Finnish Inflation: a New Keynesian Perspective

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Abstract

This paper models quarterly Finnish inflation from the perspective of the New Keynesian Model (NKM) within the cointegrated VAR framework. The restrictions implied by the core equations of the NKM, and a small open economy variant thereof, are formally tested by the Johansen and Swensen (1999, 2004) method. The restrictions are rejected. Necessary conditions on cointegration, implied by the core equations, are also tested. I find that standard measures of marginal costs cannot, by themselves, explain the long-run trends in inflation. In addition, there is evidence of an IS relationship in the data, but it is not possible distinguish whether it describes forward- or backward-looking behavior.

JEL Classification: C32, C52, E31, E52.

Keywords: New Keynesian Phillips curve, cointegration, vector autoregressive model.

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1 Introduction

This paper investigates Finnish inflation from the perspective of the new Keynesian model (NKM). Finnish inflation is modelled by fitting cointegrated VAR (Vector Auto-Regressive) models to sets of quarterly data that capture the information within closed and open economy variants of the NKM. The restrictions that are implied by the core equations of the different versions of the NKM are formally tested on the statistical models by the Johansen and Swensen (1999, 2004) method. In addition, less strict tests are conducted by investigating necessary conditions on cointegration that are implied by the core equations.

The new Keynesian model is a popular choice for analyzing inflation and monetary policy and has generated a lot of empirical attention lately\(^1\). The baseline model consists of two core equations, the optimizing IS curve, relating output to real interest rates, and the new Keynesian Phillips curve (NKPC), relating inflation to marginal costs. The majority of the empirical literature has focused on the NKPC, for instance Gali and Gertler (1999) and Sbordone (2002). There are also some studies on the optimizing IS curve, for instance Fuhrer (2000) and Kara and Nelson (2004), among others. The evidence from these contributions has generally favored the NKM, or one of its core equations. However, a number of empirical difficulties have been encountered in this literature, for example problems with identification in single equation estimates, problems of weak instruments when GMM is used, non-stationary data, and measurement problems\(^2\). In response to such difficulties, more recent contributions include system approaches, such as Linde (2005), or supply side refinements, as in Matheron and Maury (2004). Moreover, due to the common finding of unit-roots in the typical NKM data, there is a need for approaches that handle non-stationary data. Such approaches can be found in Fanelli (2005), Barkbu and Batini (2005), and Juselius (2006). Juselius (2006) applied the Johansen and Swensen method to testing the baseline NKM on U.S. and aggregate Euro area data. He also discussed necessary conditions on cointegration implied by the equations of the model.

This paper extends the analysis of Juselius (2006) in at least two ways. First, both the baseline version of the NKM and an open economy variant

\(^1\)A recent overview of this literature can be found in Henry and Pagan (2004).

\(^2\)The problems of identification and weak instruments are discussed in Ma (2002) and Mavroeidis (2004). The non-stationarity issues are are discussed in Bardsen et al. (2004), while measurement problems are discussed by Rudd and Whelan (2005).
thereof, developed by Monacelli (2005), are tested on Finnish quarterly time series data. The estimation sample is 1982:1-2005:3. Open economy versions of the new Keynesian model have previously been estimated by, among others, Batini et al. (2005) on UK data, Giordani (2004) on Canadian and U.S. data, and Rumler (2005) on data from nine European countries. The findings in these studies generally indicate that open economy extensions of the NKM strengthen the evidence in favor of the model. However, all of these studies assume that data is stationary. Consequently, one objective of this paper is to combine an open economy NKM with the sophisticated method of Johansen and Swensen. Applied to Finnish data, the restrictions implied by both the baseline and the open economy versions of the NKM are rejected. A related contemporaneous study is provided by Boug et al. (2006), who apply the Johansen and Swensen method to an open economy variant of the NKPC on Norwegian data. They reject the restrictions of the open economy NKPC.

Second, the necessary conditions on cointegration, discussed by Juselius (2006), are made more elaborate by also considering restrictions on the loadings matrix. By this approach it’s possible to get insights into the reasons for the failure of the NKM. Moreover, potential remedies can also be discovered by identifying cointegration between the variables of the statistical model. I find that the information contained within the NKM is not sufficient to fully account for the long-run stochastic trends in inflation. Accounting for these trends may correct the “wrong” sign on the output gap in the NKPC commonly found in the literature. There is also evidence of a long-run IS curve in the cointegration space. However, it is not possible to determine if it describes forward- or backward-looking behaviour, due to the formal rejection of the overall restrictions. I also find that money does not matter in the open economy NKM, in line with the predictions of the model.

