} + (1 - m_p) \sum_{j=1}^s b_{pj} p_{t-j} + \sum_{i=1}^n b_{yi} y_{t-i} + e_t \quad (2)$$

The current rate of inflation is explained by a weighted average of past and future inflation rates as well as the current and lagged variables of the output gap. No consensus has yet emerged up to which degree the price setting behaviour of economic agents is governed by forward-looking behaviour. Table 1 presents some evidence from estimated and calibrated ‘baseline’ versions. The presented baseline estimates of the degree of forward-lookingness vary from 0.1 to 0.75. This dispersion in estimates is somewhat inconvenient. In section 4 we demonstrate that the degree of forward-lookingness critically changes the correlation structure of the model and hence the impact of monetary policy itself.

2.2 The New Keynesian IS-Curve: Euler Equation

The second building bloc of New Keynesian macromodels is the intertemporal IS-equation. It gives a description of the demand side of the economy. The New Keynesian IS-curve is a relationship that relates the output gap negatively to the expected real interest rate and to tomorrow's output gap. The demand shock η_t can be interpreted as a shock to the natural rate of interest or a stochastic shock to the representative households preferences.

$$y_t = \mathbf{b}_0 - \mathbf{b}_1 [i_t - E_t \mathbf{p}_{t+1}] + E_t y_{t+1} + \mathbf{h}_t \quad (3)$$

Unfortunately this relation like the NKP curve is at odds with the data as it is unable to display the inertia nested in aggregate output. The standard Euler-equation predicts that a shock to aggregate demand will generate only a single jump in output which stands in contrast to the hump shaped response documented in VAR studies (e.g., Christiano J. et al., (1998)). One remedy to this problem was offered by Fuhrer (2000). He reintroduced persistence into the aggregate spending relationship by introducing habit formation in the utility function of households. Hence households centre their optimal consumption choice around a targeted consumption level ('habit stock') which is usually expressed as a share of yesterdays personal (internal habit) or aggregate (external habit) consumption level. A second approach to generate an inertial IS-relationship is to introduce rule of thumb consumers. Rule of thumb consumers simply set today's desired consumption level equal to last periods consumption level. Thus, some fraction of households \mathbf{z} optimises while another fraction $(1-\mathbf{z})$ of households simply centres its consumption decisions around last periods consumption level. Both approaches can lead to the following (hybrid) specification of an IS-curve at a quarterly frequency:

$$y_t = \mathbf{m}_y E_{t-1} \sum_{i=1}^n \mathbf{b}_{yi} y_{t+i} + (1-\mathbf{m}_y) \sum_{j=1}^m \mathbf{b}_{yj} y_{t-j} - \mathbf{b}_r \mathbf{v}_r [\bar{i}_{t-1} - E_{t-1} \bar{\mathbf{p}}_{t+3}] + \mathbf{b}_r (1-\mathbf{m}_y) [\bar{i}_{t-1} - \bar{\mathbf{p}}_{t-3}] + \mathbf{h}_t \quad (4)$$

The parameter \mathbf{m}_y is a function of the underlying deeper parameters of the model. It depends critically on the degree of habit formation. Table 2 presents some baseline estimates for the IS-curve. Reviewing these studies there seems to crystallise a consensus that a substantial

degree of backward lookingness is needed to fit the actual data. At least 50 percent of the economic agents are assumed to be backward looking according to the reviewed studies.

2.3 Specifying the Conduct of Monetary Policy

The third building bloc of New Keynesian Model is a relationship depicting the way according to which monetary policy is conducted. The overall goal of monetary policy is to promote economic welfare. Given the legal mandate of most prominent central banks this is usually interpreted in terms of keeping the inflation rate close to the inflation target while equally stabilizing the output gap around its potential. As it is our aim to take the model to the data we additionally introduce interest rate smoothing as an independent goal of monetary policy¹. It is an observable fact that monetary policy is implemented gradually. Typically short-term rates are not changed by more but 25 or 50 basis points. In other words monetary authorities do not implement their desired interest rate target cold turkey but perform a gradual adjustment to the desired target level. This observable interest rate setting behaviour can be rationalized among others by the following argument: Policymaker's are confronted with three major types of uncertainties. Model uncertainty, parameter uncertainty and data uncertainty. It is well documented that each of these uncertainties tends to reduce the aggressiveness with which policymakers react with their instrument to the set of predetermined variables. In other words the coefficients in the optimal monetary policy rules are smaller in absolute values. This automatically translates into a smoother interest rate setting behaviour. One straightforward way to introduce interest rate smoothing in the model is to put a higher weight on interest rate smoothing in the loss function (e.g., Martin et al. ,

¹ Note we will not consider interest rate smoothing around a long run nominal equilibrium rate as alternative goal of monetary policy. As noted by Woodford (2002) this notion of smoothing might be rationalized by a desire to avoid the zero lower bound, hence a deflationary trap.

1999). Given these goals of monetary policy we can state the loss function as follows (e.g., Svensson, 2003):

$$L_t = E_t \left[\sum_{t=0}^{\infty} \left(p_{t+t}^2 + \lambda y_{t+t}^2 + \alpha \Delta i_{t+t}^2 \right) \right] \quad (5)$$

There are only a few studies available that try to pin down the preferences $(\lambda; \alpha; \beta)$ of monetary policy makers for the US. Reviewing these studies (Table 3) there seems to emerge the following consensus: Central banks seem to put a higher weight on stabilizing the inflation rate around the inflation target than stabilizing output at its capacity level. Additionally a high weight is put on interest rate smoothing. Output stabilization only seems to play a minor role for the conduct of monetary policy. An analytical explanation for this finding was given by Woodford (2003, chapter 6). Based on a second order approximation of a representative households utility function around the steady state he concluded that the driving result behind small values for λ is a flat Phillips curve. If monetary policy puts a high weight on inflation it needs to induce substantial changes in the output gap in order to control the inflation rate. Accordingly it is logically impossible to put a high weight on inflation and output stabilisation simultaneously.

3 Rewriting the Model in State Space Form

A convenient representation of the New Keynesian macromodel can be given by the following set of difference equations:

$$X_{t+1} = AX_t + Bi_t + v_{t+1} \quad (6)$$

X_t is the state vector, which defines each period the state space. The matrix A captures the structural or reduced form coefficients of the economy. B is a vector consisting of the interest rate impact multipliers. The shocks that drive the system are stacked into v_t . Due to the specific model set up the variance covariance matrix Ω is diagonal. Therefore we interpret the individual shocks as structural shocks. As some of our variables will not be predetermined we can conveniently partition the system as follows²:

$$\begin{bmatrix} X_{1t+1} \\ E_t X_{2t+1} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} X_{1t} \\ X_{2t} \end{bmatrix} + \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} i_t + \begin{bmatrix} e_{t+1} \\ 0_{n_{2 \times 1}} \end{bmatrix} \quad (7)$$

n_1 Predetermined variables: X_{1t}

n_2 Forward-Looking Variables: X_{2t}

At the start of period t X_{1t} , driven by the shock terms e_t is realized. Then the central bank, conditional on the available information set $(e_t, X_{1t}, e_{t-1}, X_{1t-1}, i_{t-1}, \dots)$ chooses i_t . At the end of period t X_{2t} results. Finally rational expectations on $E_t X_{2t+1}$ are formed on the available information at the end of period t . Assume for the moment that we can represent the instrument of monetary policy as a linear function of the state variables.

$$r_t = -FX_t \quad (8)$$

Given our system we can then evaluate the closed loop dynamics (the economy in conjunction with the policy rule) if we insert $r_t = -FX_t$ in the dynamic law of motion:

² For an in depth discussion of state space systems containing forward looking variables see Söderlind (1999), Svensson (1999).

$$X_{t+1} = (A - BF)X_t + v_{t+1} \quad (9)$$

Hence we arrive at the following modified system:

$$X_{t+1} = MX_t + v_{t+1} \text{ With } M = (A - BF) \quad (10)$$

Equation (10) gives a complete description of the closed loop dynamics. Therefore it represents our basic equation when analysing the properties of monetary policy rules. The variance of the state vector is given by the expression:

$$vec(\Sigma_{xx}) = [I - M \otimes M]^{-1} vec(\Omega) \quad (11)$$

The second equation, which completes the description of our state space system, is the so-called measurement equation. It can be stated as follows:

$$Y_t = C_x X_t + C_i F \quad (12)$$

The measurement equation defines the vector of variables as a function of the state variables and the specified monetary policy rule. If we partition C_x in two blocs associated with the backward and forward looking state variables we arrive at the following equation:

$$Y_t = (C_{x1} + C_{x2}) X_t + C_i i_t, \quad (13)$$

which can equally be expressed only in terms of predetermined variables:

$$Y_t = (C_{x1} + C_{x2}C + C_iF) X_{1t} \quad (14)$$

Therefore we can write the variance of the variables in which we are interested as follows:

$$\Sigma_{YY} = E[Y_t Y_t'] = C^* X_{1t} (C^* X_{1t})' = C^* \Sigma_{XX} C^{*'} \quad (15)$$

$$\text{with } C^* = C_{x1} + C_{x2}C + C_iF$$

4 Calibrating the Model

In the following section we will propose a calibration scheme that simultaneously calibrates the degree of forward-lookingness in the Phillips curve and the IS-curve as well as the preference vector of monetary policy. For the remaining parameters we use estimates as provided by Rudebusch (2000). Compared to related literature (See Castelnuovo (2003), Söderlind et. al. (2002)) we do not rely on simulation techniques but on an analytically constructed variance-covariance matrix which allows us to compute diverse moments. The estimation relies on minimising the distance between empirically observed moments and those generated by the model.

