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ECONOMETRIC INFLATION TARGETING

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Econometric inflation targeting*

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Abstract

Inflation targeting requires inflation forecasts, yet most models in the literature are either theoretical or calibrated. The motivation for this paper is therefore threefold: We seek to test and implement an econometric model for forecasting inflation in Norway—one economy recently opting for formal inflation targeting rather than a managed nominal exchange rate. We also seek to quantify the relative importance of the different transmission mechanisms—with basis in empirical estimates rather than calibrated values. Finally, we want to focus on and exploit econometric issues required in the design and estimation of econometric models used for inflation forecasting and policy analysis.

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JEL classification: *C3, C5, E3, E5, J3.*

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1 Introduction

Research on monetary policy has recently focussed on the conditional inflation forecast as the operational target for monetary policy, yet the literature is dominated by either theoretical or calibrated models—recent examples are Ball (1999), Batini and Haldane (1999), Holden (1999), Røisland and Torvik (1999), Svensson (2000), Walsh (1999), and Woodford (2000). We will argue that econometric evaluation of models are necessary, not only as an aid in the preparation of inflation forecasts, but also as a way of testing, quantifying, and elucidating the importance of transmission mechanisms in the inflationary process. In this way, inflation targeting moves the quality of econometric methodology and practice into the limelight of economic policy debate.

The motivation for this paper is therefore threefold: We seek to test and implement an econometric model for forecasting inflation in Norway—one economy recently opting for formal inflation targeting rather than a managed nominal exchange rate.[1] We also seek to quantify the relative importance of the different transmission mechanisms—with basis in empirical estimates rather than calibrated values. Finally, we want to focus on and exploit econometric issues required in the design and estimation of econometric models used for inflation forecasting and policy analysis.

Other comparable econometric studies addressing inflation targeting do exist. Sgherri and Wallis (1999) estimate a small structural model for wages and prices in the UK, which is related to our core model. Their main focus is on the role of expectations and on evaluating monetary policy rules, including inflation forecast targeting rules. Two other contributions comparable to our paper are the work by Jacobson et al. (2001) and Haldane and Salmon (1995). Jacobson et al. (2001) investigate the empirical basis for inflation targeting in Sweden within a vector autoregressive framework. Our paper departs from Jacobson et al. (2001) in three main

[1] Norway introduced a formal inflation target of 2.5% annual inflation on 29 March 2001.

respects: we try to make judgements about the exogeneity status of the variables; we test an explicit theoretical model of the inflation process; finally, we model the transmission mechanisms of "shocks" as well as instruments. There is some common ground between our approach and the paper by Haldane and Salmon (1995), in that both investigations start form a core model of the supply-side. Nevertheless, in terms of methodology and the eventual model properties, the differences are easy to see. First, we attempt to test theoretical predictions—like the existence or not of a vertical long-run supply schedule—that Haldane and Salmon (1995) impose without testing. Second, the estimated inflation uncertainty is much smaller in our dynamic forecasts than in Haldane and Salmon's study.

Expectations are important in modelling inflation. Rudebusch and Svensson (1999) argue in favour of backward-looking models, while Woodford (2000) has recently argued that optimal monetary policy in general must be history dependent. We model expectations as backward-looking, following Ball (1999) and Rudebusch and Svensson (1999). If expectations are improperly modelled in the dynamic simultaneous equations model developed below, the model's parameters might change when policies change, generating misleading policy simulations, as emphasized by Lucas (1976). However, empirical evidence for the Lucas critique is scarce, as documented by Ericsson and Irons (1995). We test for non-constancy with respect to changes in exchange rate regimes that occurred within sample in Section 4.5, and we test for constancy of model parameters over the sample. We cannot find any evidence against backward-looking expectations.

In the rest of the paper logs of variables are denoted by lower-case symbols. Section 2 sets out the core model of inflation as a wage-price system, conditional on output, productivity, unemployment, and the exchange rate. The steady-state properties of this model are evaluated in Section 3.1, while we derive a dynamic model for wage and price growth in Section 3.2. We enlarge this core model to a small simultaneous equations model with relationships for output, productivity, unemployment, and exchange rates in Section 4, where the exogeneity assumptions underlying such a modelling strategy are examined in Section 4.5. We evaluate the properties of the simultaneous equations model for inflation forecasting and policy analysis in Sections 5 and 6. Section 7 concludes.

2 The inflation process

The inflation process is modelled as emerging from the labour market. Firms set their prices pp_t to reflect a mark-up m_2 over marginal costs. Assuming a constant returns to scale production function, the target nominal price pp^* is set as a constant mark-up over normal (log) unit labour costs:

$$pp_t^* = m_2 + w_t - pr_t + \tau 1_t, \tag{1}$$

where w_t is the wage rate, pr_t is productivity, and $\tau 1_t$ is the payroll tax-rate. Derived from first principles, equation (1) should be a discounted stream of expected future marginal costs—see Gali and Gertler (1999)—so (1) can be interpreted as a steady-state relationship. At first sight, (1) seems to exclude on important channel for import prices on inflation. However, in the following we are focusing on nominal wages and the consumer price index p_t, defined as

$$p_t \equiv (1-\zeta)\, pp_t + \zeta pi_t + \eta \tau 3_t,\ 0 < \zeta < 1, \quad 0 < \eta \leq 1, \tag{2}$$

where the import price index pi_t naturally enters. The parameter ζ measures of the openness of the economy. Also, the size of the parameter η will depend on how much of the retail price basket is covered by the indirect tax-rate index $\tau 3_t$.

Conflicting real wage claims are arguably the primary domestic source of inflation in economies where market forces are impeded by bargaining between organizations and intervention by the government, as in Norway as well as most other European economies. A simple log-linear wage equation derived from the bargainers' respective utility functions and budget constraints can be written as:

$$w_t^* = \delta_{12} pp_t + \delta_{13} pr_t - \delta_{15} u_t - \delta_{16} \tau 1_t - \delta_{17} \tau 2_t + (1 - \delta_{12}) p_t, \tag{3}$$

where w_t^* denotes the target nominal wage from the wage bargaining side of the economy. The real wage faced by firms is affected by producer prices pp_t, productivity pr_t, and a payroll tax-rate $\tau 1_t$. The real wage faced by employees is affected by consumer prices p_t, and income tax-rate $\tau 2_t$. The unemployment rate, u_t, represents the degree of tightness in the labour market which influences the outcome of the wage bargain.

We assume that (2) also holds for planned variables. Hence, substituting out pp_t^* from

$$p_t^* \equiv (1 - \zeta) pp_t^* + \zeta pi_t + \eta \tau 3_t,$$

we obtain the target equations

$$\begin{aligned} w_t^* &= (1 + \zeta d_{12}) p_t + \delta_{13} pr_t - \zeta d_{12} pi_t - \delta_{15} u_t - \delta_{16} \tau 1_t - \delta_{17} \tau 2_t - \eta d_{12} \tau 3_t, && (4) \\ p_t^* &= (1 - \zeta)(w_t - pr_t + \tau 1_t) + \zeta pi_t + \eta \tau 3_t, && (5) \end{aligned}$$

or, in terms of real wages for workers and firms:

$$\begin{aligned} rw_w^* &= \zeta d_{12} p_t + \delta_{13} pr_t - \zeta d_{12} pi_t - \delta_{15} u_t - \delta_{16} \tau 1 - \delta_{17} \tau 2_t - \eta d_{12} \tau 3_t, && (6) \\ rw_f^* &= \zeta w_t + (1 - \zeta)(pr_t - \tau 1_t) - \zeta pi_t - \eta \tau 3_t && (7) \end{aligned}$$

where $rw_w^* = w_t^* - p_t$ and $rw_f^* = w_t - p_t^*$, and $d_{12} = \delta_{12}/(1 - \zeta)$.

The static equilibrium considered in a number of earlier studies is defined by $rw_w^* = rw_f^* = rw^e$, where rw^e is the static equilibrium real wage. The two equation are seen to imply a NAIRU, see e.g. Layard et al. (1994). The NAIRU is independent of the price level, if (4) and (5) are both homogenous of degree one. However, and rather obviously, the static model has no implications for the dynamics of prices and wages.[2] Hence, to be able to derive formal implications for the changes in w_t and p_t (i.e. for inflation) we must decide on a dynamic version of the model, as discussed by Kolsrud and Nymoen (1998). For the dynamic model the relevant equilibrium concept is the steady state of the system, which in general (in the case of a stable dynamic system) is different from the static equilibrium corresponding to (6) and (7).

So far the model is made up of the competing claims equations for the real wage and a definitional equation for the consumer price index. Formally, the model is not determined since we have more unknowns than equations. In terms of economic content the model is incomplete since nothing has been said about the development of targeted and actual real wages. Although firms and unions have separate views about what real wage level should be, they can only influence real wages through nominal adjustment of wages and prices. In this way conflicting views about the appropriate real wage level become an important source of inflation.

In the following, we embed the conflict view of inflation in a model that captures all the other relevant causes of inflation. In particular we allow wage growth Δw_t to interact with current and past price inflation, changes in unemployment, changes in tax-rates, and previous deviations from the desired wage level

$$\begin{aligned} \Delta w_t - \alpha_{12,0}\Delta pp_t &= c_1 + \alpha_{11}(L)\Delta w_t + \alpha_{12}(L)\Delta pp_t + \beta_{12}(L)\Delta pr_t \\ &\quad -\beta_{14}(L)\Delta u_t - \beta_{15}(L)\Delta\tau 1_t - \beta_{16}(L)\Delta\tau 2_t \\ &\quad -\gamma_{11}(w - w^*)_{t-m} + \beta_{18}(L)\Delta p_t + \epsilon_{1t}, \end{aligned} \tag{8}$$

where Δ is the difference operator, the $\alpha_{ij}(L)$ and $\beta_{ij}(L)$ are polynomials in the lag operator L:

$$\begin{aligned} \alpha_{1j}(L) &= \alpha_{1j,1}L + \cdots + \alpha_{1j,(m-1)}L^{m-1},\ j = 1, 2, \\ \beta_{1j}(L) &= \beta_{1j,0} + \beta_{1j,1}L + \cdots + \beta_{1j,(m-1)}L^{m-1},\ j = 2, 4, 5, 6. \end{aligned}$$

[2] Clearly, the common statement that inflation increases if $rw_w^* > rw_f^*$ and falls if $rw_w^* < rw_f^*$ is *ad hoc*.