The next section introduces both closed and open economy variants of the new Keynesian model, while section 3 presents the Johansen and Swensen method. Data and information sets are discussed in section 4. The different versions of the NKM are tested in section 5. The necessary conditions are tested section 6, where also cointegration between the variables is explored. Section 7 concludes.
2 The New Keynesian model

This section introduces the baseline New Keynesian model and an open economy variant developed by Monacelli (2005). The NKM belongs to a class of “miniature” dynamic stochastic general equilibrium (DSGE) models that are based on optimizing households and firms, rational expectations (RE), and nominal price rigidities. Following the standard approach by assuming Calvo pricing, the baseline model can be represented in terms of two core equations

\begin{align}
y_t &= \varphi_{11}E_t y_{t+1} - \varphi_{12}(i_t - E_t \Delta p_{t+1}) + \varphi_{13}y_{t-1} \\
\Delta p_t &= \varphi_{21}E_t \Delta p_{t+1} + \varphi_{22}x_t + \varphi_{23}\Delta p_{t-1}
\end{align}

where $y_t$ is real output, $i_t$ is a short-term nominal interest rate, $p_t$ is a price index, $x_t$ is real marginal costs, $E_t$ is the expectations operator conditional on the agents information set at time $t$, and $0 \leq \varphi_{ij} \leq 1$ for all $i$ and $j$ in equations (1)-(5). The first equation is the optimizing “IS curve”, while the second equation is the new Keynesian Phillips curve. In addition to these equations, a policy rule for the nominal interest rate is usually obtained by specifying a policy objective and solving under discretion or commitment. The coefficients, $\varphi_{ij}$, are functions of the structural parameters from the underlying theory. Equations (1) and (2) include lagged terms and are hybrid versions of the purely theoretical NKM, defined by the restrictions $\varphi_{13} = \varphi_{23} = 0$ and $\varphi_{11} = 1$.

Real marginal costs, $x_t$, in (2) are not directly observable. However, $x_t$ is proportional to the flexible price output gap, $\tilde{y}_t = y_t - y^f_t$, under certain conditions, where $y^f_t$ is the flexible price equilibrium output. Under another set of conditions, marginal costs are proportional to labor’s share, $w_t n_t / y_t p_t$, where $w_t$ is wages and $n_t$ is the number of employed. Both of these measures have been extensively used in the literature, and are discussed in section 4.

The baseline model has been extended in several ways, for instance by incorporating labor market imperfections (Erceg et al., 2000) or by accounting for investments in capacity (Razin, 2005). Open economy issues have been investigated by several authors, for example Clarida et al. (2002), Gali and Monacelli (2002), McCallum and Nelson (2000), Obstfeld and Rogoff (2000), and Svensson (2000). I ignore labor market imperfections and investments

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3Detailed derivations can be found in Walsh (2003) and McCallum and Nelson (1999), among others.

4See Gali and Gertler (1999) and Fuhrer (2000) for derivations of the hybrid forms.
in the present paper, but allow for an open economy specification developed by Monacelli (2005).

Clarida et al. (2001) show that open economy NKMs are isomorphic to the closed economy model, given a set of simplifying assumptions. However, these models invariably assume complete exchange rate pass-through, i.e. that $\text{PPP}$ holds exactly. This is in stark contrast to the empirical evidence on the $\text{PPP}$ (see Rogoff (1996)). A more realistic approach is provided by Monacelli (2005) who assumes imperfect exchange rate pass-through, while still retaining the assumption that the uncovered interest parity holds

$$i_t - i^*_t = E_t \Delta e_{t+1}$$

where $i^*_t$ is the foreign nominal interest rate and $e_t$ is the nominal exchange rate. In this case the two core equations have the (hybrid) representations

$$\tilde{y}_t = \phi_{31} E_t \tilde{y}_{t+1} - \phi_{32}(i_t - E_t \Delta p_{H,t+1} - r_t) + \phi_{33} E_t \Delta \psi_{F,t+1} + \phi_{34} \tilde{y}_{t-1}$$

$$\Delta p_t = \varphi_{41} E_t \Delta p_{t+1} + \varphi_{42} \tilde{y}_t + \varphi_{43} \psi_{F,t} + \varphi_{44} \Delta p_{t-1}$$

(3) (4)

where $p_{H,t}$ is the price of domestic goods, $r_t$ is the natural real interest rate. The variable $\psi_{F,t}$ captures deviations from the law of one price, and is defined as $\psi_{F,t} = e_t + p^*_t - p_{F,t}$, where $p^*_t$ is the foreign price level and $p_{F,t}$ is the domestic currency price of imports. For latter use we define the real exchange rate $q_t = p_t - e_t - p^*_t$, and note that $\psi_{F,t} = -q_t + p_t - p_{F,t}$.