4.1 Calibration Method

Let us make (as untested apriority) the assumption that a New Keynesian Macro Model describes the true data generating process at a quarterly frequency. Taking this apriority we

calibrate the model in order to meet simultaneously a set of well-defined criteria. We calibrate simultaneously the vector $\mathbf{y} = [\mathbf{m}_p; \mathbf{m}_y; \mathbf{m}_r; \mathbf{l}; \mathbf{u}]$ with:

- \mathbf{m}_p the degree of forward lookingness in the Phillips curve.
- \mathbf{m}_y the degree of forward lookingness in the IS-curve.
- \mathbf{m}_r the degree of forward lookingness with respect to real interest rates in the IS-curve.
- \mathbf{l} weight monetary policy puts on output stabilization relative to stabilizing the inflation rate.
- \mathbf{u} weight the central bank puts on interest rate smoothing relative to inflation rate stabilization.

Let us in particular define the following measurement vector.

$$\mathbf{Y}_t = [\mathbf{p}_t \ \bar{\mathbf{p}}_t \ \mathbf{p}_{t-1} \ \mathbf{p}_{t-2} \ \mathbf{p}_{t-3} \ y_t \ y_{t-1} \ i_t \ i_{t-1} \ i_{t-2} \ i_{t-3} \ \Delta i_t \ \Delta i_{t-1} \ \Delta i_{t-2} \ \Delta \mathbf{p}_t \ \Delta \mathbf{p}_{t-1} \ \Delta \mathbf{p}_{t-2} \ \Delta y_t]$$

with variance covariance matrix as defined by equation (15). The calibration technique proceeds along the following lines:

We iterate the individual parameters over the following ranges:

- \mathbf{m}_p in the interval from 0 to 1 with step size 0.1.
- \mathbf{m}_y from 0 to 1 with step size 0.1.
- \mathbf{m}_r was set alternatively equal to null or one.
- \mathbf{l} in the interval from 0 to 4 with step size 0.05.
- \mathbf{u} in the interval from 0 to 6 with step size 0.1.

For each preference vector $\mathbf{y} = [1, \mathbf{l}, \mathbf{n}, \mathbf{m}_p, \mathbf{m}_y, \mathbf{m}_r]$ we simultaneously compute the implied variances, covariances and autocorrelations of the measured variables. In the next step we compute the following criterion:

$$(\mathbf{q}(\mathbf{y}) - \hat{\mathbf{q}})' \mathbf{W} (\mathbf{q}(\mathbf{y}) - \hat{\mathbf{q}}) \quad (16)$$

Where \mathbf{q} is a vector consisting of the chosen criteria. For a detailed definition of the individual criteria see Appendix 4. Each individual element of each criterion consists of the absolute squared percentage difference between the individual variances, covariances, and auto correlations of each variable (the inflation rate, the output gap, the interest rate and the respective differences) implied by $\mathbf{y} = [1 \quad \mathbf{l} \quad \mathbf{n} \quad \mathbf{m}_p \quad \mathbf{m}_y \quad \mathbf{m}_r]$ minus the corresponding empirically observed values in the historical data (1987:4-2002:2). This sample period covers the term of the chairman Alan Greenspan. As weightening matrix \mathbf{W} we use the identity matrix. Accordingly \mathbf{W} is specified as:

$$\mathbf{W} = \mathbf{I}_{6,6} \quad (17)$$

Among this the set of 960.000 parameter constellations we choose to identify those ten combinations \mathbf{y} that minimize the following criteria:

$$\begin{aligned} & \text{Min}_{\psi} \left((\boldsymbol{\theta}(\psi) - \hat{\boldsymbol{\theta}})' \mathbf{W} (\boldsymbol{\theta}(\psi) - \hat{\boldsymbol{\theta}}) \right) \\ & \text{s.t.: } \Delta\% \sigma_y \leq c; \Delta\% \sigma_{\pi} \leq c; \Delta\% \sigma_{\Delta i} \leq c; \end{aligned} \quad (18)$$

As can be seen from equation (18) we additionally impose the restriction that the individual standard deviations of the goal variables should not display a greater percentage deviation but c from historical counterparts. Hence we implicitly give a dominant role to the individual variances of the time series while calibrating the model. We set $c=0.5$.

4.2 Calibrating the Remaining Parameters

The backward looking inflation polynomial in the Phillips curve \mathbf{a}_{pi} , the impact of economic activity on inflation \mathbf{a}_y , the interest rate sensitivity of economic activity in the IS-curve \mathbf{b}_r , and the autoregressive part in the output gap equation \mathbf{b}_{yi} was specified by estimates as reported by Rudebusch (2000) which are displayed in Table 4. Rudebusch (2000) used the following specifications: \mathbf{p}_t was specified as the quarterly inflation rate in the GDP chain-weighted price index p_t seasonally adjusted and calculated at an annual rate $4(\ln P_t - \ln P_{t-1})$; $\bar{\mathbf{p}}_t$ is the four quarter moving average constructed as $(1/4)\sum_{i=0}^3 \mathbf{p}_{t-j}$; \bar{i}_t is the four quarter average federal funds rate, hence $\frac{1}{4}\sum_{i=0}^3 i_{t-j}$; y_t is the output gap constructed as the percentage deviation of the output Y_t from trend output Y_t^* , where Y_t^* was taken from the Congressional Budget Office. All variables were demeaned prior to estimation. Note in particular that the specification as proposed by Rudebusch (2000) implies that the sum over the inflation polynomial ($\sum_{i=1}^4 \mathbf{b}_{pi} = 1$) is equal to one, so that the long run neutrality of money holds. This means in steady state ($\mathbf{p}_t^T = \mathbf{p}_{t+1}^T = \mathbf{p}_{t-2}^T = \mathbf{p}_{t-3}^T = \dots = \bar{\mathbf{p}}$) it holds that:

$$y = \frac{(1 - [\mathbf{b}_{p1} + \mathbf{b}_{p2} + \mathbf{b}_{p3} + \mathbf{b}_{p4}])}{\mathbf{a}} \mathbf{p}^T \quad (19)$$

Obviously the property of long run neutrality is violated as long as $[\mathbf{b}_{p1} + \mathbf{b}_{p2} + \mathbf{b}_{p3} + \mathbf{b}_{p4}] = \mathbf{b} \neq 1$. Higher inflation targets \mathbf{p}^T could boost output permanently,

which would violate the long run neutrality of money³. Thus, it is desirable to set the slope coefficient equal to one $\beta=1$, which translates into $\frac{1-b}{a}=0$. This is from an economic point of view somewhat problematic as b should be interpreted as a discount factor.

5 Calibration Results: An Evaluation of the Proposed Baseline Calibration⁴

In the following section we will present and evaluate the outcomes of the proposed evaluation method. The proposed toolkit to analyse the identified baseline specification proceeds along the following lines. In a first step we will analyse the basic plausibility of the identified baseline calibration by computing the impulse response patterns following a supply, demand and interest rate shock. The impulse response analysis serves as a cross cheque for the implied correlation structure embedded in our preferred calibration vector $y = [1 \quad l \quad n \quad m_p \quad m_y \quad m_r]$. As a second crude tool we will evaluate the stability and the uniqueness properties by testing whether the number of unstable eigenvalues is equal to the number of forward looking variables as proposed by Blanchard et al. (1980). Additionally we will compute regions of determinacy. Following these preliminary examinations we will systematically analyse the mechanics of the model by a battery of baseline evaluations.

³ Note that standard New Keynesian Macro-Models typically exhibit a modest degree of non-neutrality as β has the economic interpretation of households discount factor.

⁴ All codes for basic computations were taken from Paul Söderlind homepage: <http://www.hhs.se/personal/PSoderlind/Research/MonEEAMatLab.zip>

5.1 Top Ranked Calibration Vectors: Uniqueness and Stability

The top ranked vector combinations \mathbf{y} identified by the proposed calibration method are displayed in Table 5. Following Blanchard et al (1980) we test for uniqueness and stability by computing the eigenvalues. It has to hold that the number of unstable eigenvalues is equal to the number of forward-looking variables. A look at the partitioned state vector tells us that the number of predetermined variables is equal to nine. The number of forward-looking variables is equal to four:

- $X_{1t} = \{\mathbf{p}_t, \mathbf{p}_{t-1}, \mathbf{p}_{t-2}, \mathbf{p}_{t-3}, y_t, y_{t+1}, i_{t+1}, i_{t+2}, i_{t+3}\}'$
- $X_{2t} = \{E_t \mathbf{p}_{t+3}, E_t \mathbf{p}_{t+2}, E_t \mathbf{p}_{t+1}, E_t y_{t+1}\}'$

Table 6 confirms that for $\mathbf{y}_{10} = [1 \quad 0.15 \quad 1.85 \quad 0.4 \quad 0.4 \quad 1]$ the number of forward-looking variables satisfies the proposition as stated by Blanchard et al. (1980). Hence we conclude that the identified baseline configuration \mathbf{y}_{10} generates a stable and unique solution. We have equally tested for stability and uniqueness for the combinations \mathbf{y}_{1-9} . All identified vectors were stable, but not unique. In other words the number of stable eigenvalues was larger than the number of predetermined variables.

Figure 1 shows how determinacy is affected for the baseline calibration as we alter the degrees of aggressiveness with which monetary policy reacts to deviations from the inflation and output target. Figure 1 impressively illustrates that as soon as monetary policy puts price stability in its main focus determinacy is assured in the quarterly setting. Nevertheless in the case where monetary policy neglects its legal mandate to safeguard stable prices, hence if $\mathbf{f}=0$ the model becomes indeterminate. Additionally combinations of high degrees of forward-lookingness in price setting and high degrees of forward-lookingness in consumption

decisions induce indeterminacy, whereas a higher degree of price stickiness builds in ‘path-dependency’ that generates determinacy.