The $\beta-$polynomials are defined so that they can contain contemporaneous effects. m denotes the lag order. This is a generalization of the typical European wage curve, where the American version is derived by setting $\gamma_{11} = 0$—see Blanchard and Katz (1999)

Any increase in output above the optimal trend exerts a (lagged) positive pressure on prices, measured by the output gap_t, as in Phillips-curve inflation models—see Clarida et al. (1999). In addition, product price inflation interacts with wage growth and productivity gains and with changes in the payroll tax-rate, as well as with corrections from an earlier period's deviation from the equilibrium price (as a consequence of e.g. information lags, see Andersen (1994, Chapter 6.3)):

$$\begin{aligned} \Delta pp_t - \alpha_{21,0}\Delta w_t &= c_2 + \alpha_{22}(L)\,\Delta pp_t + \alpha_{21}(L)\,\Delta w_t + \beta_{21}(L)\,gap_t \\ &\quad - \beta_{22}(L)\,\Delta pr_t + \beta_{25}(L)\,\Delta\tau 1_t - \gamma_{22}\left(pp - pp^*\right)_{t-m} + \epsilon_{2t}, \end{aligned} \tag{9}$$

where

$$\begin{aligned} \alpha_{2j}(L) &= \alpha_{2j,1}L + \cdots + \alpha_{2j,(m-1)}L^{m-1},\ j = 1,2, \\ \beta_{2j}(L) &= \beta_{2j,0} + \beta_{2j,1}L \cdots + \beta_{2j,(m-1)}L^{m-1},\ j = 1,2,5. \end{aligned}$$

Solving (2) for pp_t and substituting out in equations (3), (8), (1), and (9), the theoretical model condenses (3)–(9) to a wage-price model suitable for estimation:

$$
\begin{bmatrix} 1 & -a_{12,0} \\ -a_{21,0} & 1 \end{bmatrix} \begin{bmatrix} \Delta w \\ \Delta p \end{bmatrix}_t = \begin{bmatrix} \alpha_{11}(L) & -a_{12}(L) \\ -a_{21}(L) & \alpha_{22}(L) \end{bmatrix} \begin{bmatrix} \Delta w \\ \Delta p \end{bmatrix}_t +
$$

$$
\begin{bmatrix} 0 & \beta_{12}(L) & -\zeta\frac{\alpha_{12}(L)}{1-\zeta} & -\beta_{14}(L) & -\beta_{15}(L) & \beta_{16}(L) & -\eta\frac{\alpha_{12}(L)}{1-\zeta} \\ b_{21}(L) & -b_{22}(L) & \zeta\alpha_{22}(L) & 0 & b_{25}(L) & 0 & \eta\alpha_{22}(L) \end{bmatrix} \begin{bmatrix} gap \\ \Delta pr \\ \Delta pi \\ \Delta u \\ \Delta\tau 1 \\ \Delta\tau 2 \\ \Delta\tau 3 \end{bmatrix}_t \qquad (10)
$$

$$
-\begin{bmatrix} \gamma_{11} & 0 \\ 0 & \gamma_{22} \end{bmatrix} \times \begin{bmatrix} 1 & -(1+\zeta d_{12}) & -\delta_{13} & \zeta d_{12} & \delta_{15} & \delta_{16} & \delta_{17} & \eta d_{12} \\ -(1-\zeta) & 1 & (1-\zeta) & -\zeta & 0 & -(1-\zeta) & 0 & -\eta \end{bmatrix} \begin{bmatrix} w \\ p \\ pr \\ pi \\ u \\ \tau 1 \\ \tau 2 \\ \tau 3 \end{bmatrix}_{t-m}
$$

$$
+\begin{bmatrix} e_1 \\ e_2 \end{bmatrix}_t,
$$

where

$$
\begin{aligned}
a_{12,0} &= \frac{\alpha_{12,0}}{1-\zeta} + \beta_{18,0}, \\
a_{21,0} &= (1-\zeta)\,\alpha_{21,0}, \\
a_{12}(L) &= \frac{\alpha_{12}(L)}{1-\zeta} + \beta_{18}(L), \\
a_{21}(L) &= (1-\zeta)\,\alpha_{21}(L), \\
b_{2j}(L) &= (1-\zeta)\,\beta_{2j}(L),\ j = 1, 2, 5, \\
d_{12} &= \frac{\delta_{12}}{1-\zeta}, \\
e_1 &= \epsilon_1, \\
e_2 &= (1-\zeta)\,\epsilon_2.
\end{aligned} \qquad (11)
$$

map from the theoretical parameters in (8) and (9) to the coefficients of the model (10). This point is used to test parameter restrictions in Section 3.2.

The model (10) contains the different channels and sources of inflation discussed so far: Imported inflation Δpi_t, and a range of domestic channels: the output gap, changes in the rate of unemployment, in productivity, and in tax rates.

In particular, the role of conflicting wage claims is made explicit by expressing the levels part of (10) as

$$-\begin{bmatrix} \gamma_{11} & 0 \\ 0 & \gamma_{22} \end{bmatrix} \times \begin{bmatrix} (w-p)_{t-m} - (w^{*}-p)_{t-m} \\ -(w-p)_{t-m} + (w-p^{*})_{t-m} \end{bmatrix}.$$

Note that significance of the two EqCM terms implies refutation of the Phillips-curve formulations that dominates much of the literature. Put differently, $\gamma_{11} = \gamma_{22} = 0$ in (10) is seen to exclude conflicting real wage claims as a separate inflation mechanism, which in the present setting amounts to no cointegration. Cointegration is tested in Section 3.1.

The model in (10) can be re-written in terms of two real variables, $(w-p)_t$ and $(pi-p)_t$, real wages and the real exchange rate. Kolsrud and Nymoen (1998) investigate the special case with first order dynamics, and show that the dynamic system of $(w-p)_t$ and $(pi_t-p)_t$ is stable under quite general assumptions about the parameters. For example, the model has a steady-state solution with $\Delta^2 p_t = 0$ even when one imposes *dynamic homogeneity*. The steady state is conditional on any given rate of unemployment, which amounts to saying that the core model does not tie down the equilibrium rate of unemployment. Instead, there is a stalemate in the dynamic "tug-of-war" between workers and firms that occurs for a given rate of unemployment. The analysis shows that the main insight of Haavelmo's conflict model of inflation, see e.g. Qvigstad (1975), namely that inflation is a generic equilibrating mechanism of conflicting claims, generalizes to the open economy case.

We conjecture that a similar stability property for our version of the model, although it has more general dynamics, a conjecture that is confirmed by properties of the empirical model in Section 3.2. Given stability of the dynamic wage-price model, the implied steady-state inflation rate follows immediately: Since $\Delta(pi - p)_t = 0$ in steady state, domestic inflation is equal to imported inflation, which is determined outside the core model. If there is a constant long-run imported inflation rate then

$$\Delta p_t = \Delta pi_t = \text{constant}. \tag{12}$$

Since,

$$pi_t = v_t + pf_t,$$

where v_t is the nominal exchange rate, and the index of import prices in foreign currency is denoted pf_t, the stability of imported inflation in (12) requires some degree of stability in the nominal exchange rate, v_t.[3] To anticipate events slightly, our empirical model meets the requirement in the sense that $\Delta^2 v_t \rightarrow 0$ in the long-run. But our results also indicate that "constant" in (12) is affected by the nominal exchange rate, and that the rate of inflation is therefore influenced by monetary policy also in the long run.

3 Building the wage-price model

3.1 Modelling the steady state

From equation (10), the variables that contain the long-run real wage claims equations are collected in the vector $\begin{bmatrix} w & p & pr & pi & u & \tau 1 & \tau 3 \end{bmatrix}^T$. The wage variable w, is average hourly wages in the *mainland economy*, excluding the North-Sea oil producing sector and international shipping. The productivity variable pr is defined accordingly. The price index p is measured by the official consumer price index. Import prices pi are measured by the official index. The unemployment variable u is defined as a "total" unemployment rate, including labour market programmes. The tax-rates $\tau 1$ and $\tau 3$ are rates of payroll-tax and indirect-tax , respectively.[4]

[3] Assuming that Δpf_t is exogenous.

[4] Compared to the theoretical model the income tax rate $\tau 2$ is omitted from the empirical model, since it is insignificant in the model. This finding is in accordance with previous studies of aggregate

In addition to the variables in the wage-claims part of the system, we include gap_{t-1}—the lagged output gap measured as deviations from the trend obtained by the Hodrick-Prescott filter. Institutional variables are also included. Wage compensation for reductions in the length of the working day is captured by changes in the length of the working day Δh_t—see Nymoen (1989). The intervention variables *Wdum* and *Pdum*, and one impulse dummy $i80q2$, are used to capture the impact of incomes policies and direct price controls.[5] Finally, $i70q1$ is a VAT dummy. This system, where all main variables enter with three lags, is estimated over 1966(4)–1996(4).

All the empirical results are obtained wih *PcFiml 9.2*—see Doornik and Hendry (1996). The steady-state properties are evaluated using the Johansen (1988) cointegration procedure, after first establishing the presence of two cointegrating vectors.[6] Different forms of restricted claims equations suggested in the literature can be retrieved in (10) by suitable parameter restrictions on the equilibrium-correction part of the model. We start from the two general claims equations

$$w^* = p + \delta_{13}pr - \delta_{15}u - \delta_{16}\tau 1 - \delta_{17}\tau 2 + d_{12}\zeta\left(p - pi - \frac{\eta}{\zeta}\tau 3\right) \quad (13)$$

$$p^* = (1-\zeta)(w - pr + \tau 1) + \zeta pi + \eta\tau 3 \quad (14)$$

where $d_{12} = \delta_{12}/(1-\zeta)$. The omission of the income tax-rate $\tau 2$ from the system implies that $\delta_{17} = 0$.

Panel 2 in Table 1 reports the statistical long-run relationship in the form of

wage formation, see e.g. Calmfors and Nymoen (1990) and Rødseth and Nymoen (1999), where no convincing evidence of important effects from the average income tax rate $\tau 2$ on wage growth could be found.

[5] *Wdum* and *Pdum* are defined in the appendix.

[6] The test is based on a system that includes a restricted deterministic trend, following the procedure suggested by Harbo et al. (1998). Using their Table 2 for the case with 5 exogenous variables, the *Trace*-statistics of 82.73 and 30.20 (degrees of freedom corrected) gives formal support to 2 cointegrating vectors: The 5% critical values are 49.3.(for the null of no cointegration) and 25.3 (for the null of $r = 1$ against the alternative of $r = 2$). The economic identification of the two relationships can proceed without the deterministic trend, since a test of its significance (based on $r = 2$) shows that it can be dropped from the system: $\chi^2(2) = 2.0911[0.3515]$.

the theoretical equations in Panel 1. The remaining panels report a sequence of valid simplifications of Panel 2. Panel 3 shows a simplification where $\delta_{12} = 0$ (and hence $d_{12} = 0$), corresponding to full wage indexation to consumer prices.[7] Panel 4 allows productivity to be fully reflected in wages ($\delta_{13} = 1$). Finally, if there are no effects from producer prices, but the full payroll tax-incidence is borne by the firms, so $\delta_{16} = 0$, the two target equations can be formulated as:

$$\begin{aligned} w^* &= p + pr - \delta_{15} u, && (16) \\ p^* &= (1 - \zeta)(w - pr + \tau 1) + \zeta pi + \eta \tau 3, && (17) \end{aligned}$$

with estimation results in Panel 4.

[Table 1 about here.]