The equations derived by Monacelli (2005) are of the purely theoretical form, with $\phi_{34} = \varphi_{44} = 0$ and $\phi_{31} = 1$. Here, I have extended Monacelli’s equations in an ad hoc fashion to the corresponding hybrid versions (3) and (4). It seems plausible that this can be done as in the previous literature by for instance assuming habit persistence and rule of thumb pricing.

The natural real rate of interest in (3) is clearly not observable. For empirical purposes it can be treated as a constant in (3) or, alternatively, approximated by some other variable. One possibility would be the long-term real interest rate, i.e. $r_t = i^l_t - E_t \Delta p_{H,t+1}$, where $i^l_t$ is the long-term nominal interest rate. Substituting this expression into (3) yields

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5Foreign goods enter Monacelli’s model only through the utility functions of the consumers, i.e. they are not used as intermediary goods by domestic producers. Since the variable $\psi_{F,t}$ captures the deviation between the world price and the domestic price of imports, it captures all deviations from the law of one price.

6Yet another possibility would be to estimate it, as is done by Garnier and Wilhelmsen (2005). This option is not explored is this paper.
\[
\tilde{y}_t = \phi_{51} E_t \tilde{y}_{t+1} - \phi_{52} (i_t - i'_t) + \phi_{53} E_t \Delta \psi_{F,t+1} + \phi_{54} \tilde{y}_{t-1}
\]  
(5)

which combined with equation (4) provides another representation of Monacelli’s model. Equations (5) and (4) reduce to the purely theoretical forms by the restrictions \( \phi_{51} = 1 \) and \( \phi_{54} = \phi_{44} = 0 \). The restrictions implied by equations (1)-(5) are formally tested on Finnish data in section 5.

3 Testing exact rational expectations within a cointegrated VAR model

This section describes the main results from Johansen and Swensen (2004) on testing rational expectations in a cointegrated VAR model with a linear trend restricted in the cointegration space. The \( p \)-dimensional VAR model in error correction form is given by

\[
\Delta X_t = \Pi X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \mu_0 + \mu_1 t + \Phi D_t + \varepsilon_t
\]  
(6)

where the vector process \( X_t \) is assumed to be at most \( I(1) \), \( \varepsilon_t \sim N_p(0, \Sigma) \), and \( D_t \) is a \( p \times m \) matrix that collects the other deterministic components. The matrix \( \Pi \) is assumed to be of reduced rank, \( r \), where \( 0 < r < p \), and can be decomposed as

\[
\Pi = \alpha \beta'
\]

where \( \alpha \) and \( \beta \) are two \( p \times r \) matrices of full column rank. Let the subscript \( \perp \) denote the orthogonal complement of a matrix. The deterministic trend is assumed to be restricted to the cointegration space, i.e. \( \alpha'_1 \mu_1 = 0 \). Hence, \( \mu_1 = \alpha \kappa_1 \), where \( \kappa_1 \) is an \( r \)-dimensional vector. These assumptions imply that (6) can be written as

\[
\Delta X_t = \alpha \beta^* X^*_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \mu_0 + \Phi D_t + \varepsilon_t
\]  
(7)

where \( \beta^* = (\beta', \kappa_1)' \) is a \((p + 1) \times r \) matrix and \( X^*_{t-1} = (X'_{t-1}, t)' \).

\(^7\)See Johansen (1995) for a full treatment of this model.
Johansen and Swensen consider expectations of the form

\[ E[c'_1X_{t+1} \mid \Theta_t] + c'_0X_t + c'_{-1}X_{t-1} + \ldots + c'_{-k+1}X_{t-k+1} + c_c + c_r(t+1) + c_\phi D_{t+1} = 0 \]  

(8)

where the \( p \times q \) \((0 < q < r)\) matrices \( c_i \) \((i = -k+1, \ldots, 1)\), \( c_r \), and \( c_\phi \) are known. The \( q \)-dimensional vector \( c_c \) can contain unknown parameters. The expectational equation (8) can be re-parameterized so that it corresponds to (7) by

\[ E[c'_1\Delta X_{t+1} \mid \Theta_t] - d'_1X_t + d'_{-1}\Delta X_{t-1} + \ldots + d'_{-k+1}\Delta X_{t-k+2} + c_c + c_r(t+1) + c_\phi D_{t+1} = 0 \]  

(9)

where \( d_{-i+1} = -\sum_{j=i-1}^{k-1} c_{-j} \) \((i = 0, \ldots, k)\). Let \( d_1^* = (d'_1, -c_r)' \). Then the restrictions on the statistical model (7) implied by (9) are

\[ \beta^* \alpha' c_1 = d_1^* \]

\[ \Gamma' c_1 = -d_{-i} \]

\[ \mu' c_1 = -c'_c \]

\[ \Phi' c_1 = -c'_\phi. \]

(10)