The estimated vector combination $\mathbf{y}_{10} = [1 \ 0.15 \ 1.85 \ 0.4 \ 0.4 \ 1]$ is described by the following characteristics:

- The weight λ of stabilising squared deviations of the output gap around zero is rather small compared to the weight put on the other two goal variables of monetary policy. It is well known that this does not mean that monetary policy does not care on the output gap. This is quickly confirmed if one takes a look at the optimal monetary policy rule which is given by:

$$i_t = 0.2947p_t + 0.1140p_{t-1} + 0.1169p_{t-2} + 0.0166p_{t-3} + 0.2348y_t + 0.0701y_{t-1} + 0.6391i_{t-1} \quad (20)$$

- Monetary policy reacts on impact with an increase of 0.2348 to current changes in the output gap and with a coefficient of 0.0701 to changes in last periods output gap. This can be explained as follows: Even a central bank that only puts a modest weight on output stabilisation opts to react on movements in economic activity in order not to loose control over the inflation rate as the output gap is the driving variable of the inflation process (e.g., Svensson, 2003). The finding that output gap stabilisation only seems to be of minor importance as an independent goal of monetary policy is well in line with related studies that coherently come to the same result.
- The relatively high weight on financial market stability as an independent goal of monetary policy confirms earlier results by Dennis (2001) and Söderlind et al. (2002). The high weight on interest rate smoothing is reflected in the optimal discretionary monetary policy rule as the coefficient on i_{t-1} is equal to 0.6391.

- The degree of forward-lookingness in the Phillips curve is identified to be equal to 0.4. Hence 40 percent of economic agents seem to build rational expectations on the inflation rate whereas 60 percent set their prices based on rule of thumbs. This result lies in the midst of the estimates presented by related studies. Accordingly the calibration results give further evidence that purely forward-looking Phillips curves do not fit the facts.
- The degree of forward lookingness in the IS equation is identified to be equal to 0.4. Hence only a modest degree of forward lookingness seems to be present in the data, which confirms earlier results by Fuhrer (2000)⁵. In other words a purely forward looking IS-equation is not able to describe the optimal consumption plan of households. Consumption decisions seem to be mainly driven by rule-of-thumb behaviour and habit formation. Households centre their current and future spending decisions around yesterdays consumption level or alternatively around some targeted level of consumption.

As Table 7 indicates the identified vector $\mathbf{y}_{10} = [1 \ 0.15 \ 1.85 \ 0.4 \ 0.4 \ 1]$ captures the correct signs of the autocorrelation functions over all relevant variables. Nevertheless the model has some problems in displaying the low variance in the inflation rate and the low variance in the first difference of the output gap.

5.2 Impulse Response Functions

The main characteristics of our identified baseline configuration are depicted in Figure 2. The high degree of interest rate smoothing and the lags in the hybrid Phillips-curve and the IS-equation translate into hump shaped impulse response functions that can be considered in line

⁵ Linde (2002) comes to the same conclusion: “I have not been able to find any estimates of \mathbf{b}_f [degree of forward looking ness, the author] and \mathbf{b}_b [degree of backward lookingness, the author], but the results in the literature Fuhrer (2000) suggests that \mathbf{b}_f is consistently less than one and that \mathbf{b}_b is positive”.

with conventional New Keynesian Macro Models (e.g., Walsh (2003), chapter 11). We will shortly discuss each impulse response function in term.

Quite remarkably the impulse response function of the inflation rate with respect to an interest rate shock does not exhibit a prize puzzle Figure 2(b). Following an interest rate shock the impulse response function of the interest rate starts to decline and reaches its peak response after three quarters. Due to the drop in economic activity the inflation rate equally starts to decline and reaches its peak response with a lag of six quarters. After approximately 20 periods all series are back at their baseline values. Hence long run neutrality holds. The impulse response functions nicely depict the transmission structure encapsulated within this particular specification of a New Keynesian Macro Model. The peak response in the output gap leads the peak response in the inflation rate which can be explained by the backward looking inflation dynamics in the hybrid Phillips curve. This reflects that the output gap is the driving variable of the inflation process within a hybrid specification and that monetary policy can only disinflate by deeds. Given the identified parameter constellation ψ monetary policy largely accommodates supply shocks (see Figure 2(a)). The initial unit supply shock leads to a pronounced but modest increase in the interest rate, which goes hand in hand with a drop in the output gap induced by a tighter stance in monetary policy (peak response after 3 quarters). Consequently the inflation rate starts to decline and returns to its baseline after 13 quarters. The output gap exhibits a pronounced reaction, which reaches its peak response after 6 quarters. Following a positive unit demand shock (see Figure 2(b)), monetary policy reacts by raising real interest rates (peak response after 3 quarters). Due to the stronger economic activity the inflation rate equally starts to rise. It reaches its peak response after 3 quarters. All depicted time series return to their baseline values after 13 quarters. This somewhat pronounced response compared to a supply shock reflects that monetary policy only puts a modest weight on output gap stabilization ($\lambda = 0.15$).

5.3 Baseline Evaluation: Robustness of the Identified Solution

In the following section we will perform a battery of baseline evaluations to get a deeper understanding on the mechanics of the model. In particular we will take a look at the sensitivity of the variances, covariances and the implied autocorrelations and cross correlations with respect to changes in the individual elements of the identified vector $\mathbf{y} = [1 \quad l \quad n \quad m_p \quad m_y \quad m_r]$. Figure 3 shows how the variances of the goal variables respond ceteris paribus to a change in the individual elements of \mathbf{y} . The results are largely in line with expectations. An increasing weight on the individual goal variables, hence the inflation rate, the output gap and the change in interest rate s respectively lead to a drop in the variances of each of these variables. E.g. if monetary policy puts an increasing weight on interest rate smoothing (increasing n) the variance of the interest rate starts to decline. The same holds true for the other target variables of monetary policy. But of course reducing the variance of one goal variable is no free lunch. Let us assume that monetary policy puts a higher weight on stabilizing the inflation rate (increasing ϕ). As side effect the variance of the interest rate increases. In other words the central bank needs to make a more rigorous use of its instrument in response to supply and demand shocks. This is in particular obvious if we take a look at **Figure 3(b)**. **Figure 3(b)** depicts what happens ceteris paribus if monetary policy has a greater concern for economic activity. As we see the variance of the output gap drops with an increasing λ . Nevertheless this can only be realized at the cost of an increase in the variance of the inflation rate. This means in particular that central banker's take a less vigorous stance on supply shocks thereby increasing the fluctuations in inflation. With respect to the degree of forward lookingness the following seems to hold true. An increasing degree of forward lookingness in the hybrid Phillips curve m_p and in the intertemporal IS-curve m_y

result in a sharp drop of the variance of the interest rate. Hence if we keep the preference vector corresponding to the period loss function $L_t = \mathbf{p}_t^2 + 0.15y_t^2 + 1.85\Delta i_t^2$ fixed an increasing degree of forward-lookingness serves as a substitute for a more aggressive monetary policy stance. Therefore one might say that an increasing degree of forward lookingness implies that monetary policy does not need to “lean against strong persistence” in the data.

Hence the results presented by purely backward looking models stating that estimated response coefficients in monetary policy rules are smaller than optimal coefficients retrieved by control methods may be spurious. In the light of the results these studies might simply neglect the degree of forward-lookingness $\mathbf{m}_y = \mathbf{m}_p = 0.4$ present in the data⁶.

Figure 3 evaluates the impact of changes in the identified vector $\mathbf{y} = [1 \quad \mathbf{l} \quad \mathbf{n} \quad \mathbf{m}_p \quad \mathbf{m}_y]$ on the autocorrelation patterns of the inflation rate. As one would expect an increasing weight on stabilizing the inflation rate around the inflation target leads to a drop in the persistence of the inflation process (see **Figure 3(a)**). In other words if monetary policy uses its instrument more rigorously to keep the inflation rate close to the inflation target the degree of persistence in the inflation process declines. This underlines that the degree of persistence is endogenous to the monetary policy regime. Nevertheless the ‘beneficial’ reduction of persistence in one variable comes at a cost. E.g., an increasing weight on stabilising the output gap leads to an increase in the persistence of the inflation process. One likely explanation can be given as follows: As monetary policy tends to react stronger to movements in the output gap it will tend to ‘overlook’ supply shocks leading to a higher degree of persistence in the inflation rate. An increasing weight on stabilising the change in interest rates leads to an increase in the inflation persistence, which can be quite naturally explained by the fact that monetary policy uses its instrument less vigorously to keep the inflation rate on track. As expected an increasing

⁶ Influential backward looking models are for instance Ball (1997) or Rudebusch et al (1999).

degree of forward lookingness leads to a drop in the degree of persistence of the inflation rate, as shocks are more self-stabilising if monetary policy is conducted according to a stable and unique policy rule, as some price setters that are called upon to reset their prices optimally anticipate future monetary policy decisions. Note that in the limit with \mathbf{m}_p converging to one, when we approximate the purely forward looking NKPC the inflation process converges towards white noise.

Figure 4 shows the sensitivity of the autocorrelations of the interest rate with respect to the individual elements in \mathbf{y} . Increasing weights on interest rate stabilization raises the persistence in interest rates as monetary policy uses its instrument more cautious and gradual (Figure 4(c)). Hence the interest rate reaction in response to shocks will be more sustained. This automatically leads to a higher degree of persistence. Varying weights on stabilizing the output gap do not have a significant impact on the autocorrelation structure (Figure 4(b)).

Figure 5 depicts some cross correlations inherently nested in the chosen baseline calibration \mathbf{y} . Figure 5 depicts the cross correlation of the inflation rate \mathbf{p}_t with the lagged differences of the interest rate $\Delta i_t, \Delta i_{t-1}$ and Δi_{t-2} . An increasing degree of forward lookingness in the IS-curve strengthens the correlation between past changes in the interest rate and today's inflation rate. This result can be interpreted as a faster 'path-through' effect running from interest rates to the inflation rate. Figure 5(b) depicts the cross correlation between the current output gap y_t and past changes in the interest rate $\Delta i_t, \Delta i_{t-1}$ and Δi_{t-2} . It can be seen that an increasing degree of forward lookingness in the IS-curve weakens the link between changes in yesterday's interest rate and changes in the output gap. This reflects that relatively modest movements in the change of interest rates are sufficient to control the output gap. Interestingly for values of \mathbf{m}_y larger than 0.5 the crosscorrelations $Corr(y_t, \Delta i_{t-1})$ and $Corr(y_t, \Delta i_{t-2})$ become negative which seems to be at odds with both, intuition and the data. Hence given the preference vector $\mathbf{y} = [1 \quad 0.15 \quad 1.85 \quad 0.4 \quad 0.4 \quad \mathbf{m}_y]$ there is a restriction on the set of

reasonable parameter constellations \mathbf{m}_y . Values larger than approximately 0.6 do not seem to be realistic. Figure 5(d) depicts the cross correlations between the interest rate i_t and the output gap y_t and y_{t-1} . The identified preference vector puts again restrictions on the set of reasonable parameter constellations. The model needs at least 40% of economic agents that are forward looking.