The last results are very close to the results for Norway in Bårdsen et al. (1998) for a sample ending in 1993(1), which is evidence of invariance to a sample extension of 15 new observations. Figure 1 records the stability over the period 1978(3)-1996(4) of the coefficient estimates of Panel 4 in Table 1 (β in the graphs) with $\pm$ 2 standard errors ($\pm$2se in the graphs), together with the tests of constant cointegrating vectors over the sample. The estimated wage responsiveness to the rate of unemployment is approximately 0.1, which is close to the finding of Johansen (1995) on manufacturing wages. This estimated elasticity is numerically large enough to represent a channel for economic policy on inflation.

[Figure 1 about here.]

On the basis of Table 1 we therefore conclude that the steady-state solution of our system can be represented as

[7] Interestingly, an alternative that was rejected is defined by $\delta_{17} = 0$ and $\delta_{16} = \delta_{12} = 1$, which amounts to an equation where wage-costs depend on the real exchange rate $(p_t - pi_t)$

$$w_t^* + \tau 1_t - p_t = \delta_{13} pr_t - \delta_{15} u_t + \frac{\zeta}{1-\zeta}(p_t - pi_t) - \frac{\eta}{1-\zeta}\tau 3_t. \qquad (15)$$

$$
\begin{aligned}
w &= p + pr - 0.1u \\
p &= 0.6\,(w + \tau 1 - pr) + 0.4pi + \tau 3.
\end{aligned}
$$

3.2 The dynamic wage-price model

We have established the steady-state properties of the wage-price model, as predicted by (4) and (5). We now want to estimate (10) in order to test the predictions of the model set out in Section 2. We impose the estimated steady state from Panel 4, Table 1, on a subsystem for $\{\Delta w_t, \Delta p_t\}$ conditional on $\{\Delta pr_t, \Delta y_t, \Delta u_{t-1}, \Delta \tau 1_t, \Delta \tau 3_t\}$ with all variables entering with two additional lags. In addition to gap_{t-1}, we also augment the system with $\{\Delta h_t,\ i80q2,\ i70q1, Wdum,\ Pdum\}$ to capture short-run effects, as described above.

[Figure 2 about here.]

We start out by simplifying the system by deleting insignificant terms, establishing a parsimonious statistical representation of the data in $I\,(0)$-space, following Hendry and Mizon (1993). The diagnostics of the system are reported in the upper part of Table 2, while recursive tests of parameter constancy are reported in Figure 2. First, the two 1-step residuals with their $\pm$ 2 estimated residual standard errors, $\pm 2\sigma$ in the graphs. The third panel shows the a sequence of recursive forecast Chow-tests together with their one-off 5 per cent critical level.

Next, we test whether the dynamic restrictions implied by (10) are data-acceptable—see Appendix A—arriving at

$$
\begin{bmatrix} 1 & -1 \\ \underset{(0.05)}{-0.13} & 1 \end{bmatrix} \begin{bmatrix} \widehat{\Delta w} \\ \widehat{\Delta p} \end{bmatrix}_t =
$$

$$
\begin{bmatrix} 0 & 0 & -0.4 \times 0.36 & 0 & -L^2 & \underset{(0.08)}{-0.36L^2} \\ \underset{(0.02)}{0.06L} & 0 & 0.4 \times 0.07 & 0 & 0.13L^2 & \underset{(0.03)}{0.07L^2} \end{bmatrix} \begin{bmatrix} gap \\ \Delta pr \\ \Delta pi \\ \Delta u \\ \Delta \tau 1 \\ \Delta \tau 3 \end{bmatrix}_t \tag{18}
$$

$$
- \begin{bmatrix} \underset{(0.01)}{0.08} & 0 \\ 0 & \underset{(0.01)}{0.08} \end{bmatrix} \begin{bmatrix} L & -L & -1 & 0 & 0.1L & 0 & 0 \\ -0.6 & L^2 & 0.6 & -0.4 & 0 & -0.6 & -L^2 \end{bmatrix} \begin{bmatrix} w \\ p \\ pr \\ pi \\ u \\ \tau 1 \\ \tau 3 \end{bmatrix}_{t-1}
$$

[Table 2 about here.]

The lower part of Table 2 contains diagnostics for the model (18). We note that the insignificance of *Overidentification* $\chi^2(9)$ shows that the theory restrictions in (10) are not refuted by the data.

The first equation in (18) shows that a one percent in the rate of inflation raises wage growth by one percent. However, closer inspection of the equation shows that this is not the case in general: The wage equation includes an indirect tax-rate, lagged, with a negative coefficient. The effects of the discretionary policy variables are not shown, but they include a negative coefficient of the VAT dummy ($i70q1_t$) and (ceteris paribus) positive effects of price controls ($Pdum_t$). Hence discretionary policies have clearly succeeded in affecting consumer real wage growth over the sample period. However, in periods where such policies are off, aggregate wages react quickly to "normal" or expected consumer price increases as captured by the unit coefficient of Δp_t. Import price growth is likely to be the most important "unexpected" part of price inflation, so given the unit coefficient on Δp_t, it is not surprising that Δpi_t is attributed a negative estimated coefficient. The equilibrium-correction term is highly significant, as expected. Finally, the change in normal working-time Δh_t enters the wage equation with a negative coefficient, as expected. In addition to equilibrium-correction and the dummies representing incomes policy, price inflation is significantly influenced by wage growth and the output gap, together with effects from import prices and indirect taxes—as predicted by the theoretical model.

As discussed by Kolsrud and Nymoen (1998), the question whether systems like ours have a NAIRU property hinges on the detailed restrictions on the short run dynamics. We note that the wage growth equation comes close to being homogenous in consumer price and import price growth. Using, $\Delta p_t \equiv (1-\zeta)\Delta pp_t + \zeta \Delta pi_t$ this is seen to imply that wage growth is almost homogenous in domestic producer prices (Δpp_t) and imported inflation. However, this does not imply that we are close to having a NAIRU property: Kolsrud and Nymoen (1998) show that a necessary condition for the NAIRU property is that wage growth is homogenous with respect to Δpp_t alone. That homogeneity restriction does not hold in equation (18): Using the estimated value of $\zeta = 0.38$ from (1) the implied wage elasticities with respect to Δpp_t and Δpi_t are 0.62 and 0.24.[8] The wage equation therefore implies that we do not have a NAIRU model. Instead we expect that inflation stabilizes to the rate of imported inflation for any given rate of unemployment, see Section 2 above.

[Figure 3 about here.]

The model has a very good fit, as Figure 3 documents, as well as having constant parameters, as shown in Figure 4, which contains the one-step residuals and recursive Chow-tests for the model. Finally, the lower left panel of Figure 4 shows that the model encompasses of the system at every sample size. There are no evidence of any misspecified expectations mechanisms.

[Figure 4 about here.]

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[8] If we introduce Δpp_t in the model we find a signicant effect of the fourth lag, Δpp_{t-4} with coefficient 0.14. The coefficient of Δp_t falls to 0.71 but retain a t-value of 4.2. If we use $\zeta = 0.38$ the implied elasticity with respect to producer price growth is 0.58, practically the same as implied by the maintained model.

4 The full model

The essential steps in constructing a full econometric model of inflation are illustrated in Figure 5. The core model of the inflation process corresponds to wage-price model in the figure. There are three types of explanatory variables: feedback variables , non-modelled variables (tax-rates, world-prices), and monetary policy instruments.

We initially treat feedback variables, *e.g.* unemployment, output gap, productivity, import prices, etc., as weakly exogenous variables in the wage-price model. This is a testable property that we address after modelling the feedback relationships in Section 4. The figure indicates that the feed-back variables are not only functions of lagged wages and prices. Empirically they may depend on both the non-modelled explanatory variables and on the policy variables.

Central banks do set interest rates, but (hopefully) differently under the different monetary policy regimes found in our sample. Thus finding an empirically constant reaction function from inflation forecasts to interest rates is a non-starter. We therefore treat the short-run interest rate as a policy variable. The exchange rate, however, which depend both on inflation and foreign variables, is the important monetary feedback variable.

[Figure 5 about here.]

Regime shifts may induce non-constancies in the parameters of the wage-price model. If that is the case, the usefulness of the model for policy analysis is reduced, as it then falls prey to the Lucas-critique. However, invariance can be tested within the sample. We test if the parameters of the inflation model have remained constant despite the parameter changes in the marginal models in Section 4. Invariance with respect to structural changes *outside* the sample period cannot be tested directly. However, it is possible to gain some insight through more indirect methods, since there now exists a body of evidence from other countries. Sweden, who share many of the wage setting institutions of Norway, changed her monetary regime in 1993:

Rødseth and Nymoen (1999) do not find any impact on the parameters of their estimated equation for Swedish manufacturing wages. Also, United Kingdom wage-price formation has recently been investigated in Bårdsen and Fisher (1999) and Bårdsen et al. (1998) with data spanning several changes in regime, including moving from exchange rate targeting to inflation targeting.[9] The parameters of the model remained constant across these changes in regime.

We also note that, unless inflation targeting is in every respect a truly new regime, there may be periods in the sample where monetary instruments were used in a way that resembles what one might expect if a formal inflation target regime was in place. In particular, one can argue that this has been the case after December 1992, when the Norwegian Krone (NOK) went floating. Moreover, the exchange rate that we use as a predictor of inflation, *i.e.* the trade-weighted exchange rate variable, shows variation even in periods where the official target exchange rate is relatively constant. Thus, even a successful exchange rate targeting regime may entail considerable variation in the trade-weighted exchange rate. Hence, while not claiming to prove invariance of the Wage-price model with respect to a shift to formal inflation targeting, we believe that invariance (or lack thereof) to changes in the way the managed float regime have been implemented over the sample is a relevant property of the model.

We have established a wage-price model conditional upon the rate of unemployment u_t, average labour productivity pr_t, import prices pi_t, and GDP mainland output y_t. In this section we enlarge the model to include relationships for these four variables. This serves three purposes: First, all of these variables are potentially affected by interest rates and are therefore potential channels for monetary instruments to influence inflation. Second, none of these variables are likely to be strongly exogenous. For example, import prices depend by definition on the nom-

[9] The data covered the period 1976(2)–1993(1). The United Kingdom joined the ERM on 8 October 1990. Membership was suspended on 6 September 1992. The new framework was announced in October first by a short letter from the Chancellor and then his 'Mansion House speech' later that month. The first Inflation Report was published in February 1993. Prior to 1990 sterling had been 'freely' floating since the early seventies.

inal exchange rate. Below we report a model that links the exchange rate to the lagged real exchange rate, which in turn depend on the domestic price level. Third, we make use of the marginal model to test the hypothesis of weak exogeneity that underlies the wage-price model.