The maximum likelihood under the restrictions is

\[ L_{H_{\max}}^{-2/T} = |\tilde{\Sigma}_{22}^*| |S_{11}^*| \prod_{i=1}^{r-q}(1 - \tilde{\lambda}_i^*) / |c'_1 c_{1\perp}| |c'_1 c_{1\perp}| \]  

(11)

where \( \tilde{\Sigma}_{22}^* \) is the likelihood from the marginal model, \( c'_1 \Delta X_t \), the remaining terms are the likelihood from the conditional model, \( c'_{1\perp} \Delta X_t \). The product in (11) is 1 when \( q = r \). The maximum likelihood from the unconstrained model (7) is

\[ L_{\max}^{-2/T} = |S_{00}^*| \prod_{i=1}^{r}(1 - \hat{\lambda}_i^*), \]

(see Johansen, 1995). The likelihood ratio (LR) test statistic of the restrictions is

\[ -2\ln Q = T \left( \ln |\tilde{\Sigma}_{22}^*| + \ln |S_{11}^*| + \sum_{i=1}^{r-q} \ln(1 - \tilde{\lambda}_i^*) \right) - T \left( \ln |S_{00}^*| + \sum_{i=1}^{r} \ln(1 - \hat{\lambda}_i^*) + \ln(|c'_1 c_{1\perp}| |c'_{1\perp} c_{1\perp}|) \right). \]
The test statistic is asymptotically $\chi^2$-distributed with $kpq + q(m + 1)$ degrees of freedom. The procedure assumes that the $c_i$ matrices are known. However, estimates of unknown parameters in the $c_i$ matrices can be obtained by numerical optimization techniques in most cases. In this case, the degrees of freedom are $kpq + q(m + 1) - w$, where $w$ is the number of additional unknown parameters.

4 Information sets and data

The minimal, theory consistent, information set that can be used to test the baseline NKM is clearly, $I_0 = \{\Delta p, i, y, x\}$. This information set can be extended to include a monetary aggregate, as explained by Juselius (2006), although it should be redundant according to theory. However, the prediction that money is redundant is clearly interesting and can be tested empirically. To allow for this possibility, $I_0$ is augmented by a monetary aggregate in this paper.

Section 2 offered two potential proxies for real marginal costs, the flexible price output gap or labor’s share. This paper only reports the results of using the output gap measure. The results from using labor’s share are very similar to those reported below\footnote{Most importantly, all specifications of the NKM were rejected using this measure. Also, the necessary conditions in section 6 were similar. The results are available upon request.}. Furthermore, marginal costs are no longer proportional to labor’s share under the assumptions in Monacelli (2005), while the output gap remains appropriate.

It is common to approximate the flexible price output gap by, $x_t = y_t - y^n_t$, where $y^n_t$ is some measure of potential output. This measure is used here, although it may not be in close correspondence with the theoretical gap. Setting $x_t = y_t - y^n_t$ in $I_0$ contains precisely the same information as having $y^n_t$ unrestricted in the information set. If $y^n_t$ is unrestricted, $x_t$ is defined by the restriction $y_t - y^n_t$ on the statistical model. In this case, the information set $I_1 = \{\Delta p, i, m, y, y^n\}$ is used to test the baseline NKM below.

The information set $I_1$ must be extended by measures of the natural real interest rate, $r_t$, the price of domestic goods $p_{H,t}$, and the deviation from the law of one price, $\psi_{F,t}$, to enable testing of Monacelli’s open economy model. Since, the natural real interest rate is not observable two alternatives are considered. Treating it as a constant in equation (3) or approximating it
by the real long-term interest rate, $i_t - E_t \Delta p_{t+1}$, leading to equation (5). In the first case $I_2 = \{\Delta p, i, m, y, y^n, q, s\}$ is used, where $s_t = p_t - p_{F,t}$ and $\psi_{F,t}$ is defined by the restriction $\psi_{F,t} = -q_t + s_t$. In the second case $I_3 = \{\Delta p, i, m, y, y^n, q, s, i^l\}$ is used. Note also that $s_t \neq p_{H,t}$, so that $p_{H,t}$ should be included in both information sets as well. However, the difference between $p_{H,t}$ and $p_t$ is likely to be minor and, hence, only $p_t$ is used in this paper.

Finally, when the information set $I_1$ is extended to $I_3$, both $m_t$ and $s_t$ become empirically redundant. In anticipation of these results, a fourth information set is defined as $I_4 = \{\Delta p, i, y, y^n, q, i^l\}$.

In accordance with these informations sets, I have collected quarterly Finnish data on the CPI price index, $p_t$, a short-term interest rate, $i_t$, a long-term interest rate, $i^l_t$, the monetary aggregate M3, $m_t$, real GDP, $y_t$, potential output, $y^n$, the real effective exchange rate, $q_t$, and the price of imports $p_{F,t}$. The sample is 1982:1-2005:3. A detailed description of the data is provided in appendix 4. Finnish inflation is plotted in figure 1. Figure 2 plots the two marginal costs measures while figure 3 plots $\psi_{F,t}$ and the real exchange rate.