An increasing degree of forward lookingness in the Phillips curve tightens the link between interest rate changes and past movements of the output gap. Past movements in the output gap are faster transmitted into changes in the interest rate. Figure 5(e) reflects that an increasing weight on interest rate smoothing leads to a modest increase in cross correlations of the interest rate with past movements in the output gap. Figure 5(f) shows that an increasing weight on stabilizing the inflation rate around the inflation target loosens the link between lagged inflation rates and the current interest rate $Cor(i_t; \mathbf{p}_{t-i})$. Hence, an increasing degree of aggressiveness with which monetary policy reacts on inflation breaks the persistence in the inflation process which automatically weakens the link between past changes in the inflation rate and the current use of the interest rate.

6 Concluding Remarks

It has become standardized practice to evaluate the performance of alternative simple and optimal monetary policy rules based on the associated monetary policy outcomes. We take the point of view that this exercise necessarily rests on the apriority that key parameters of the New Keynesian macromodel are correctly specified. Within this paper we proposed a calibration technique that is based on matching variances and autocorrelations. Based on this technique we present evidence that around 60 percent of the pricing and consumption

decisions are not made by optimising agents but by rule of thumb setters. This result is in line with earlier studies and underlines that purely forward-looking NKPC and intertemporal IS-equations are unable to match the persistence present in the data. The finding that a majority of households and firms do not seem to optimise but base their decisions on heuristics may be a fruitful area for future research as it sheds doubt on the notion of rational expectations.

The paper made the point that some ‘conventional wisdom’ stating that estimated coefficients in the instrument rule of monetary policy are smaller than those retrieved by means of optimal control may be spurious. The analysis of the level of variances present in the data as well as the evaluation of selected cross correlations clearly indicates that some degree of forward lookingness is necessary to fit the facts. If monetary policy opts for a stable and unique rule, the job of monetary policy makers is much easier as it would be in a purely backward looking system, due to the implied self-stabilizing properties of forward-looking systems grounded on peoples expectations on stabilizing monetary policy itself (self-fulfilling expectations). The evaluation of some selected crosscorrelations served as a useful benchmark to put restrictions on the degree of forward-lookingness in the hybrid Phillips curve and the intertemporal IS-equation. The identified preference vector of monetary policy indicates that the dominant goal of monetary policy is the stabilization of the inflation rate around the inflation target. Output gap stabilization as an independent goal of monetary policy only seems to play a minor role for the conduct of monetary policy.

Appendix 1

The General Model Setup

Closely following Söderlind et al (2002) we can rewrite our basic equation in state space form as follows. In a first step we lead our model one period ahead and solve for the rational expectations variables $E_t \mathbf{p}_{t+4}$ and $E_t y_{t+2}$ with the highest time index:

$$\begin{aligned} \frac{m_p}{4} E_t \mathbf{p}_{t+4} = & \left(1 - \frac{m_p}{4}\right) E_t \mathbf{p}_{t+1} - \frac{m_p}{4} E_t \mathbf{p}_{t+2} - \frac{m_p}{4} E_t \mathbf{p}_{t+3} \\ & - (1 - m_p) [\mathbf{a}_{p1} \mathbf{p}_t + \mathbf{a}_{p2} \mathbf{p}_{t-1} + \mathbf{a}_{p3} \mathbf{p}_{t-2} + \mathbf{a}_{p4} \mathbf{p}_{t-3}] - \mathbf{a}_y y_t \\ \\ m_y E_t y_{t+2} + \frac{b_r m_r}{4} E_t \mathbf{p}_{t+4} = & E_t y_{t+1} - (1 - m_y) [\mathbf{b}_{y1} y_t + \mathbf{b}_{y2} y_{t-1}] \\ & + \mathbf{b}_r m_r \left[i_t - \frac{1}{4} E_t (\mathbf{p}_{t+1} + \mathbf{p}_{t+2} + \mathbf{p}_{t+3}) \right] \\ & + \frac{b_r (1 - m_r)}{4} [i_t + i_{t-1} + i_{t-2} + i_{t-3} - \mathbf{p}_t - \mathbf{p}_{t-1} - \mathbf{p}_{t-2} - \mathbf{p}_{t-3}] \end{aligned}$$

Hence we can rewrite the general model in state space form as:

$$\begin{aligned} A_0 \begin{bmatrix} X_{1t+1} \\ E_t X_{2t+1} \end{bmatrix} &= A \begin{bmatrix} X_t \\ X_{2t} \end{bmatrix} + B i_t + \begin{bmatrix} \mathbf{e}_{t+1} \\ 0_{n2 \times 1} \end{bmatrix} \\ X_{1t} &= \{\mathbf{p}_t, \mathbf{p}_{t-1}, \mathbf{p}_{t-2}, \mathbf{p}_{t-3}, y_t, y_{t-1}, i_t, i_{t-1}, i_{t-2}, i_{t-3}\}' \\ X_{2t} &= \{E_t \mathbf{p}_{t+3}, E_t \mathbf{p}_{t+2}, E_t \mathbf{p}_{t+1}, E_t y_{t+1}\}' \\ \mathbf{n}_{1t} &= \{\mathbf{e}_t, 0, 0, 0, \mathbf{h}_t, 0, 0, 0, 0\}' \end{aligned}$$

Where X_{1t} is a 9×1 vector of predetermined state variables X_{2t} is a 4×1 vector of forward looking variables and \mathbf{n}_{1t} is a vector of shocks. Following Söderlind et al. (2002) we have made use of the fact that $\mathbf{p}_{t+1} = E_t \mathbf{p}_{t+1} + \mathbf{e}_{t+1}$ and that $y_{t+1} = E_t y_{t+1} + \mathbf{h}_{t+1}$.

$$A_0 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{m_p}{4} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{b_r m_r}{4} & 0 & 0 & m_y \end{bmatrix}$$

$$A = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ (1-m_p)a_{p_1} & (1-m_p)a_{p_2} & (1-m_p)a_{p_3} & (1-m_p)a_{p_4} & -a_{p_5} & 0 & 0 & 0 & 0 & -\frac{m_p}{4} & -\frac{m_p}{4} & (1-\frac{m_p}{4}) & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ \frac{-b_r(1-m_r)}{4} & \frac{-b_r(1-m_r)}{4} & \frac{-b_r(1-m_r)}{4} & \frac{-b_r(1-m_r)}{4} & b_{y1}(1-m_r) & b_{y2}(1-m_r) & \frac{b_r(1-m_p)}{4} & \frac{b_r(1-m_p)}{4} & \frac{b_r(1-m_p)}{4} & -\frac{b_r m_r}{4} & \frac{b_r m_r}{4} & -\frac{b_r m_r}{4} & 1 & 1 \end{bmatrix}$$

$$B_1 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & b_r m_r + b_r(1-m_r)/4 \end{bmatrix}$$

Appendix 2

The Linear Quadratic Control Problem

The starting point of the linear quadratic control problem is the following value function:

$$V(X, t) = \min_{i_t} \left\{ \sum_{t=0}^T \mathbf{b}' \left(\frac{1}{2} X_t' Q_t X_t + i_t' R i_t \right) + \frac{1}{2} X_{T+1}' W_{T+1} X_{T+1} \right\}$$

Subject to the constraint:

$$\begin{bmatrix} X_{1t+1} \\ E_t X_{2t+1} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} X_{1t} \\ X_{2t} \end{bmatrix} + \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} i_t + \begin{bmatrix} v_{t+1} \\ 0_{n2 \times 1} \end{bmatrix}$$

Premultiplying by A_0 yields the standard state space form:

$$\begin{bmatrix} X_{1t+1} \\ E_t X_{2t+1} \end{bmatrix} = A \begin{bmatrix} X_{1t} \\ X_{2t} \end{bmatrix} + B i_t + v_{t+1}$$

With $A = A_0^{-1} A_1$ and $B = A_0^{-1} B_1$. Given the specific structure of the matrix A_0 it holds that:

$A_0^{-1} v_{t+1} = v_{t+1}$. The variance covariance matrix will be given by:

$$\Sigma_{v1} = A_0^{-1} v_t (A_0^{-1} v_t)' = A_0^{-1} v_t v_t' A_0^{-1}$$

Consequently it holds that the variance-covariance matrix stays a diagonal matrix with the following diagonal elements: $\text{diag} \{ \mathbf{s}_e^2 \quad 0 \quad 0 \quad 0 \quad \mathbf{s}_h^2 \quad 0 \quad 0 \quad 0 \quad 0 \}$

The value function has to satisfy in each period the following Bellman equation:

$$V(X_t) = \min_{i_t} \{ X_t' Q X_t + i_t' R i_t + \mathbf{b} V(X_{t+1}) \}$$

A cornerstone assumption in order to solve the model is to postulate a (linear) way according to which expectations are formed. We make the fundamental assumption that expectations are built as follows:

$$E_t X_{2,t+1} = C_{t+1} E_t X_{1,t+1}$$

As every distinct policy rule is linked to a different C matrix the approach takes care of the well-known Lucas critique. The policy maker cannot take expectations as given when changing the policy rule. With this assumption at hand one can arrive at a value function, which is only expressed in terms of predetermined variables:

$$V(t) = X_{1t}' Q_t^* X_{1t} + r_t' R_t^* r_t + \mathbf{b} E_t(V_{t+1})$$

Taking the F.O.C we arrive again at expressions for the optimal feedback rule as well as for the Ricatti-matrix V. Nevertheless contrasting the backward looking case our solution algorithm is quite different, as we do not only lack the matrix V but also the matrix C. Therefore the algorithm functions as follows. With an initial guess for V_0 and C_0 at hand we can iterate on the respective matrix equation until some matrix norm $\|C_{t+1} - C_t\| < \epsilon$ and $\|V_{t+1} - V_t\| < \epsilon$ has converged.