4.1 The nominal exchange rate v_t

The nominal exchange rate affects wages and prices via import prices pi. Hence, as a first step in the completion of the model, we make use of the identity

$$pi_t = v_t + pf_t,$$

and attempt to model the (log) of the trade weighted exchange rate index v_t. However, Akram and Eitrheim (1999) model the exchange rate as equilibrium correcting to the real exchange rate

$$v_t - p_t + pck_t,$$

where pck_t is log of a trade weighted index of foreign consumer prices. We build upon their work, but also include an interest rate arbitrage effect from

$$(RS_t - 4\Delta p_{t-1}) - (RSECU_t - 4\Delta pck_t)\,,$$

giving the combined equilibrium-correction term

$$EqCMv\,(t) = (RS_t - 4\Delta p_{t-1} - RSECU_t + 4\Delta pck_t) + (v - p + pck)_{t-1}$$

where $RSECU_t$ is the foreign interest rate, and pck_t is the (logarithm of) the foreign consumer price index (in foreign currency). Akram (1999) documents significant non-linear effects of the USD price of North-Sea oil. Our model is built along the same lines and therefore features non-linear effects from oil prices (OIL_t) in the form of two smooth transition functions, see Teräsvirta (1998),

$$OILST_t = 1/\left\{1 + exp\left[4\left(OIL_t - 14.47\right)\right]\right\}$$

and

$$DOILST = 1/\left[1 + exp\left(OIL - OIL_{t-1}\right)\right].$$

The implication of the first function is that an oil price below 14 USD triggers depreciation of the krone, while the second captures depreciation caused by falling oil prices. In addition, there is a negative (appreciation) effect of the change in the money market interest rate ΔRS_t. Finally, there is a composite dummy

$$Vdum_t = i78q2 + 2 \times i82q3 + i86q4 + i87q4$$

to take account of devaluation events. Figure 6 shows the sequence of 1-step residuals for the estimated Δv_t equation, together with similar graphs for the three other marginal models reported below.

$$\begin{aligned}
\Delta v_t = &\underset{(0.07)}{0.27}\Delta\left(v - p + pck\right)_{t-1} - \underset{(0.04)}{0.1}\, EqCMv\left(t\right) - \underset{(0.02)}{0.13}\Delta oil_t \times OILST_t \\
&- \underset{(0.007)}{0.03}\,\Delta oil_{t-2} \times OILST_t - \underset{(0.007)}{0.02}\,\Delta oil_{t-1} \times DOILST_t \\
&-\underset{(0.08)}{0.24}\Delta RS_t + \underset{(0.004)}{0.02}\, Vdum_t
\end{aligned}$$

$$T = 1972\,(1) - 1996\,(4) = 100$$

$$\begin{aligned}
\hat{\sigma} &= 0.96\% \\
AR\ 1-5\ F(5,88) &= 1.24[0.30] \\
Normality\ \chi^2(2) &= 1.35[0.50] \\
Heteroscedasticity\ F(31,61) &= 0.88\,[0.64]
\end{aligned}$$

[Figure 6 about here.]

4.2 GDP output y_t

The model for Δy_t is adapted from the "AD" equation in Bårdsen and Klovland (2000):

$$\Delta y_t = -\underset{(0.08)}{0.71}\Delta y_{t-1} - \underset{(0.09)}{0.51}\Delta y_{t-2} - \underset{(0.05)}{0.32} EqCMy\,(t) + \underset{(0.12)}{0.70}\Delta cr_{t-1} + \underset{(0.01)}{0.06}\,[i85q1 + i86q2]_t$$

$$\begin{aligned} T = 1972\,(1) - 1996\,(4) = 100 \\ \hat{\sigma} &= 1.61\% \\ AR\ 1-5\ F(5,86) &= 1.44[0.22] \\ Normality\ \chi^2(2) &= 3.04[0.22] \\ Heteroscedasticity\ F(31,59) &= 1.09[0.38] \end{aligned}$$

Apart from the autoregressive part, the model is mainly driven by the equilibrium-correction mechanism for the product market, denoted $EqCM_y(t)$:

$$EqCMy\,(t) = y_{t-3} - 0.5co_{t-3} - 0.4yf_{t-3} - 0.1(pi-p)_{t-2} + 0.9RRB_{t-1},$$

where co is real public consumption expenditure, yf is real foreign demand, $(pi-p)$ is accounting for the real exchange rate, and RRB denotes the real bond rate, defined as

$$RRB = RB_t - 4\Delta p_t$$

where RB is the nominal bond rate (5 year maturity). The equilibrium-correction term $EqCMy(t)$, measuring the difference between (log) mainland GDP and aggregate demand, has an estimated adjustment coefficient of -0.32, suggesting a fairly quick reaction to shocks to demand—the median lags to shocks in co and RRB are 5 and 3 quarters, respectively. The variable Δcr_{t-1} captures the impact of financial deregulation (real credit expansion) on output. Δcr_{t-1} is important for explaining output growth in the mid 80s, but in addition an impulse dummy for 1985p1 and 1986p2 are required to capture the two highest growth rates in this period. The estimated equation also includes a constant and three seasonal dummies.

4.3 Unemployment u_t

The change in the rate of unemployment is explained by output growth. Another important factor is labour market policy, represented by the variable $amun_t$ (log of the ratio of labour market programmes to total unemployment) and of a variable STU_{t-1} that captures non-linearities in labour demand (see Moene et al. (1997)). STU acts as a shift in the intercept of the equation, the shift occurring at a 4% rate of unemployment (our measurement of u). The interaction with Δco and Δyf indicates that demand growth factors have relatively bigger effects in periods of high unemployment. There is are two sets of seasonals in this equation that are designed to capture the gradual change in seasonal pattern over the period. The coefficients are omitted, together with the constant.

This equation has direct implications for the properties of the full model, see Section 6 below. In particular, the level unemployment cannot be permanently influenced by fiscal policy (a change in the level of co) or monetary policy (a change in RRB). This follows since u_t is a function of GDP growth, not the level of GDP. Hence, although the wage-price part of the system does not imply a NAIRU, the equilibrium rate of unemployment implied by the full model is independent of the level of aggregate demand. Instead, it is determined by the growth rate of the economy and of the governments willingness to accommodate open unemployment by labour market programmes. There is one important caveat which stems from the non-linear variable STU: If for example a cut in the interest rate causes the rate of unemployment to fall below 4% (the threshold value of STU), equilibrium unemployment reduces. The estimated coefficients of u_{t-1} and STU_{t-1} indicate that equilibrium unemployment is shifted down by 1.5 percentage points. More generally, in a situation where the economy runs a rate of unemployment in the neighbourhood of the threshold value, transitory shocks may be transformed into permanent effects on the rate of unemployment.

$$\Delta u_t = \underset{(0.07)}{0.30}\Delta u_{t-1} - \underset{(0.04)}{0.24}u_{t-1} - \underset{(0.37)}{1.79}\Delta y_t - \underset{(0.22)}{1.13}\Delta y_{t-1} - \underset{(0.04)}{0.14}amun_t + \underset{(0.08)}{0.46}STU_{t-1}$$
$$-\underset{(0.32)}{0.62}\Delta co \times STU_{t-3} - \underset{(3.08)}{7.45}\Delta yf \times STU_{t-3} - \underset{(0.33)}{0.76}\Delta\left(pi - p\right)_{t-1}$$
$$T = 1967\,(1) - 1996\,(4) = 120$$
$$\begin{aligned} \hat{\sigma} &= 0.081 \\ AR\ 1-5\ F(5,99) &= 1.42[0.23] \\ Normality\ \chi^2(2) &= 4.83[0.09] \\ Heteroscedasticity\ F(27,76) &= 1.61[0.06] \end{aligned}$$

4.4 Productivity pr_t

The productivity equation is basically an autoregressive process augmented with a negative effect of Δu_{t-1} and dummies that help whiten the residuals (again the estimated constant and three centered seasonals are omitted).

$$\Delta pr_t = -\underset{(0.06)}{0.37}\Delta_3 pr_{t-1} - \underset{(0.01)}{0.03}\Delta u_{t-1} - \underset{(0.01)}{0.08}i86\,(2)_t + \underset{(0.01)}{0.04}\left[i79q2 - i91q3\right]_t$$
$$T = 1967\,(1) - 1996\,(4) = 120$$
$$\begin{aligned} \hat{\sigma} &= 1.35\% \\ AR\ 1-5\ F(5,107) &= 3.14[0.01] \\ Normality\ \chi^2(2) &= 5.42[0.07] \\ Heteroscedasticity\ F(17,94) &= 1.37[0.17] \end{aligned}$$

4.5 Testing the exogeneity assumptions

Weak and super exogeneity refer to different aspects of "exogeneity", namely the question of "valid conditioning" in the context of estimation and policy analysis respectively—see Engle et al. (1983). In the light of the results reported above, it is important to assess the possible exogeneity of output, productivity, unemployment, and exchange rates. First, the cointegrating vectors have been estimated conditional on output, productivity, unemployment, and exchange rates, and efficient estimation requires that these variables are weakly exogenous for the cointegration vectors (see e.g. Johansen (1992)). Second, policy analysis involves as a necessary condition that the wage and price equations are *invariant* to the interventions occurring in the marginal models of output, productivity, unemployment, and exchange rates; together with weak exogeneity (if that holds) invariance implies super exogeneity.

As a means to perform tests of weak and super exogeneity, we supplement the two equation models for wages and prices for Norway, with the marginal models for output, productivity, unemployment, and exchange rates.

These marginal models (described in the previous section) can be written on the form

$$\begin{aligned} \begin{pmatrix} \Delta y \\ \Delta pr \\ \Delta u \\ \Delta v \end{pmatrix}_t &= \mathbf{A}(L) \begin{pmatrix} \Delta y \\ \Delta pr \\ \Delta u \\ \Delta v \\ \Delta w \\ \Delta p \end{pmatrix}_{t-1} + \mathbf{B} \cdot \mathbf{X}_t + \mathbf{C} \cdot \mathbf{DUM}_t \\ &+ \mathbf{D} \begin{pmatrix} EqCMw\,(t) \\ EqCMp\,(t) \end{pmatrix} + \begin{pmatrix} \varepsilon_y \\ \varepsilon_{pr} \\ \varepsilon_u \\ \varepsilon_v \end{pmatrix}_t . \end{aligned} \tag{19}$$

The autoregressive lag-polynomial matrix $\mathbf{A}(L)$ has all roots outside the unit circle. The matrix $\mathbf{B}$ contains the coefficients of the maintained exogenous variables $\mathbf{X}_t$ in the four marginal models described above. Auxiliary variables affecting the mean of the variables under investigation —significant dummies and non-linear terms — are collected in the $\mathbf{DUM}_t$ matrix, with coefficients $\mathbf{C}$. By definition, the elements in $\mathbf{DUM}_t$ are included because they pick up linear as well as non-linear features of y_t, pr_t, u_t or v_t that are left unexplained by the information set underlying the price wage systems above. In the following, we will refer to the auxiliary variables as *structural break dummies*, notwithstanding the fact that they depend fundamentally on the initial choice of information set used above to model wages and prices.

While the first line of (19) can be seen as necessary step to ensure that the usual assumptions about constant parameters and white-noise residuals are approximately fulfilled for the marginal model, the second line of the equation enables us to test weak exogeneity. Following Johansen (1992) weak exogeneity of y_t, pr_t, u_t and v_t with respect to the cointegration parameters requires that the 4×2 matrix with equilibrium-correction coefficients $\mathbf{D} = \mathbf{0}$, i.e. $EqCMw\,(t)$ and $EqCMp\,(t)$ are the equilibrium-correction terms for wages and prices. Note that, in testing weak exogeneity, we are addressing the validity of an assumption underlying the analysis contained in the sections above. Finally, to test super exogeneity we follow Engle and Hendry (1993) and test the significance of the structural break dummies $\mathbf{DUM}_t$.