\section{Testing the NKM}

This section is devoted to testing the NKM and the open economy version, developed by Monacelli (2005), on Finnish data. The cointegrated VAR model (7) was fitted to the data with, $X_t^* = (\Delta p_t, i_t, m_t, y_t, y^n_t, t)'$, $X_t^* = (\Delta p_t, i_t, m_t, y_t, y^n_t, q_t, s_t, t)'$, $X_t^* = (\Delta p_t, i_t, m_t, y_t, y^n_t, q_t, s_t, i^l_t, t)'$, and $X_t^* = (\Delta p_t, i_t, y_t, y^n_t, q_t, i^l_t, t)'$ corresponding to the the information sets.
Figure 2: The output gap (upper figure) and labor’s share (lower figure). The boom and recession of the late 80’s and early 90’s are visible in both measures.

Figure 3: The theoretical measure $\psi_{F,t}$ (upper figure) and the real exchange rate (lower figure).

$I_1$-$I_4$ (for future reference, models 1, 2, 3 and 4). Initial modelling suggested $k = 2$ and that a restricted linear trend is needed in all four models.

Table 1 reports the rank test statistic of the models. The rank test statistic suggest that the rank should be set to three in all models\(^9\). Hence, the additional information that is provided by $q_t$, $s_t$ and $i_t$ does not increase the cointegration rank. The additional variables must either be redundant or weakly exogenous. This is formally tested in table 2, along with tests of stationarity. Several interesting conclusions emerge from the table. Stationarity

\(^9\)It can be seen from table 1 that $r = 2$ is borderline accepted in model 2. However, since increases in information should not reduce the rank, this choice is not considered.
Table 1: The rank test statistic (trace test) of the four different models of the Finnish data. In the table, $\lambda_i$ are the eigenvalues from the reduced rank regression (see Johansen, 1995). Trace95 is the 95th-percentile of the trace distribution. Rejection at the 1% significance level is denoted by (**) and rejection at the 5% significance level is denoted by (*).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>trace</th>
<th>trace95</th>
<th>p-value</th>
<th></th>
<th>trace</th>
<th>trace95</th>
<th>p-value</th>
</tr>
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<tbody>
<tr>
<td><strong>$\mathcal{I}_{1,t}$, model 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>$\mathcal{I}_{2,t}$, model 2</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>0</td>
<td>0.47</td>
<td>154.93**</td>
<td>88.55</td>
<td>0.00</td>
<td>0.59</td>
<td>228.27**</td>
<td>150.35</td>
<td>0.00</td>
</tr>
<tr>
<td>1</td>
<td>0.38</td>
<td>95.24**</td>
<td>63.66</td>
<td>0.00</td>
<td>0.41</td>
<td>145.58**</td>
<td>117.45</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>0.30</td>
<td>51.06**</td>
<td>42.77</td>
<td>0.00</td>
<td>0.37</td>
<td>96.97*</td>
<td>88.55</td>
<td>0.01</td>
</tr>
<tr>
<td>3</td>
<td>0.10</td>
<td>17.88</td>
<td>25.73</td>
<td>0.36</td>
<td>0.27</td>
<td>54.26</td>
<td>63.66</td>
<td>0.25</td>
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<tr>
<td>4</td>
<td>0.08</td>
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<td>12.48</td>
<td>0.29</td>
<td>0.15</td>
<td>25.14</td>
<td>42.77</td>
<td>0.78</td>
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<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.07</td>
<td>10.34</td>
<td>25.73</td>
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<td>6</td>
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<td>–</td>
<td>–</td>
<td>–</td>
<td>0.04</td>
<td>3.72</td>
<td>12.48</td>
<td>0.78</td>
</tr>
</tbody>
</table>

| **$\mathcal{I}_{3,t}$, model 3** |   |      |        |         | **$\mathcal{I}_{4,t}$, model 4** |   |      |        |         |
| 0 | 0.62 | 267.86** | 187.25 | 0.00 | 0.51 | 183.53** | 117.45 | 0.00 |
| 1 | 0.42 | 178.91** | 150.35 | 0.00 | 0.38 | 116.41** | 88.55  | 0.00 |
| 2 | 0.39 | 127.81** | 117.45 | 0.00 | 0.33 | 72.21**  | 63.66  | 0.00 |
| 3 | 0.29 | 81.32    | 88.55  | 0.15 | 0.20 | 35.04   | 42.77  | 0.24 |
| 4 | 0.26 | 49.92    | 63.66  | 0.42 | 0.10 | 14.89   | 25.73  | 0.59 |
| 5 | 0.12 | 21.64    | 42.77  | 0.92 | 0.06 | 5.44    | 12.48  | 0.54 |
| 6 | 0.06 | 9.24     | 25.73  | 0.95 | –    | –      | –     | –     |
| 7 | 0.04 | 3.36     | 12.48  | 0.82 | –    | –      | –     | –     |