The (converged) time invariant solution can be written as:

TIME INVARIANT SOLUTIONS IN THE BACKWARD LOOKING MODEL
$X_{1t+1} = (A_{11} + A_{12}C - B_1F)X_{1t}$ $X_{2t} = CX_{1t}$ $F = -\left(R_t^* + \mathbf{b}B_t^*V_{t+1}B_t^*\right)^{-1}\left(U_t^{*'} + \mathbf{b}B_t^{*'}V_{t+1}A_t^*\right)X_{1t}$

The solution nicely depicts the expectational feedback, as the variable C does not only determine the forward looking variables X_{2t} but also influences the predetermined variables X_{1t} .

Appendix 3

Defining the Measurement Equation

Let us define a vector Y_t of measurement variables in which the monetary policy maker is interested in. We assume that the goal variables are given by:

$$Y_t = [\mathbf{p}_t \ \bar{\mathbf{p}}_t \ \mathbf{p}_{t-1} \ \mathbf{p}_{t-2} \ \mathbf{p}_{t-3} \ y_t \ y_{t-1} \ i_t \ i_{t-1} \ i_{t-2} \ i_{t-3} \ \Delta i_t \ \Delta i_{t-1} \ \Delta i_{t-2} \ \Delta \mathbf{p}_t \ \Delta \mathbf{p}_{t-1} \ \Delta \mathbf{p}_{t-2} \ \Delta y] \quad (\text{A.1})$$

We can define the target variables as a function of the state variables and the interest rate.

$$Y_t = (C_{x1} \ C_{x2})X_t + C_i i_t \quad (\text{A.2})$$

$$C_{x_1} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0,25 & 0,25 & 0,25 & 0,25 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \\ 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 \end{bmatrix} \quad (\text{A.3})$$

$$C_{X2} = 0_{18 \times 4} \quad (A.4)$$

$$C_i = [0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 1 \ 0 \ 0 \ 0 \ 1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0]' \quad (A.5)$$

Appendix 4

The Individual Calibration Criterion were Specified as Follows

$$\textbf{Criterion 1: } Crit1 = (1/4) \left[\begin{array}{l} abs((stdv(\mathbf{p}) - stdv(\mathbf{p}_{87-02})) / stdv(\mathbf{p}_{87-02})) \\ + abs((AC1(\mathbf{p}) - AC1(\mathbf{p}_{87-02})) / AC1(\mathbf{p}_{87-02})) \\ + abs((AC2(\mathbf{p}) - AC2(\mathbf{p}_{87-02})) / AC2(\mathbf{p}_{87-02})) \\ + abs((AC3(\mathbf{p}) - AC3(\mathbf{p}_{87-02})) / AC3(\mathbf{p}_{87-02})) \end{array} \right]^2$$

$$\textbf{Criterion 2: } Crit2 = (1/2) \left[\begin{array}{l} abs((stdv(y) - stdv(y)_{87-02}) / stdv(y)_{87-02}) \\ + abs((AC1(y) - AC1(y)_{87-02}) / stdv(y)_{87-02}) \end{array} \right]^2$$

$$\textbf{Criterion 3: } Crit3 = (1/4) \left[\begin{array}{l} (abs(stdv(i) - stdv(i)_{87-02}) / stdv(i)_{87-02}) \\ + (abs(AC1(i) - AC1(i)_{87-02}) / AC1(i)_{87-02}) \\ + (abs(AC2(i) - AC2(i)_{87-02}) / AC2(i)_{87-02}) \\ + (abs(AC3(i) - AC3(i)_{87-02}) / AC3(i)_{87-02}) \end{array} \right]^2$$

$$\textbf{Criterion 4: } Crit4 = (1/3) \left[\begin{array}{l} abs(stdv(d(\mathbf{p})) - stdv(d(\mathbf{p})_{87-02}) / stdv(d(\mathbf{p})_{87-02})) \\ abs(AC1(d(\mathbf{p})) - AC1(d(\mathbf{p})_{87-02}) / AC1(d(\mathbf{p})_{87-02})) \\ abs(AC2(d(\mathbf{p})) - AC2(d(\mathbf{p})_{87-02}) / AC2(d(\mathbf{p})_{87-02})) \end{array} \right]^2$$

$$\textbf{Criterion 5: } Crit5 = [abs((stdv(d(y)) - stdv(d(y))_{87-02}) / stdv(d(y))_{87-02})]^2$$

$$\textbf{Criterion 6: } Crit6 = (1/3) \left[\begin{array}{l} (abs(stdv(d(i)) - stdv(d(i))_{87-02}) / stdv(d(i))_{87-02}) \\ + (abs(AC1(d(i)) - AC1(d(i))_{87-02}) / AC1(d(i))_{87-02}) \\ + (abs(AC2(d(i)) - AC2(d(i))_{87-02}) / AC2(d(i))_{87-02}) \end{array} \right]^2$$

We have proposed an equal weighting of all constructed six criteria.

The constructed criterion is given by:

$$Kriterium = \sum_{i=1}^6 Crit_i$$

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Table 1 : Hybrid: Phillips Curves

Study	Phillips -curve	Period	Method
Castelnuovo		1987Q3-	Calibration
(2003)	$\mathbf{p}_t = 0.1 \cdot E_{t-1} \mathbf{p}_{t+3}$ $+ 0.9 \cdot [0.282 \cdot \mathbf{p}_{t-1} - 0.025 \cdot \mathbf{p}_{t-2} + 0.292 \cdot \mathbf{p}_{t-3} + 0.385 \cdot \mathbf{p}_{t-4}]$ $+ 0.141 \cdot y_{t-1}$	2001 Q1	based on a distance criterion
Linde		1960Q1-	FIML
(2002)	$\mathbf{p}_t = 0.463 E_t \mathbf{p}_{t+1} + 0.72 \mathbf{p}_{t-1} + 0.032 y_t + \mathbf{e}_p$	1997Q4	
Söderlind et al.		1987Q4-	Calibration,
(2002)	$\mathbf{p}_t = 0.1 \cdot E_{t-1} \mathbf{p}_{t+3}$ $+ 0.9 \cdot [0.67 \cdot \mathbf{p}_{t-1} - 0.14 \cdot \mathbf{p}_{t-2} + 0.4 \cdot \mathbf{p}_{t-3} + 0.07 \cdot \mathbf{p}_{t-4}]$ $+ 0.13 \cdot y_{t-1}$	1999Q4	based on Matching Moments
Domenech et al.		1986Q1-	GMM
(2001)	$\mathbf{p}_t = 0.537 E_t \mathbf{p}_{t+1} + 0.463 \mathbf{p}_{t-1} + 0.063 y_{t-1}$	2000Q4	
Jondeau et al.			GMM
(2001)	$\mathbf{p}_t = 0.747 E_{t+1} \mathbf{p}_{t+1} + 0.462 \mathbf{p}_{t-1} + 0.037 mc_t$		
Gali et al.		1960:1-	GMM
(2001)	$\mathbf{p}_t = 0.364 E_{t+1} \mathbf{p}_{t+1} + 0.599 \mathbf{p}_{t-1} + 0.02 mc_t$	1994:4	
Rudd et al.		1960:Q1-	GMM
(2001)	$\mathbf{p}_t = 0.605 E_{t+1} \mathbf{p}_{t+1} + 0.393 \mathbf{p}_{t-1} - 0.000 y_t$	1997 Q4	
Rudebusch		1968:3-	OLS
(2000)	$\mathbf{p}_t = 0.29 E_t \mathbf{p}_{t+1} + 0.71 \mathbf{p}_{t-1} + 0.13 y_t$	1996:Q4	
Gali et al.		1960:1-	GMM
(1999)	$\mathbf{p}_t = 0.682 E_{t+1} \mathbf{p}_{t+1} + 0.252 \mathbf{p}_{t-1} + 0.037 mc_t$	1994:4	

Table 2: Hybrid IS-Equations

Study	Phillips-Curve	Period	Method
Castelnuovo (2003)	$y_t = 0.2 \cdot E_{t-1} y_{t+1} + 0.8 \cdot [1.229 \cdot y_{t-1} - 0.244 y_{t-2} - 0.073(i_{t-1} - E_{t-1} \bar{p}_{t+3})] + h_t$	1987:Q3- 2001:Q1	Calibration based on a distance criterion
Söderlind et al. (2002)	$y_t = 0.5 \cdot E_{t-1} y_{t+1} + 0.5 \cdot [1.15 \cdot y_{t-1} - 0.27 y_{t-2} - 0.09(i_{t-1} - E_{t-1} \bar{p}_{t+3})] + h_t$	1987Q4- 1999Q4	Calibration based on matching moments
Domenech et al. (2001)	$y_t = 0.499 E_t y_{t+1} + 0.488 y_{t-1} + 0.047 y_{t-2} - 1.09 y_{t-3} + 0.161 y_{t-4} - 0.08181 r_{t-2} - 0.00819 r_{t-3}$	1986Q1- 2000Q4	GMM
Smets et al (2003)	$y_t = 0.41 E_t y_{t-1} + 0.588 y_{t-1} - 0.88(r_t - p_{t+1})$		Bayesian techniques