Table 3 shows the results of testing weak exogeneity of output growth, productivity, unemployment and exchange rate within the marginal system.

[Table 3 about here.]

First, the eight restriction implied by $\mathbf{D} = \mathbf{0}$ in (19) are each acceptable, hence the weak exogeneity assumptions of output, productivity, unemployment,and exchange rates for the long-run parameters appear to be tenable. Looking at the detailed results, only the error-correction coefficient of the equilibrium-correction coefficient of $EqCMw\,(t)$ in the productivity equation obtained a t-value of that came even close to significance (-1.7), all the other error correction coefficients had t-values equal to one or smaller than one in absolute value.

Turning to the Lucas-critique, we note that the significance in the *exchange rate equation* of the structural break dummies, *i.e.* $Vdum_t$ and the three variables that involve $OILST$ variables, are overall quite high. Hence, the invariance test based on these variables in the wage and price equations should be powerful for detecting the empirical relevance of the Lucas-critique. We test the joint significance of these four variables and the impulse dummies from the other three marginal models ($i79q2$, $i82q4$, $i85q1$, $i86q2$, and $i91q3$) in each of the two equations of the wage-price model and we find the following test statistics: $\chi^2(9) = 6.6529[0.67]$ for wage equation and $\chi^2(9) = 13.331\ [0.15]$ for the price equation. The insignificant test statistics do not lend support to the Lucas-critique: If oil-prices and the regime-shift dummies induce shifts in expectations, and if forward-looking behaviour is an unaccounted feature of wage-price formation, we would expect significant, not insignificant, chi-square statistics.

5 Forecasting inflation

In the next two sections we use the model to forecast inflation and simulate effects of monetary policy. To close the model we include three "reaction functions". The first is a policy reaction function for labour market programmes ($amun$), the second captures that the bond rate RB reacts to changes in the short interest rate RS, with a lag and the third equation shows how real credit expansion (Δcr) depends on output growth and the cost of interest bearing debt. Finally, in order to take account of all implied feed-back links, the model is completed with the necessary set of identities for the equilibrium-correction terms, real wages, the real exchange rate, the real bond rate and so forth. With these new equations in place the system is fundamentally driven by the following exogenous variables:

- real world trade (yf_t) and real public expenditure.
- Nominal trade prices in foreign currency (pf_t), and nominal consumer price growth abroad (Δpck_t).
- The USD oil-price (oil_t).
- The monetary policy instrument, i.e. the short term interest rate (RS_t).

Figure 7 illustrates how the model forecast some important variables over the period from 1995(1) to 1996(4). The model parameters are estimated on a sample that ends in 1994(4). These dynamic forecast are conditional on the actual values of the non-modelled variables (ex post forecasts). The quarterly inflation rate Δp_t only has one significant bias, in 1996(1). In that quarter there was a reduction in the excises on cars that explains around 40 per cent of this particular overprediction.

In the graphs of the annual rate of inflation $\Delta_4 p_t$ this effect is naturally somewhat mitigated. The quarterly change in the wage rate Δw_t is very accurately forecasted, so the only forecast error of any importance for real wages $\Delta(w-p)_t$ also occurs in 1996(1). The forecasts for the rate of unemployment are very accurate for the first 5 quarters, but the reduction in unemployment in the last 3 quarters does not appear to be predictable with the aid of this model.

[Figure 7 about here.]

Figure 7 also contains the 95% prediction intervals in the form of ± 2 standard errors, as a direct measure of the uncertainty of the forecasts. The prediction intervals for the annual rate of inflation are far from negligible and are growing with the length of the forecast horizon. However, forecast uncertainty appears to be much smaller than similar results for the UK: Haldane and Salmon (1995) estimate one standard error in the range of 3 to $4\frac{1}{2}$ percentage points, while Figure 7 implies a standard error of 0.9 percentage points 4-periods ahead, and 1.2 percentage points 8-periods ahead. One possible explanation of this marked differences is that Figure 7 understates the uncertainty, since the forecast is based on the actual short-term interest rate, while Haldane and Salmon (1995) include a policy rule for interest rate.

To make our estimate of inflation uncertainty comparable to Haldane and Salmon (1995), we calculated new forecasts for a model that includes an equation for the short-term interest rate as a function the lagged rates of domestic and foreign annual inflation, of nominal exchange rate depreciation, and of the lagged output gap. The results showed a systematic bias in the inflation forecast, due to a marked bias in the forecasted interest rate, but the effect on forecast uncertainty was very small. Hence it appears that the difference in forecast uncertainty stems from the other equations in the models, not the interest rate policy rule. For example, Haldane and Salmon (1995) use a Phillips-curve equation for wage-growth, and the other equations in their model are also in differences, implying non-cointegration in both labour and product markets. In contrast, Bårdsen et al. (1998) find that a core wage-price model with equilibrium-correction terms give very similar results for Norway and the UK. Hence it is clearly possible that a large fraction of the inflation forecast uncertainty in Haldane and Salmon's study is a result of model misspecification. However, future research should look more closely into the sources of inflation forecast uncertainty.

6 Propagation mechanisms

In this section we discuss the dynamic properties of the model. In the simulations below we have not incorporated the non-linear effect in the unemployment equation. Hence the results should be interpreted as showing the impact of monetary policy when the initial level of unemployment is so far away from the threshold value that the non-linear effect will not be triggered by the change in policy.

6.1 Effects of monetary policy

Figure 8 shows the simulated accumulated responses to a permanent rise in the interest rate RS_t by 1 point, i.e. by 0.01. This experiment is stylized in the sense that it is illuminating the dynamic properties of the model rather than representing a realistic monetary policy scenario. Notwithstanding this, we find that a permanent change in the signal rate by 1 percentage point causes a final reduction in annual inflation (D4p in the graph) by around 0.4 percentage point.

Next, recall that a main property of the competing claims model is that the system determining $(w-p)_t$ and $(pi-p)_t$ is dynamically stable, see Section 2 above. However, that prediction applied to the conditional sub-system, *a priori* we have no way of telling whether the same property holds for the full model, were we have taken take account of the endogeneity of unemployment, productivity, the nominal exchange rate and the output gap (via the model of GDP output). However, the upper middle and rightmost graphs show that the effect of the shock on real wage growth, $\Delta(w-p)_t$, and change in the real exchange rate, $\Delta(pi-p)_t$, disappears completely in the course of the 48 quarters covered by the graph, which constitute direct evidence that stability holds also for the full system. Therefore, in direct correspondence to the analysis of Section 2, the end of period effect on the annual rate of inflation $\Delta_4 p_t$ the D4p graph) is essentially 4 times the rate of nominal appreciation, Δv_t, shown in the lower leftmost graph in the figure.

The permanent rate of appreciation is closely linked to the development of the real-exchange rate $(v-p+pck)_t$: The increase in RS_t initially appreciate the krone, both in nominal and real terms. After a couple of periods, however, the reduction in Δp_t pushes the real exchange rate back up, and it settles above its initial level. Because of the PPP mechanism in the nominal exchange rate equation, the new equilibrium features nominal appreciation of the krone, as Δv_t equilibrium corrects. This highlights the important role of nominal exchange rate determination—a different model, *e.g.* one where Δv_t is not reacting to deviations from interest rate parity, would produce different responses. Finally, the remaining panel depict the response of the unemployment rate u_t.

[Figure 8 about here.]

6.2 Inflation targeting: counteracting shocks

With inflation targeting in place an important policy decision is how much interest rates need to be adjusted up or down in order to cancel the effect of shocks on the rate of inflation. Figure 9 illustrates the effect on inflation and unemployment of a one percent permanent increase to GDP—from a change in foreign demand, say—without any monetary policy (the full lines) and when that shock is countered by a rise in the interest rate (the dotted lines). Without any change in monetary policy, annual inflation is raised one on one by one percentage point. Under a regime of inflation targeting, the signal rate has to be raised by 1.7 points (i.e. RS_t is increased by 0.017) to bring inflation back down. This policy response nearly kills the initial inflationary effect of the impulse to y_t.

The exchange rate channel appears to be the important channel for monetary policy during the first quarters after the shock. Within a 2-year horizon the effect on inflation is kept to a moderate 0.15 percent. Thereafter, the channels that go via the real economy (unemployment in the graphs) take over, and the inflation response is dying away quite rapidly.

[Figure 9 about here.]

7 Conclusions

We have argued that the success of inflation targeting on the basis of conditional forecasts rests on the econometric properties of the model being used. We have also argued that a model for wage and price interaction should be the core model of inflation in discussing inflation targeting. Our sub-model for wage-price formation, based on theories of conflicting claims, is accommodating all important types of shocks to the inflation process (domestic demand and supply shocks, foreign inflation impulses, exchange rate shocks and tax changes). We construct an empirical model that is congruent with *a priori* theory, the measurement system and available sample information in the sense of Hendry (1995), p. 365, see also Mizon (1995), p. 115. Valid conditioning of the core model is established through the estimation and testing of the marginal models for the feedback variables, and moreover, we find support for super exogeneity of these variables with respect to the parameters in the core model.

In the final exercise based on the full model, where we bring together the core model with the marginal models, we show that the model can be used to forecast inflation. As regards the effects of monetary policy on inflation targeting, simulations indicate that inflation can be affected by changing the short-run interest rate. A one percentage point permanent increase in the interest rate leads to 0.4 percentage point reduction in the annual rate of inflation. Bearing in mind that the main channel is through output growth and the level of unemployment, interest rates can be used to counteract shocks to GDP output. Inflation impulses elsewhere in the system, for example in wage setting (e.g. permanently increased wage claims), can prove to be difficult to curb by tolerable increases in the interest rate.

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A Overidentifying restrictions

The model as set out in (10) provides us with several overidentifying restrictions to test. First, in the wage equation the model predicts the following non-linear dynamic restriction between import prices and indirect prices:

$$-\zeta \frac{\alpha_{12,0}}{1-\zeta} \Delta pi_t = -\eta \frac{\alpha_{12,0}}{1-\zeta} \Delta \tau 3_t$$

while in the price equation the model predicts:

$$\zeta \Delta pi_t = \eta \Delta \tau 3_t.$$

Both hypotheses originate from the definition of the consumer price index in (2). However, if we allow for a two period lag in the effects of indirect taxes, the substituted out dynamic effects of producer prices on wages become:

$$-\zeta \frac{\alpha_{12,0}}{1-\zeta} \Delta pi_t = -\eta \frac{\alpha_{12,0}}{1-\zeta} \Delta \tau 3_{t-2}$$

so

$$\begin{aligned} \Delta w_t &= -\eta \frac{\alpha_{12,0}}{1-\zeta} \left(\frac{\zeta}{\eta} \Delta pi_t + \Delta \tau 3_{t-2} \right) + \cdots \\ &= -0.36 \left(0.4 \Delta pi_t + \Delta \tau 3_{t-2} \right) + \cdots \end{aligned}$$

Here we impose the steady-state estimates $\zeta = 0.4$ and $\eta = 1$ from Table 1; we impose an immediate effect of producer prices on wages; and we find $\widehat{\frac{\alpha_{12,0}}{1-\zeta}} = 0.36$ from $0.36 L^2 \Delta \tau 3_t$. This hypothesis cannot be rejected with the available data.