is rejected in all variables regardless of the choice of model\textsuperscript{10}. Money cannot be excluded and appears to be weakly exogenous in model 1. However, when the information is increased to include both $q_t$ and $i_{it}$ it becomes empirically redundant, implying that money does not matter in the open economy case. The table also reveals that $s_t$ can be excluded regardless of the choice of model. Finally, both $q_t$ and $i_{it}$ are found to be weakly exogenous.

Standard misspecification tests indicated some deviations from normal-

\textsuperscript{10}Trend stationarity cannot be rejected in $i_t$. This result is probably a consequence of the sample period, since a deterministic trend cannot enter the interest rate \textit{a priori}. However, the trend stationary interest rate will appear as a cointegration vector, for some rotation of the cointegration space. Such representations will be avoided in the analysis.
Table 2: Tests for weak exclusion (excl.), weak exogeneity (exog.), and stationarity (stat.). The numbers are p-values and boldface values indicate significance at the 5% level. The stationarity test is a test for unit vectors in the cointegration space accept for the variables $m_t$, $y_t$, and $y^n_t$ which included the linear trend.

11 These tests are described by Juselius and Hansen (1995) and include, two tests for the constancy of the $\beta$-vectors, a test for the constancy of the log-likelihood, fluctuation test of the eigenvalues. The results of the tests are available upon request.
Table 3: Tests of the restrictions implied by the core equations of the NKM (1)-(5) on models 1-3. The column “Equ $i$” indicates that the restrictions implied by equation $(i)$ is being tested and $\varphi_{ij}$ are the corresponding estimates. Note that the purely theoretical forms have additional restrictions described in section 2.

<table>
<thead>
<tr>
<th>Model</th>
<th>Equ $i$</th>
<th>$\varphi_{i1}$</th>
<th>$\varphi_{i2}$</th>
<th>$\varphi_{i3}$</th>
<th>$\varphi_{i4}$</th>
<th>$-2\ln Q$</th>
<th>df</th>
<th>p-value</th>
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</thead>
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<td>-</td>
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</tr>
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<td>1</td>
<td>2</td>
<td>1.637</td>
<td>-0.02</td>
<td>0</td>
<td>-</td>
<td>38.57</td>
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</tr>
<tr>
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<td>1</td>
<td>1.845</td>
<td>-4.731</td>
<td>-0.683</td>
<td>-</td>
<td>18.57</td>
<td>11</td>
<td>0.07</td>
</tr>
<tr>
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<td>-0.013</td>
<td>-0.372</td>
<td>-</td>
<td>35.10</td>
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</tr>
<tr>
<td>2</td>
<td>3</td>
<td>1</td>
<td>-0.153</td>
<td>0.066</td>
<td>0</td>
<td>51.60</td>
<td>16</td>
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</tr>
<tr>
<td>2</td>
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<td>3.008</td>
<td>-0.079</td>
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<td>0</td>
<td>39.04</td>
<td>15</td>
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</tr>
<tr>
<td>2</td>
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<td>0.788</td>
<td>-0.045</td>
<td>0.029</td>
<td>0.238</td>
<td>39.60</td>
<td>14</td>
<td>0.00</td>
</tr>
<tr>
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<td>0.048</td>
<td>-0.069</td>
<td>39.30</td>
<td>14</td>
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</tr>
<tr>
<td>3</td>
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<td>-0.349</td>
<td>0.021</td>
<td>0</td>
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</tr>
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<td>54.30</td>
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<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>0.782</td>
<td>-0.166</td>
<td>0.004</td>
<td>0.233</td>
<td>41.89</td>
<td>16</td>
<td>0.00</td>
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<tr>
<td>3</td>
<td>4</td>
<td>3.000</td>
<td>-0.083</td>
<td>0.048</td>
<td>-0.051</td>
<td>54.46</td>
<td>16</td>
<td>0.00</td>
</tr>
</tbody>
</table>

insignificant. Furthermore, the coefficients on the real interest rate and the output gap are consistently of the wrong sign. In addition, the coefficient on expected future inflation is consistently above one, suggesting a possible backward-looking solution for inflation. The results of the hybrid IS curve of models 2 and 3 are slightly more encouraging, since the coefficients on the forward and the backward terms are roughly 0.79 and 0.24, respectively. Thus, the terms approximately sum to one and imply sensible dynamics in terms of the NKM. However, the overall restrictions of the IS curves were rejected and the coefficients on the real interest rate are still negative.