Table 3: **Loss Functions**

Study	Identified Loss Function	Period	Method
Castelnuovo (2003)	$L_t = \mathbf{p}^2 + 0.5y^2 + 0.5\Delta i^2$	1987-2001	Calibration based on a distance criterion
Söderlind et al. (2002)	$L_t = \mathbf{p}^2 + 0.1y^2 + 1.5\Delta i^2$	1987-1999	Calibration, based on matching moments
Dennis (2001)	$L_t = \mathbf{p}^2 + 0.23y^2 + 12.3\Delta i^2$	1979-2000	FIML
Favero and Rovelli (2002)	$L_t = \mathbf{p}^2 + 0.00125y^2 + 0.0085\Delta i^2$	1980-1998	GMM, Euler Equation
Cecchetti and Ehrmann (1999)	$L_t = \mathbf{p}^2 + 0.25y^2$	1987-1999	Slope of the Aggregate Supply Relationship

Table 4: Calibrating the New Keynesian Model

Quarterly New Keynesian Model	
(Rudebusch 2000)	
Inflation Equation	Output Gap Equation
$a_{p1} = 0.67$	$b_{y1} = 1.15$
$a_{p2} = -0.14$	$b_{y2} = -0.27$
$a_{p3} = 0.4$	$b_r = 0.09$
$a_{p4} = 0.07$	$s_y = 0.833$
$a_y = 0.13$	
$s_p = 1.012$	

Table 5: Calibration Output

RANKING	l	n	m _p	m _y
1	0.05	1.65	0.6	0.2
2	0	1.65	0.6	0.2
3	0	1.55	0.6	0.2
4	0	1.45	0.6	0.2
5	0	1.35	0.6	0.2
6	0	1.25	0.6	0.2
7	0	1.15	0.6	0.2
8	0	1.05	0.6	0.2
9	0	0.95	0.6	0.2
10	0.15	1.85	0.4	0.4

Table 6: Stability and Uniqueness of the Identified Solution

Eigenvalues	Stability
0	Stable
0	Stable
3.97	Unstable
-1.27 + 1.67i	Unstable
-1.27 - 1.67i	Unstable
-0.122 + 0.53i	Stable
-0.122 - 0.53i	Stable
-0.157	Stable
1.05	Unstable
0.80 + 0.30i	Stable
0.80 - 0.31i	Stable
0.61	Stable
0.34	Stable

For the identified baseline calibration: $\mathbf{y} = [1 \ 0.15 \ 1.85 \ 0.4 \ 0.4 \ 1]$.

Table 7 Time Series Properties: Simulated and Actual Data: (1987:4-2002:1)

RANK	LEVELS				ONE-QUATER-CHANGES			
	STANDARD DEVIATION	AC(1)	AC(2)	AC(3)	S TANDARD DEVIATION	AC(1)	AC(2)	AC(3)
Inflation								
Data	0.9794	0.649	0.514	0.585	0.8105	-0.32	-0.283	0.101
1	1.4678	0.6325	0.4487	0.4069	1.2584	-0.2501	-0.193	
2	1.4688	0.632	0.4473	0.4042	1.2601	-0.2491	-0.1924	
3	1.4588	0.627	0.4406	0.3983	1.26	-0.2502	-0.1931	
4	1.4485	0.6217	0.4336	0.3921	1.2599	-0.2513	-0.1939	
5	1.4377	0.6161	0.4261	0.3856	1.2598	-0.2525	-0.1947	
10	1.4668	0.67328	0.49702	0.49383	1.1857	-0.23026	-0.2649	
Output Gap								
Data	1.6953	0.945	0.865	0.755	0.5462	0.28	0.278	0.049
1	1.6026	0.8256			0.9464			
2	1.613	0.8278			0.9467			
3	1.6085	0.8265			0.9475			
4	1.6038	0.8252			0.9484			
5	1.5988	0.8237			0.9493			
10	1.4906	0.78226			0.98367			
Federal Funds Rate								
Data	1.9326	0.930	0.814	0.671	0.5365	0.58	0.303	0.191
1	1.7351	0.58	0.303	0.191	0.6093	0.6042	0.2837	
2	1.7262	0.58	0.303	0.191	0.5999	0.6136	0.296	
3	1.7332	0.58	0.303	0.191	0.6075	0.6109	0.2916	
4	1.7411	0.58	0.303	0.191	0.6159	0.608	0.2869	
5	1.7501	0.58	0.303	0.191	0.6253	0.6049	0.2818	
10	1.5113	0.58	0.303	0.191	0.4626	0.5873	0.2810	

Figure 1 Regions of Determinancy

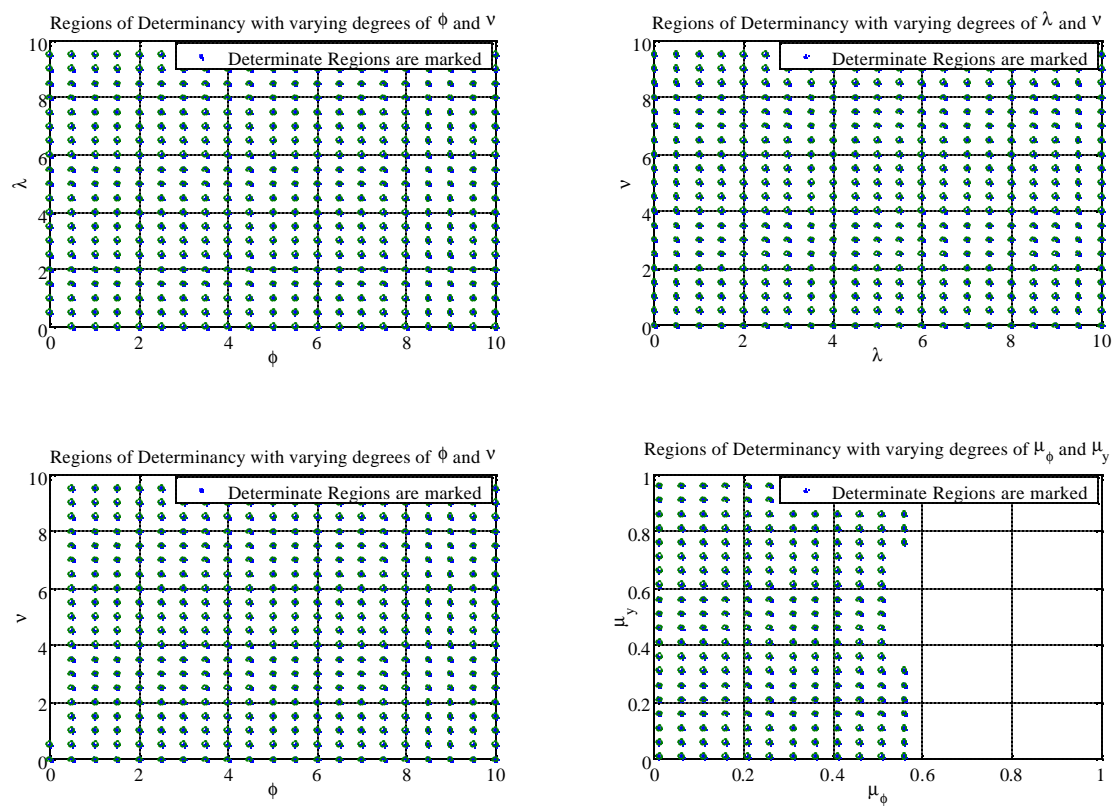
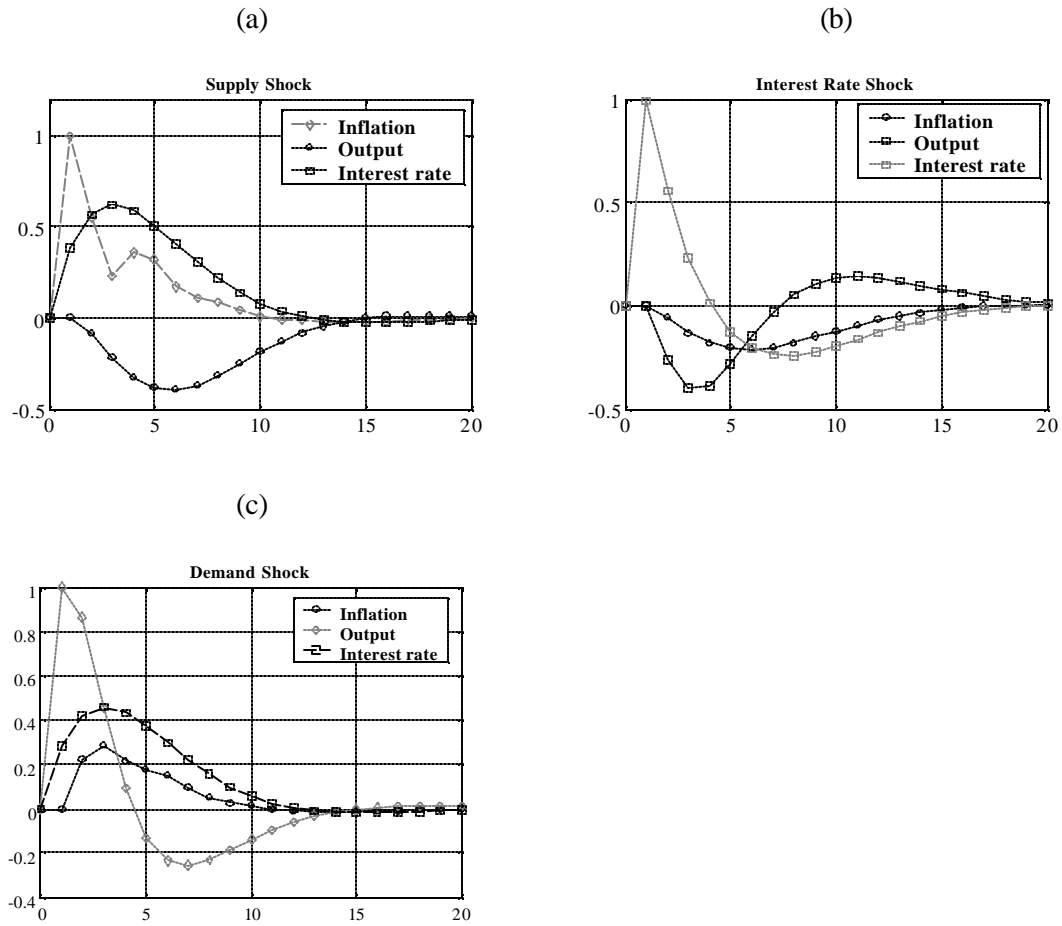
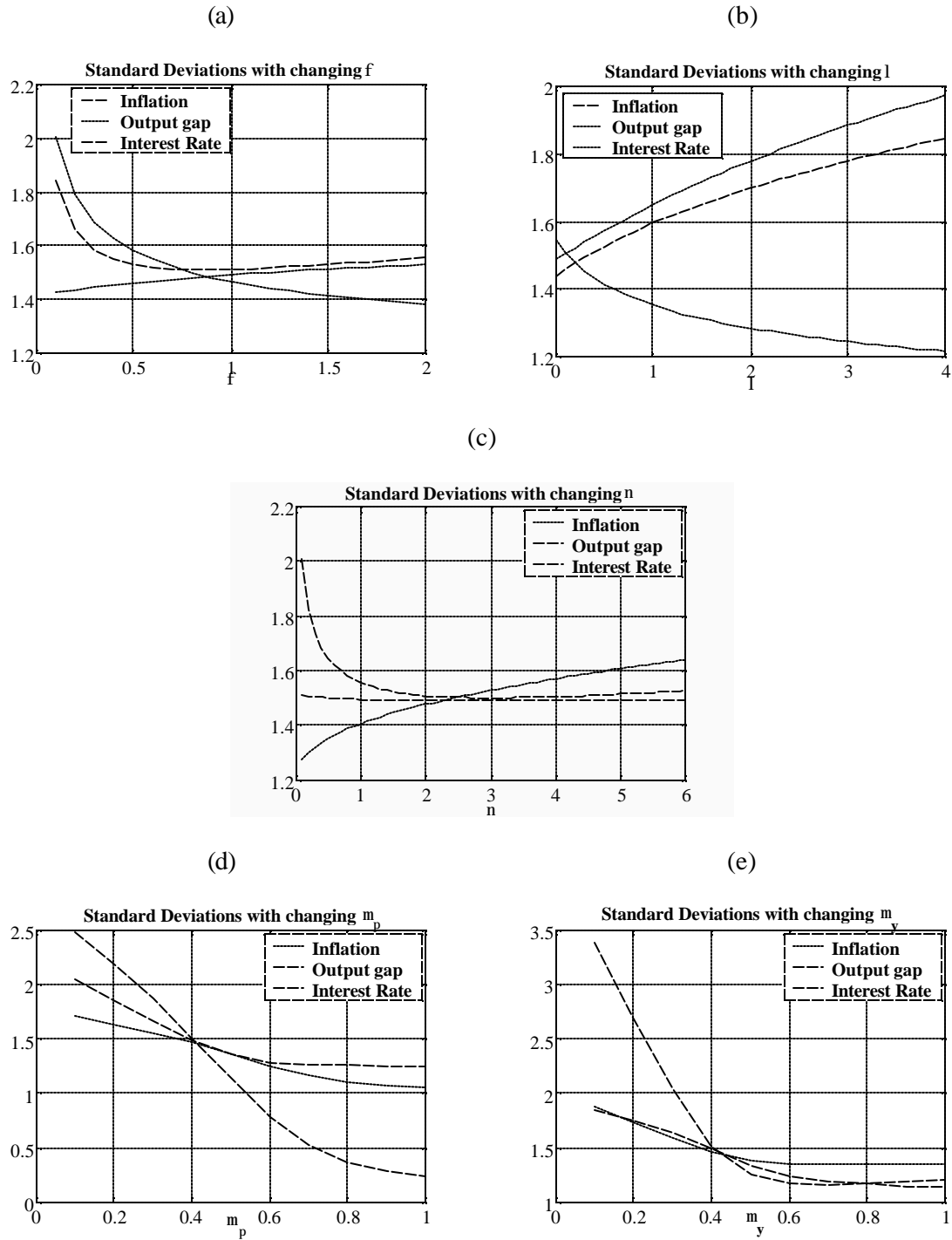