Following the same kind of argument, the dynamic effects of producer prices on consumer prices are:

$$\begin{aligned} \Delta p_t &= \eta \left(\frac{\zeta}{\eta} \Delta pi_t + \Delta \tau 3_{t-2} \right) + \cdots \\ \Delta p_t &= 0.4 \Delta pi_t + \Delta \tau 3_{t-2} + \cdots , \end{aligned}$$

This hypothesis, however, is rejected by the data. However, allowing for a weighted down dynamic effect, say by $\alpha_{22,0} < 1$, of producer prices on consumer prices suggests the following restriction in the inflation equation:

$$\begin{aligned}
\Delta p_t &= \alpha_{22,0}\zeta\Delta pi_t + \alpha_{22,0}\eta\Delta\tau 3_{t-2} + \cdots \\
\Delta p_t &= 0.07\,(0.4\Delta pi_t + \Delta\tau 3_{t-2}) + \cdots ,
\end{aligned}$$

which is accepted by the data.

B Data definitions

B.1 Notes

1. Unless another source is given, all data are taken from RIMINI, the quarterly macroeconometric model used in Norges Bank (The Central Bank of Norway).

2. For each RIMINI-variable, the corresponding name in the RIMINI-database is given by an entry [RIMINI: variable name] at the end of the description. (The RIMINI identifier is from Rikmodnotat 140, Norges Bank, Research department, 19th April 1999)

3. Several of the variables refer to the *mainland economy*, defined as total economy minus oil and gass production and international shipping.

4. In the main text, impulse dummies are denoted *i**yy**q***x**, where **yy** gives the year with two digits and **x** contains the quarter (1,2,3). Hence *i80q2* is 1 in the second quarter of 1980, and is 0 in all other quarters.

B.2 Definitions

AMUN Labour market programmes participation rate. Number of persons in active labour market programmes relative to total unemployment (registered plus labour market programmes participation). [RIMINI: AMUN]

CO Public consumption expenditure, fixed 1991 prices. Mill. NOK. [RIMINI: CO].

CR Real credit volume fixed 1991 prices. Mill. NOK. Source: Bårdsen and Klovland (2000).

gap Output gap defined as log mainland GDP(log of the variable Y as defined below) deviations from trend, where the trend is estimated by the HP-filter using $\lambda = 1600$. Fixed baseyear (1991) prices. Mill. NOK.

H Normal working hours per week. [RIMINI: NH]

OIL Per barrel Brent-Blend oil-price. USD. Source: Norges Bank's database of economic time series.

$OILST$ Smooth transition function of North-Sea oil price:

$$OILST = 1/(1 + exp(4 * (OIL - 14.47)))$$

P Consumer price index. 1991=1. [RIMINI: CPI].

PCK Consumer prices abroad in foreign currency. 1991=1. [RIMINI: PCKONK].

PI Deflator of total imports. 1991=1. [RIMINI: PB].

Y Total value added at market prices in the mainland economy. Fixed baseyear (1991) prices. Mill. NOK. [RIMINI: YF].

PR Mainland economy value added per man hour at factor costs, fixed baseyear (1991) prices. Mill. NOK. [RIMINI: ZYF].

RS 3 month Euro-krone interest rate. [RIMINI: RS].

$RSECU$ ECU interest rate.For the epriod 1967(1)-1986(3): Effective interest rate on foreign bonds, NOK-basket weighted. [RIMINI: R.BKUR] For the period

1986(4)-1996(4): ECU weighted effective rate on foreign bonds. [RIMINI: R.BECU].

STU Smooth transition function of the rate of unemployment, U as defined below,

$$STU = 1/(1 + exp((-125) * (U - 0.04)));$$

$\tau 1$ Employers tax rate. $\tau 1 = WCF/WF - 1$.

$\tau 3$ Indirect tax rate. [RIMINI: T3].

U Rate of unemployment. Registered unemployed plus persons on active labour market programmes as a percentage of the labour force, calculated as employed wage earners plus unemployment. [RIMINI: UTOT].

V Effective import weighted value of the NOK. 1991=1. [RIMINI: PBVAL].

W Nominal mainland hourly wages. Constructed from Rimini-database series as:

$$W = WIBA * TWIBA + WOTVJ * (TWTV + TWO + TWJ))/TWF$$

WC Nominal mainland hourly wage costs. [RIMINI: WCF].

YF Weighted average of GDP of trading countries, using share of Norwegian exports in 1985 as weights. 1991=1. [RIMINI: UEI].

$Wdum$ Composite dummy for wage freeze: 1 in 1979.1, 1979.2,1988.2 and 1988.3.

$Pdum$ Composite dummy for introduction and lift of direct price regulations. 1 in 1971.1, 1971.2,1976.4,1979.1. -1 in 1975.1,1980.1,1981.1,1982.1. Zero otherwise.

$Vdum$ Composite dummy for devaluation events. It is used in the marginal model for the exchange rate and it is defined by:

$$Vdum_t = i78q2 + 2 \times i82q3 + i86q4 + i87q4$$

Table 1: Testing claim hypotheses.

Panel 1: The theoretically identified claims equations with nonlinear cross equation restrictions

$$w = p + \delta_{13} pr - \delta_{15} u - \delta_{16} \tau 1 + d_{12} \zeta \left(p - pi - \frac{\eta}{\zeta} \tau 3 \right)$$

$$p = (1 - \zeta)(w + \tau 1 - pr) + \zeta pi + \eta \tau 3$$

Panel 2: Nonlinear cross equation restrictions

$$w = p + \underset{(0.16)}{0.85} pr - \underset{(0.04)}{0.08} u + \underset{(0.83)}{1.60} \tau 1 - \underset{(0.11)}{0.03} (p - pi + 2.66 \tau 3)$$

$$p = 0.64 (w + \tau 1 - pr) + \underset{(0.06)}{0.36} pi + \underset{(0.29)}{0.95} \tau 3$$

$$\chi^2(4) = 7.49[0.11]$$

Panel 3: No effect from producer prices and full effect of indirect taxation

$$w = p + \underset{(0.16)}{0.84} pr - \underset{(0.04)}{0.08} u + \underset{(0.85)}{1.51} \tau 1$$

$$p = 0.63 (w + \tau 1 - pr) + \underset{(0.02)}{0.37} pi + \tau 3$$

$$\chi^2(6) = 7.59[0.27], \; \chi^2(2) = 0.1[0.95]$$

Panel 4: Full effect of productivity and no effect of payroll-tax

$$w = p + pr - \underset{(0.02)}{0.09} u$$

$$p = 0.62 (w + \tau 1 - pr) + \underset{(0.02)}{0.38} pi + \tau 3$$

$$\chi^2(8) = 10.48[0.23], \; \chi^2(2) = 2.89[0.24]$$

Diagnostic tests for the unrestricted conditional subsystem

$AR\ 1-5\ F(20,150)$	=	1.25[0.22]
Normality $\chi^2(4)$	=	1.05[0.90]
Heteroscedasticity $F(66,183)$	=	0.49[0.99]

The sample is 1966(4) to 1996(4), 121 observations.

Table 2: Diagnostics for the system and the model.

Diagnostic tests for the conditional subsystem		
$\hat{\sigma}_{\Delta w}$	=	1.02%
$\hat{\sigma}_{\Delta p}$	=	0.42%
AR $1-5$ $F(20,190)$	=	1.43[0.11]
Normality $\chi^2(4)$	=	5.10[0.28]
Heteroscedasticity $F(66,242)$	=	0.76[0.90]
Diagnostic tests for the model in (18)		
$\hat{\sigma}_{\Delta w}$	=	1.01%
$\hat{\sigma}_{\Delta p}$	=	0.41%
Correlation of residuals	=	-0.5
Overidentification $\chi^2(9)$	=	9.92[0.60]
AR $1-5$ $F(20,200)$	=	1.20[0.26]
Normality $\chi^2(4)$	=	4.14[0.39]
Heteroscedasticity $F(66,257)$	=	0.81[0.84]

Table 3: Testing weak exogeneity

	$EqCMw\,(t)$	$EqCMp\,(t)$	$EqCMw\,(t)$ & $EqCMp\,(t)$
Δy_t	$F(1,88)=0.016$ [0.90]	$F(1,88)=0.002$ [0.96]	$F(2,88)=0.01$ [0.99]
Δpr_t	$F(1,108)=2.88$ [0.09]	$F(1,108)=0.07$ [0.80]	$F(2,108)=1.59$ [0.21]
Δu_t	$F(1,102)=0.74$ [0.39]	$F(1,102)=1.03$ [0.31]	$F(2,102)=0.63$ [0.53]
Δv_t	$F(1,91)=0.05$ [0.82]	$F(1,91)=0.08$ [0.77]	$F(2,91)=0.16$ [0.85]

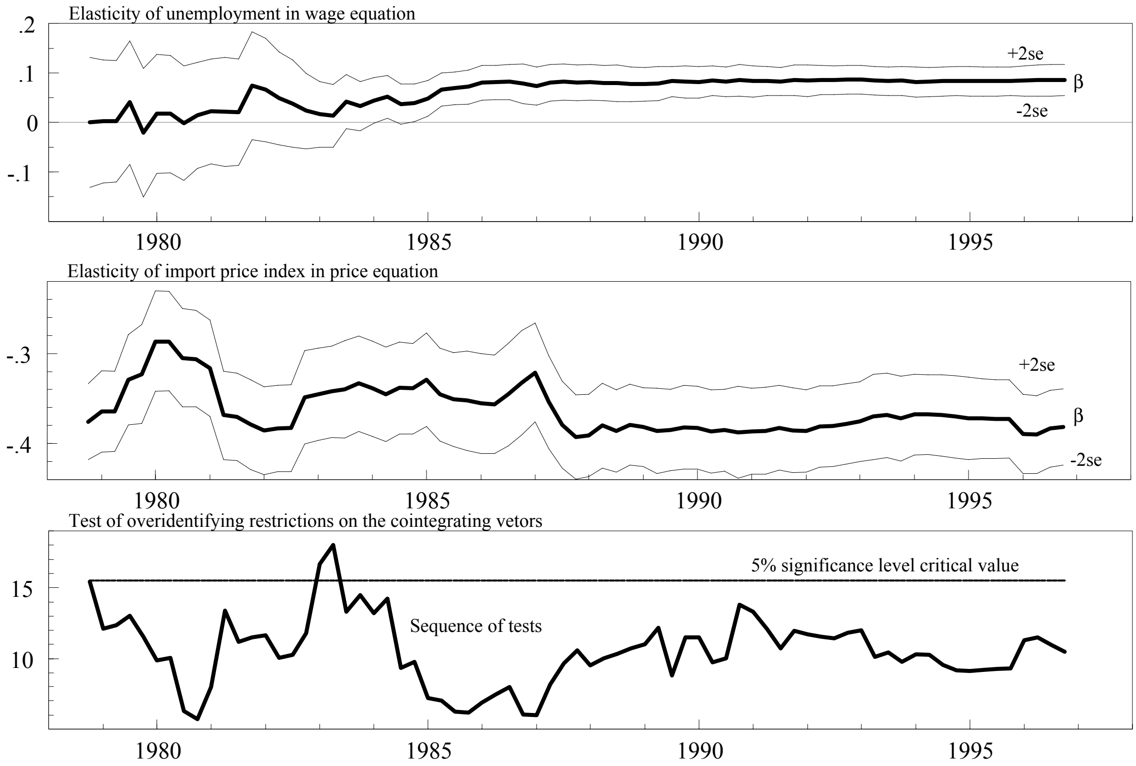

Figure 1: Identified cointegration vectors. Recursively estimated parameters and the $\chi^2(8)$ test of parameter constancy of Table 1, Panel 4.