Insights into the estimates can be gained by investigating the solution properties of the equation systems. Blanchard and Kahn (1980) demonstrate that the solution of linear RE systems can be obtained through the eigenvalues of the matrix $A$ in the representation

$$
\begin{pmatrix}
X_{t+1} \\
E_t P_{t+1}
\end{pmatrix}
= A
\begin{pmatrix}
X_t \\
P_t
\end{pmatrix}
+ \gamma Z_t
$$

where $X$ is a vector of predetermined variables, $P$ is a vector of non-predetermined variables, and $Z$ collects the exogenous variables. In particular, if the num-
ber of eigen values outside the unit circle is equal to the number of non-predetermined variables there exists an unique forward looking solution. If there are more eigen values outside the unit circle than the number of non-predetermined variables, the solution is explosive. If the number of eigen values outside the unit circle is less than the number of non-predetermined variables, there are an infinite amount of, possibly backward-looking, solutions.

Let \( X_t = (y_{t-1}, \Delta p_{t-1})' \), \( P_t = (y_t, \Delta p_t)' \), and let \( Z_t \) collect \( i_t, y_t, \psi_{F,t} \). Then, rewriting (1) and (2) in terms of (12) yield

\[
A = \begin{pmatrix}
  0 & 0 & 1 & 0 \\
  0 & 0 & 0 & 1 \\
 -\varphi_{13} & \varphi_{12} & \varphi_{11} & 0 \\
 0 & \varphi_{21} & -\varphi_{22} & \varphi_{21}
\end{pmatrix}.
\] (13)

Equations (3) and (4) yield an identical \( A \) matrix to (13) where \( \varphi_{11} = \varphi_{31} \) and so on. Similarly, (5) and (4) yield

\[
A = \begin{pmatrix}
  0 & 0 & 1 & 0 \\
  0 & 0 & 0 & 1 \\
 -\varphi_{43} & \varphi_{42} & \varphi_{41} & 0 \\
 0 & \varphi_{41} & -\varphi_{42} & \varphi_{41}
\end{pmatrix}.
\] (14)

Using the values from tables 3 to calculate the roots of (13) and (14), produces one root that is very close to unity while the rest are within the unit circle in all the different cases. This suggest that there are no unique stable solutions to the systems and, since it is unlikely that the unit roots can be rejected statistically, that the solutions are non-stationary and possibly backward-looking.

Finally, the simultaneous restrictions of (1)-(2), (3)-(4), and (5)-(4) where tested on models 1-3 respectively. As can be expected, these restrictions were strongly rejected in all cases. The results are not reported here as they are very similar to the individual equation estimates.

These results suggest that the evidence in favor of the different versions of the NKM is weak. However, as pointed out by Juselius (2006), valuable insights into why the model failed empirically may be gained by investigating the cointegration properties of the data. This is the objective of the next section.
6 Necessary conditions and cointegration

The rejection of the NKM in the previous section raises the question of the reasons for this failure. Some insights may be gained by investigating necessary conditions on cointegration that are implied by the equations of the model. In terms of the Johansen and Swensen method, the relevant condition is $d_t^* \in sp(\beta^*)$ which is implied by the restriction $\beta^* \alpha' c_1 = d_t$ in (10). Table 4 list the different $d_t^*$’s implied by equations (1), (2), (5) and (4), where the implied $d_t^*$ from equation $i$ with restrictions indexed by $j$ is denoted by $d_{t,ij}^*$. The restriction $\beta^* \alpha' c_1 = d_t^*$ also implies a necessary condition on $\alpha$ for any particular expectational equation. The condition is tedious to derive, but will as a rule of thumb involve a significant $\alpha_{ij}$ coefficient to the key variable of the expectational equation corresponding to $\beta$. As an example, assume that $X_t = (\Delta p_t, i_t, m_t, y_t, y_t^2, t)'$, $r = q = k = 1$, and that the pure NKPC is being tested. If the restrictions (10) hold, then $\beta^* = (\varphi_{21} - 1, 0, 0, 0)' = d_t^*$. Pre-multiplying $\beta^* \alpha' c_1 = d_t^*$ by $(d_t^* d_t^*)^{-1} d_t^*$ implies $\alpha' c_1 = 1$ and since, $c_1 = (\varphi_{21}, 0, 0, 0)'$ we get $\alpha_{11} = 1/\varphi_{21}$ which is positive as long as $0 < \varphi_{21} < 1$. Equation (9) then implies