Figure 2 Impulse Response Function of the Baseline Configuration



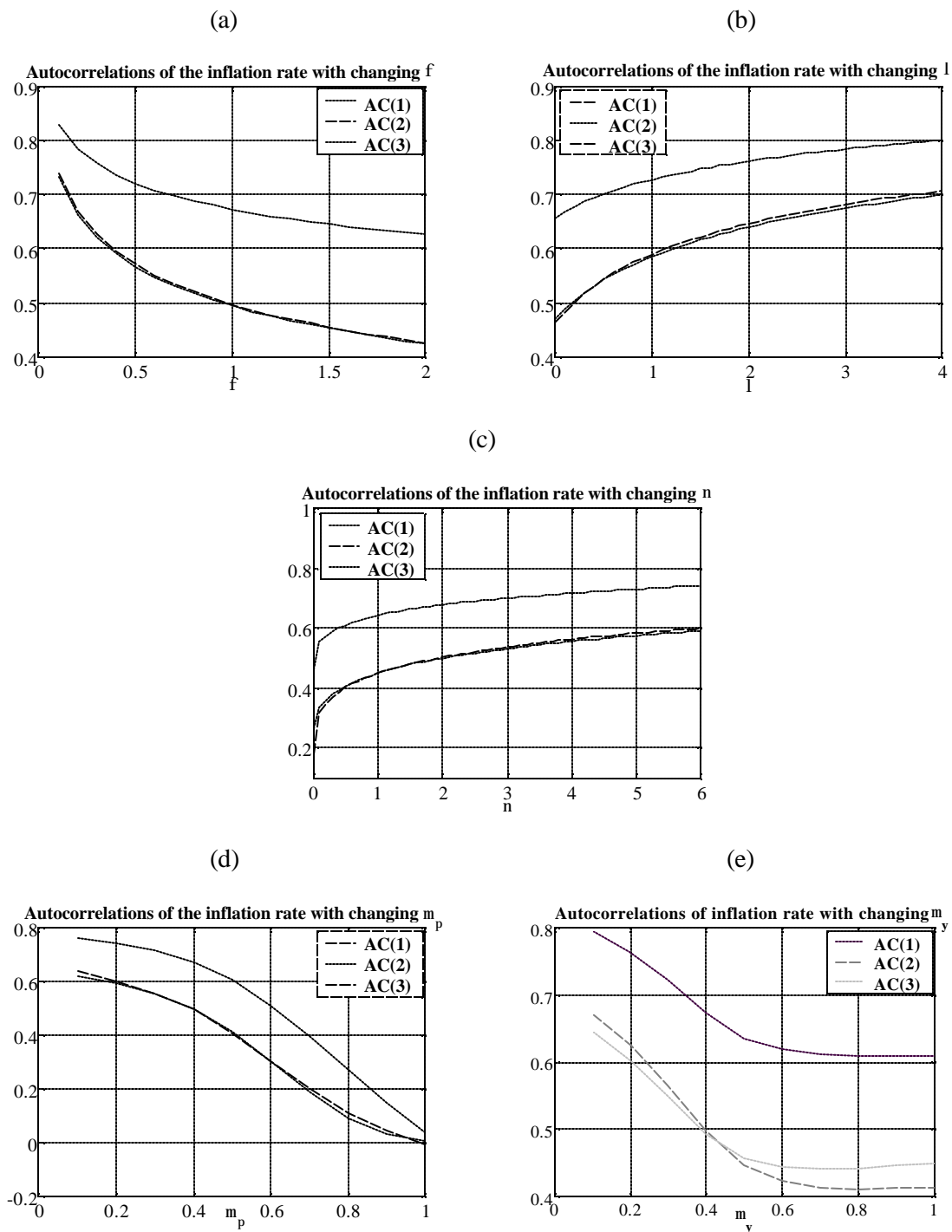
Impulse Response Function for the baseline configuration: $y = [1 \quad 0.15 \quad 1.85 \quad 0.4 \quad 0.4 \quad 1]$.

Figure 3: Variances with changing $y = [f \quad l \quad n \quad m_p \quad m_y]^*$



*setting $m_l = 1$ dominated setting $m_l = 0$ in terms of the chosen criterion, therefore we kept $m_l = 1$ for all possible specifications.

Figure 4: Autocorrelations of inflation with changing $y = [f \ l \ n \ m_p \ m_y]^*$

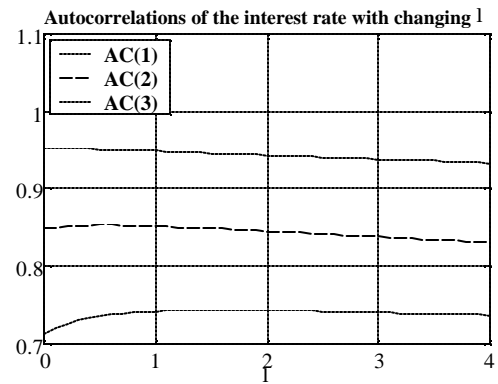
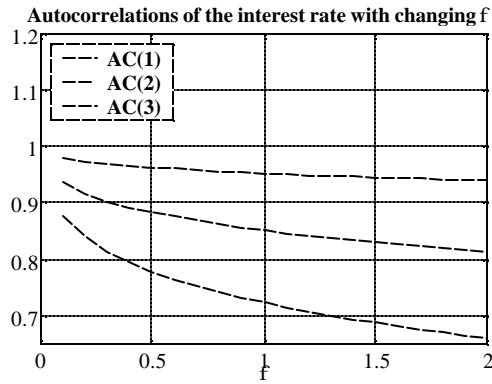


*setting $m_y = 1$ dominated setting $m_y = 0$ in terms of the chosen criterion, therefore we kept $m_y = 1$ for all possible specifications.