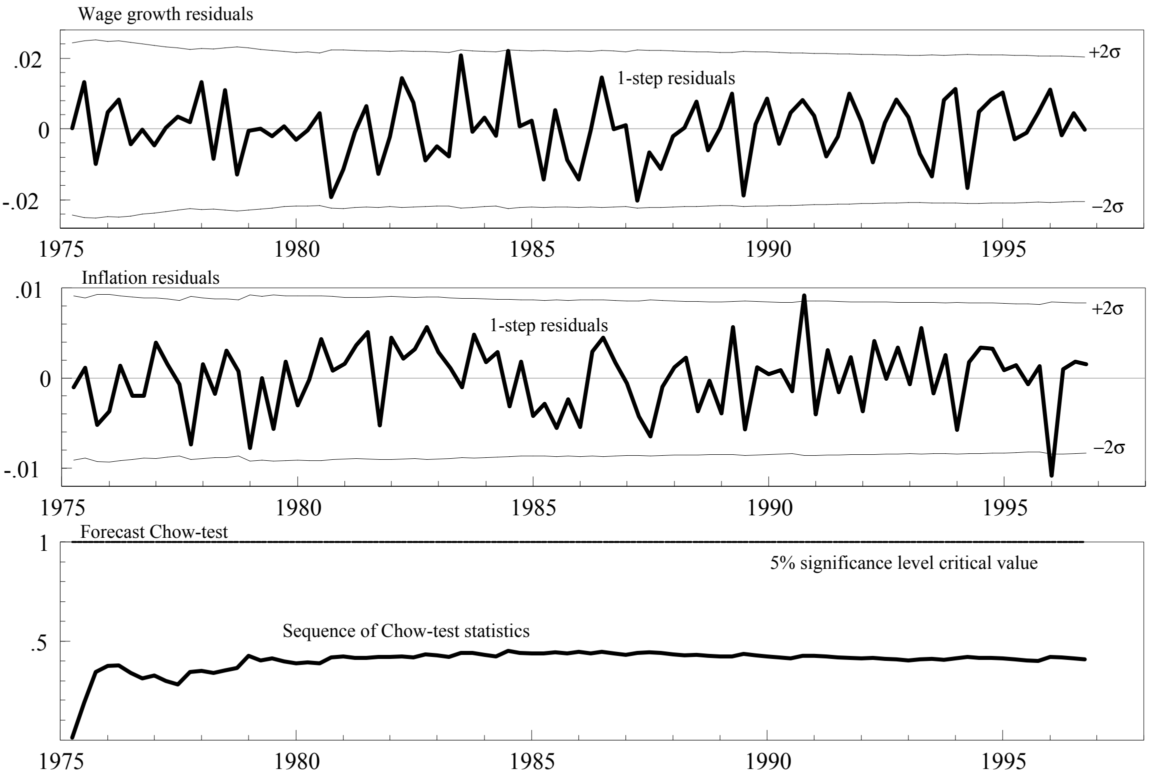

Figure 2: Recursive residuals for the conditional $I(0)$ sub-system, together with recursive Chow-tests.

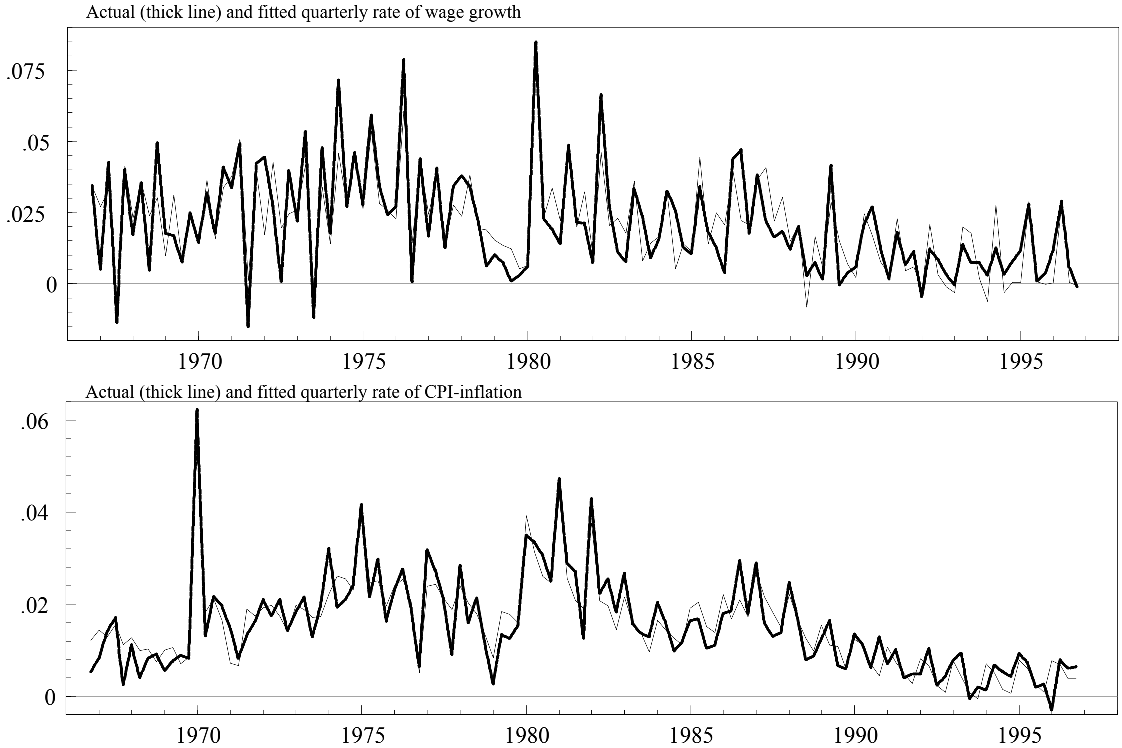

Figure 3: Actual and fitted values of quarterly wage and price inflation.

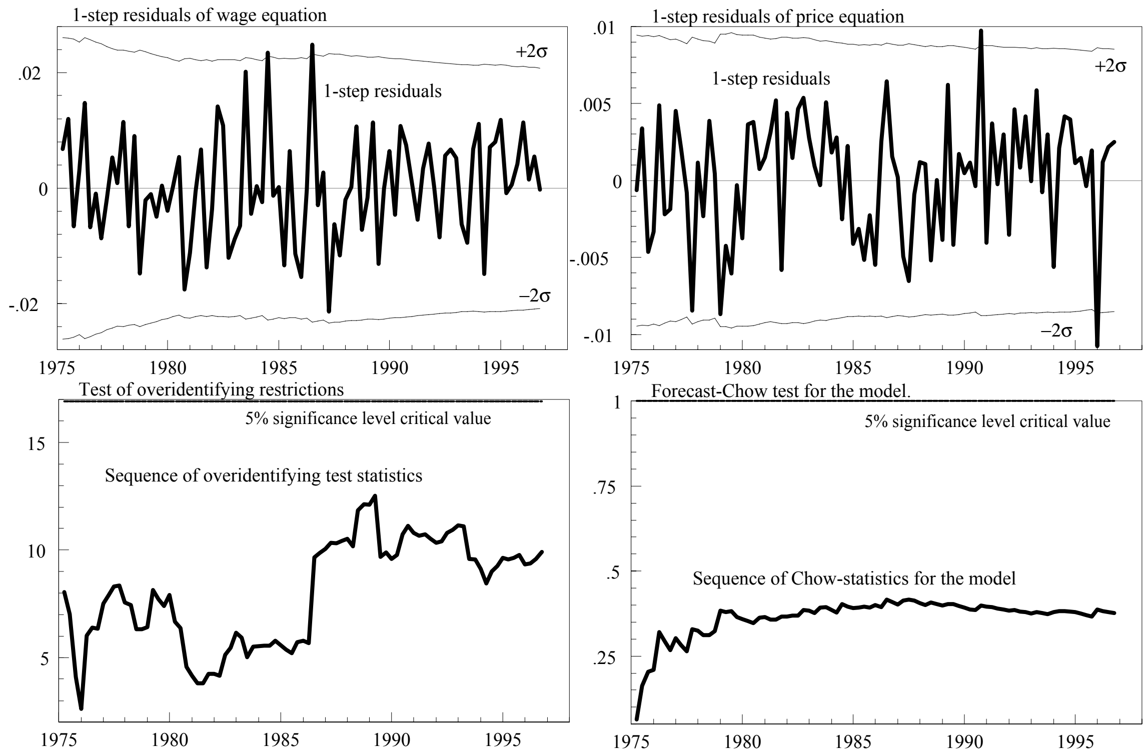

Figure 4: Recursive stability tests for the model. The upper panels show recursive residuals for the model.The lower panels show recursive encompassing tests (left) and recursive Chow-tests (right).

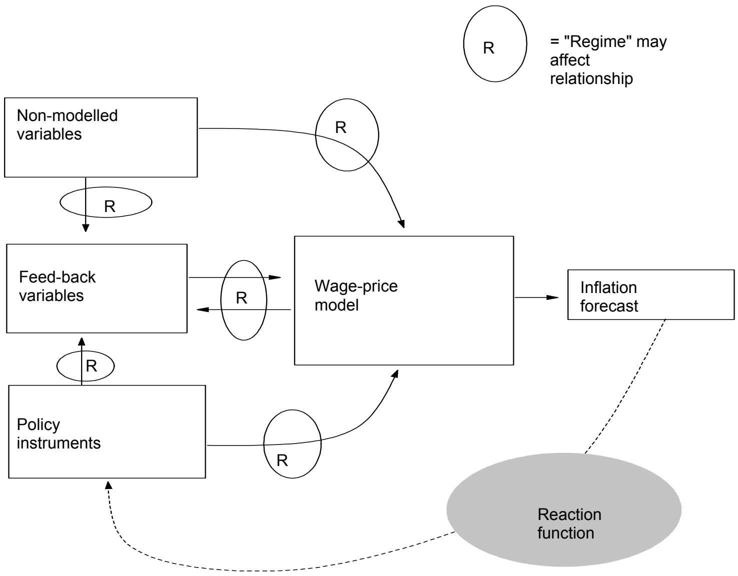

Figure 5: Model based inflation forecasts.