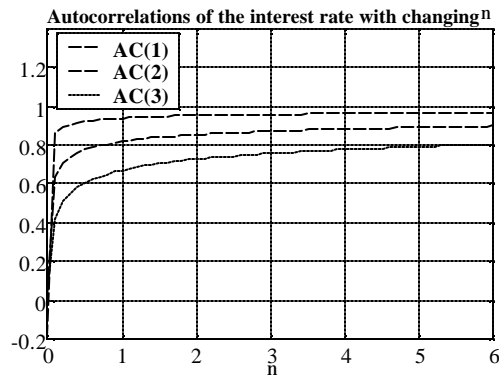
Figure 5: Autocorrelations of the interest rate $y = [f \quad l \quad n \quad m_p \quad m_y]^*$

(a)

(b)

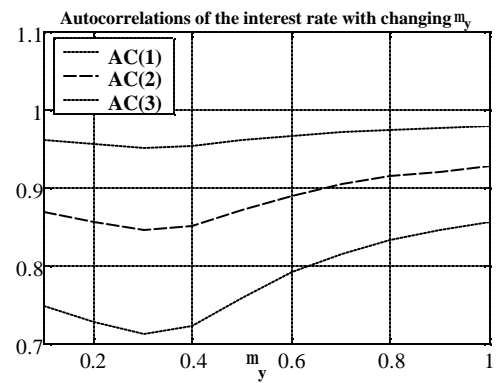
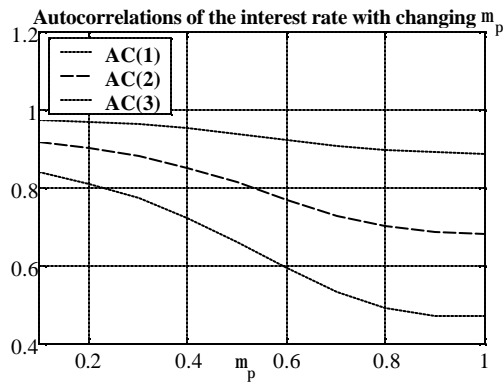


(c)



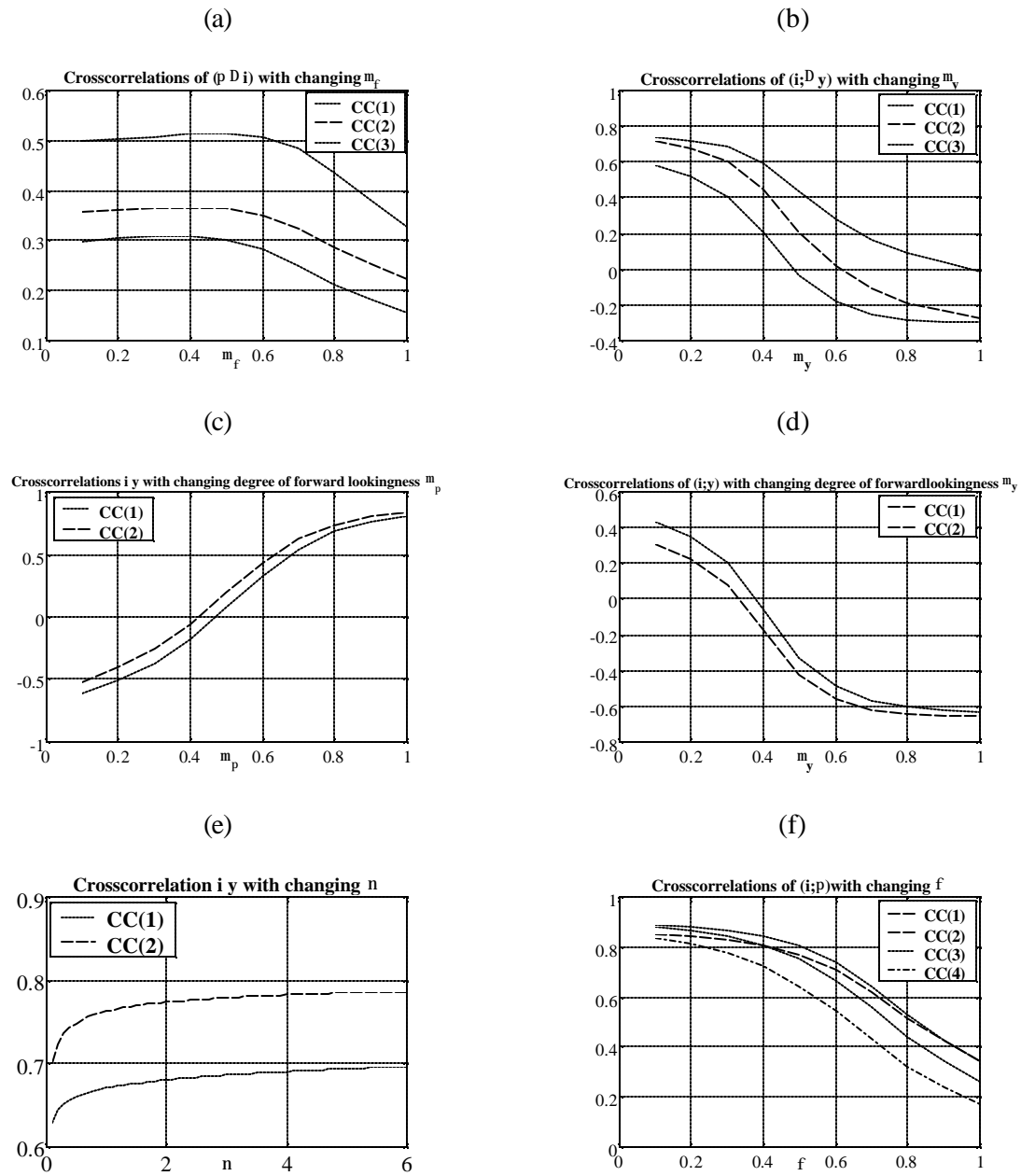
(d)

(e)



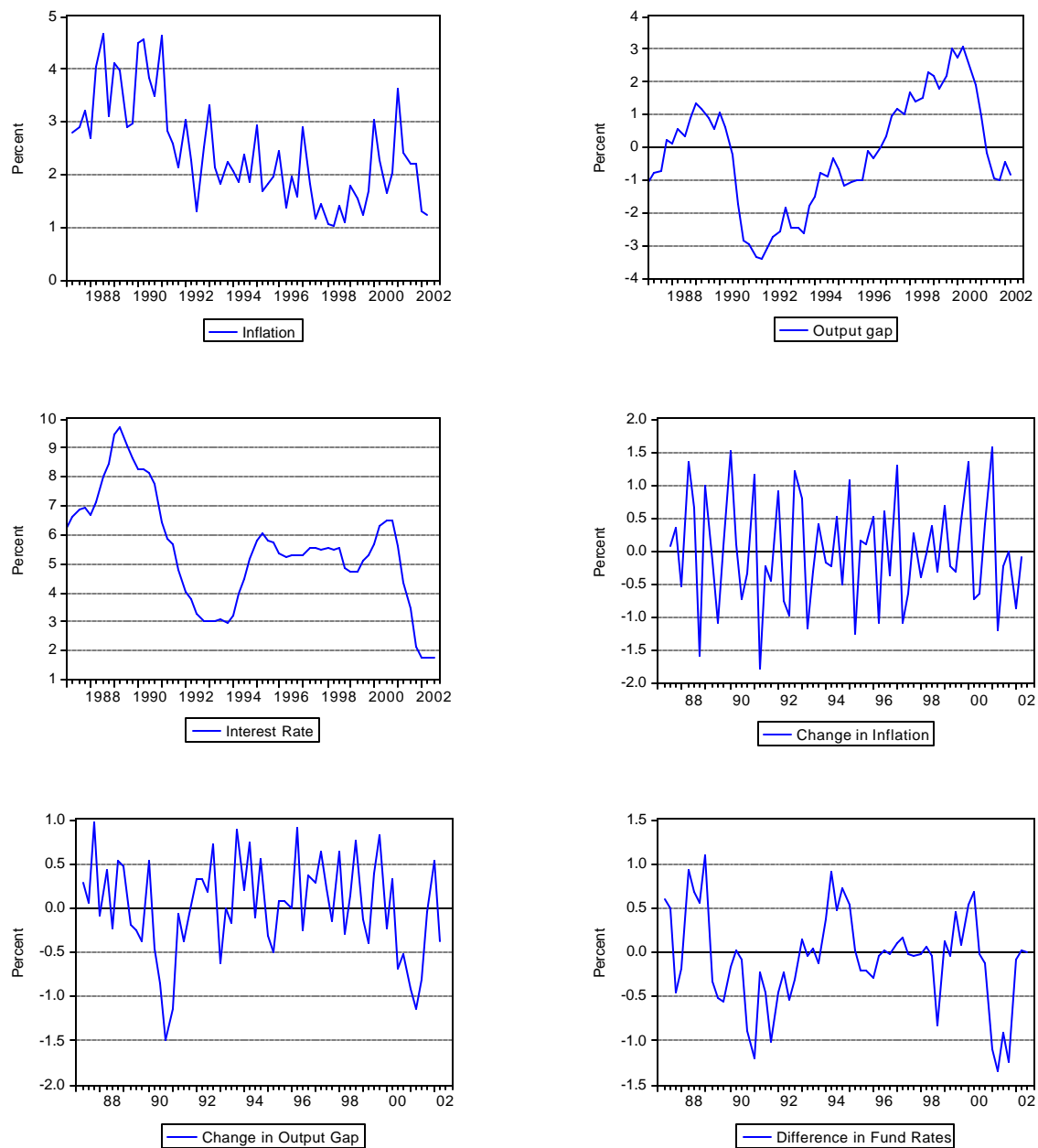
*setting $m_y = 1$ dominated setting $m_y = 0$ in terms of the chosen criterion, therefore we kept $m_y = 1$ for all possible specifications.

Figure 6: Selected Cross correlations with changing $y = [f \quad l \quad n \quad m_p \quad m_y]$



*setting $m_p = 1$ dominated setting $m_p = 0$ in terms of the chosen criterion, therefore we kept $m_p = 1$ for all possible specifications.

Figure 7: Stylised Time Series Properties: Levels and Differences



All data were taken from: <http://research.stlouisfed.org/fred/>

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