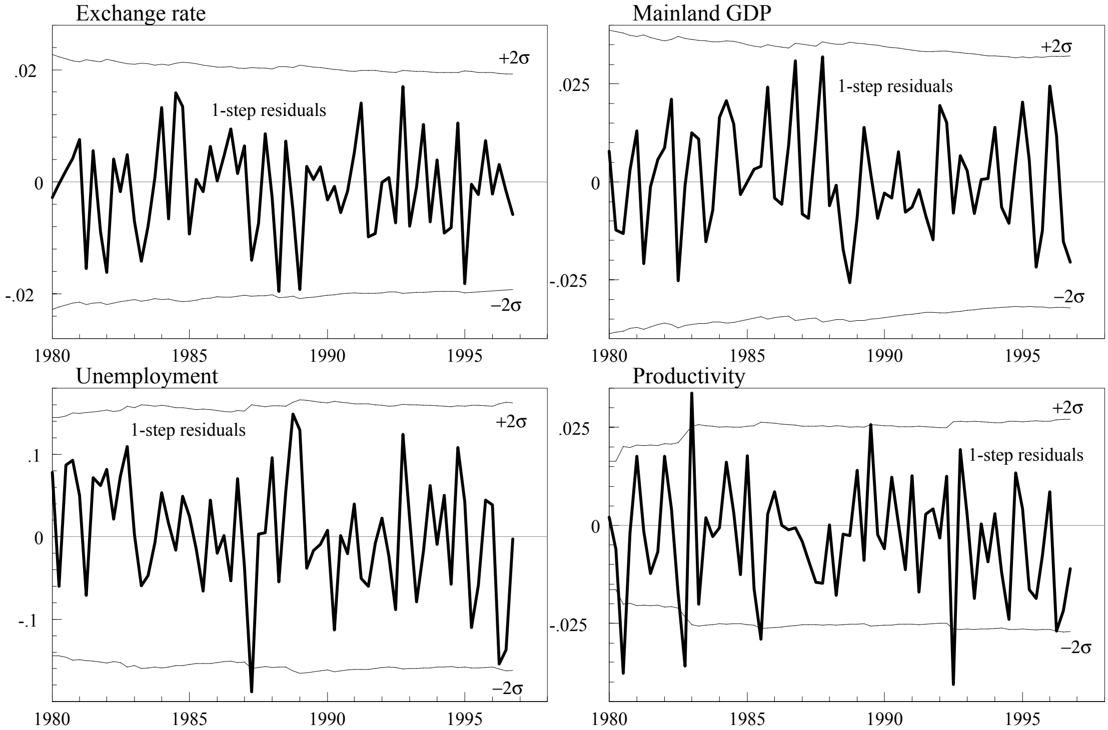

Figure 6: Marginal equations: 1 step residuals and ± 2 recursively estimated residual standard errors (σ)

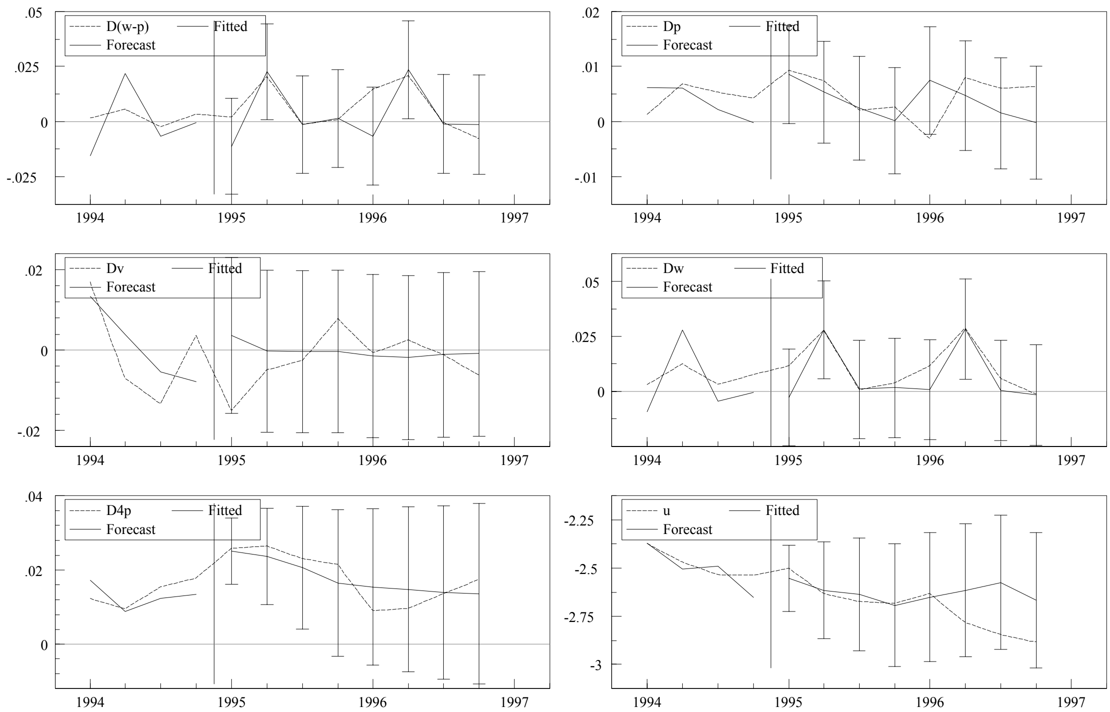

Figure 7: 8-step dynamic forecasts for the period 1995(1)–1996(4), with 95% prediction bands.

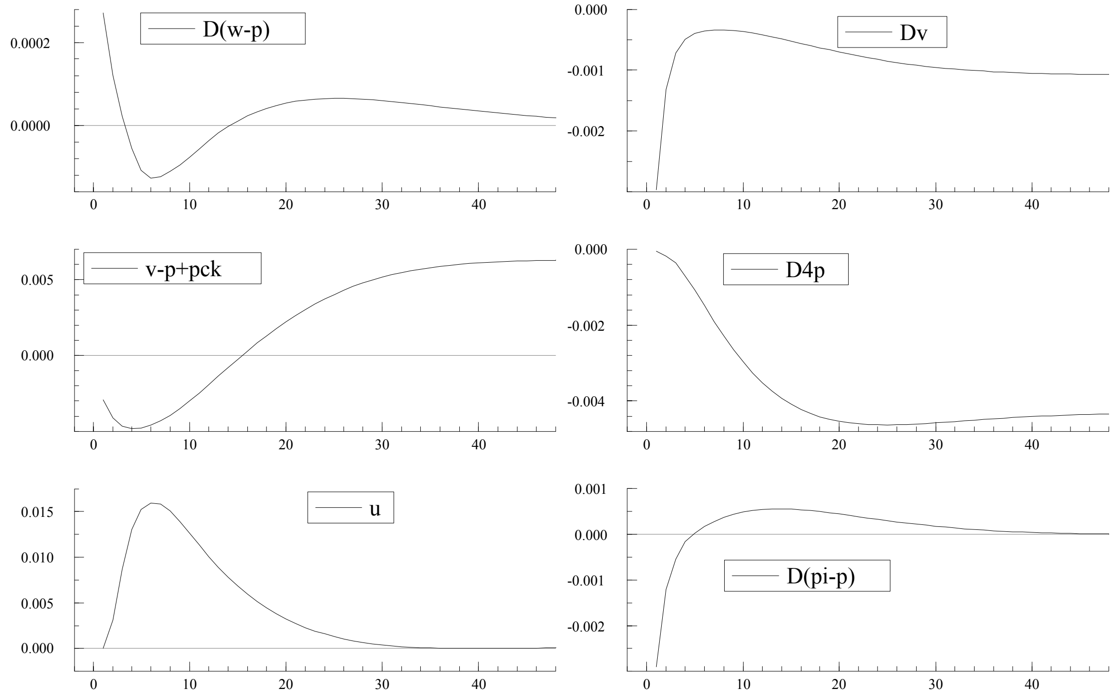

Figure 8: Accumulated responses of some important variables to a 0.01 permanent increase in the interest rate RS.

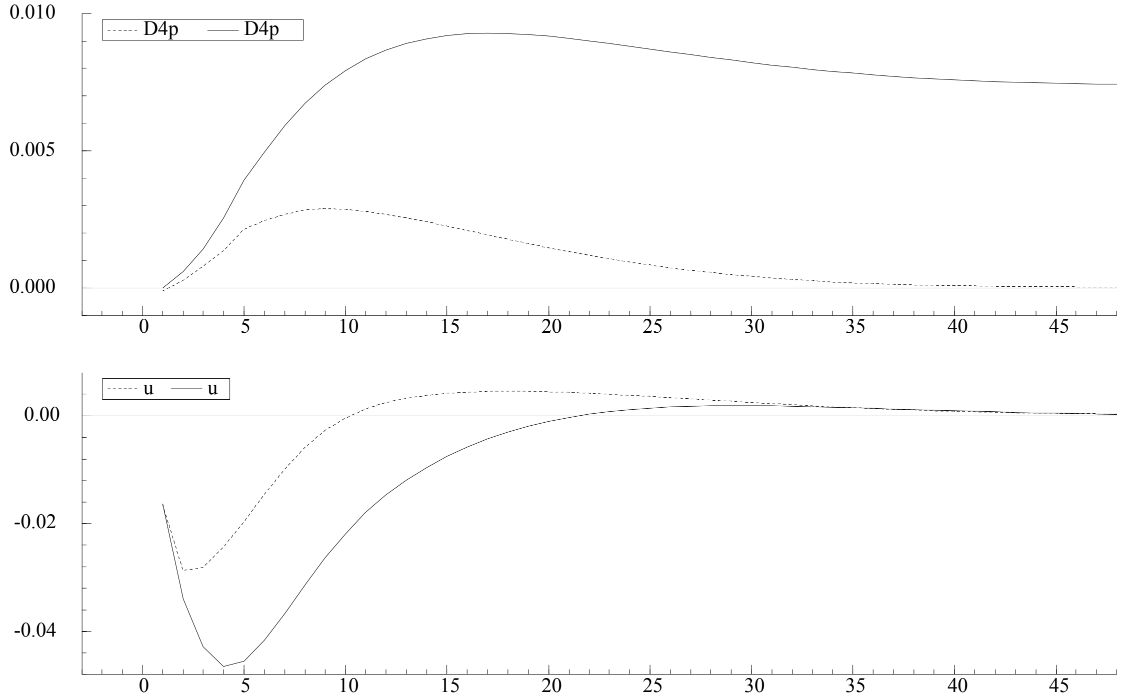

Figure 9: The lines show the effects of a 0.01 permanent autonomous shock to y_t on annual inflation and the log of unemployment. The dotted curves display the effects when the shock to y_t is met by a 0.017 rise in the interest rate RS_t.