<table>
<thead>
<tr>
<th>Equ i</th>
<th>Res</th>
<th>$d_{t,ij}^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>${ \varphi_{11} = 1, \varphi_{13} = 0 }$</td>
<td>$d_{t,111}^* = (\varphi_{12}, -\varphi_{12}, 0, 0, 0)'$</td>
</tr>
<tr>
<td>2</td>
<td>$\varphi_{23} = 0$</td>
<td>$d_{t,121}^* = (\varphi_{21} - 1, 0, 0, \varphi_{22}, -\varphi_{22}, 0)'$</td>
</tr>
<tr>
<td>1</td>
<td>$\varphi_{12} = 0$</td>
<td>$d_{t,112}^* = (\varphi_{12}, -\varphi_{12}, 0, \varphi_{11} + \varphi_{13} - 1, 0, 0)'$</td>
</tr>
<tr>
<td>2</td>
<td>$\varphi_{23} = 0$</td>
<td>$d_{t,122}^* = (\varphi_{21} + \varphi_{23} - 1, 0, 0, \varphi_{22}, -\varphi_{22}, 0)'$</td>
</tr>
<tr>
<td>5</td>
<td>${ \varphi_{51} = 1, \varphi_{54} = 0 }$</td>
<td>$d_{t,151}^* = (0, \varphi_{52}, 0, 0, 0, -\varphi_{52}, 0)'$</td>
</tr>
<tr>
<td>4</td>
<td>$\varphi_{44} = 0$</td>
<td>$d_{t,141}^* = (\varphi_{41} - 1, 0, \varphi_{42}, -\varphi_{42}, -\varphi_{43}, 0, 0)'$</td>
</tr>
<tr>
<td>5</td>
<td>$\varphi_{52} = 0$</td>
<td>$d_{t,152}^* = (0, \varphi_{52}, \varphi_{51} + \varphi_{54} - 1, 1 - \varphi_{51} - \varphi_{54}, 0, -\varphi_{52}, 0)'$</td>
</tr>
<tr>
<td>4</td>
<td>$\varphi_{44} = 0$</td>
<td>$d_{t,142}^* = (\varphi_{41} + \varphi_{44} - 1, 0, \varphi_{42}, -\varphi_{42}, -\varphi_{43}, 0, 0)'$</td>
</tr>
</tbody>
</table>

Table 4: $d_t^*$ implied by the equations (1), (2), (5) and (4). The index $i$ refers to the corresponding equation while the index $j$ takes the value 1 for the purely theoretical forms (the exact restrictions in the column “res”) and 2 for the unrestricted hybrid versions.
\[ \varphi_{21} \Delta^2 p_t = -\frac{1}{\varphi_{21}} (-\varphi_{21} + 1, 0, 0, -\varphi_{22}, +\varphi_{22}, 0)'X_t^* + \epsilon_{1t}. \]

In other words, the cointegration vector \( d_1^* \) implied by the Phillips curve must be significant in the inflation equation.

The necessary conditions provide an easy way of verifying that the long-run properties of the data are consistent with the theoretical model. Such evidence can be interpreted as a partial success of the model. Conversely, investigating cointegration provides information on the long-run structure of the data and, hence, indicates which form the necessary conditions of a theory model should have if it is to have any chance empirically. This suggests a useful way of proceeding when a particular necessary condition is rejected. For example, if the necessary condition of the new Keynesian Phillips curve is rejected, identifying a cointegration vector in which inflation is error correcting suggests in which directions the Phillips curve should be extended\(^{12}\). The objective in this section is to test the necessary conditions of the NKLM equations and, moreover, investigate cointegration if they are rejected. Before conducting this type of analysis, we discuss two empirical issues that have some implications for the remaining analysis. The first is the role of money and the second is a discussion on the theoretical measure \( \psi_{F,t} \).

### 6.1 The role of money and the measure \( \psi_{F,t} \)

It was shown in section 5 that money could not be excluded from models 1 and 2. Doing so leads to significant misspecification of the models. However, when the information set is increased, by including long-term interest rates and the real exchange rate, money becomes empirically redundant.

What accounts for this behaviour? It appears that money contains information on the stochastic trends from both the long-term interest rate and the real exchange rate. This information is clearly important for the other variables and cannot left out. However, when both long-term interest rates and real exchange rates are included in the information set, money adds nothing and becomes redundant. Hence, the prediction of the NKLM that money is irrelevant holds, provided that open economy effects and long-term interest rates are taken into account.

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\(^{12}\) A variable is error correcting a cointegrating vector contains the variable and enters the equation of the variable with a negative sign. For example, if \( y - \beta_x x \) is a cointegration vector and \( \Delta y_t = -\alpha_y (y - \beta_x x)_{t-1} \) then \( y \) is error correcting and \( y - \beta_x x \) is an error correction mechanism.
The second issue of this subsection, is the theoretical measure $\psi_{F,t}$. In section 5 it was found that $s_t$ could be excluded from models 2 and 3. A possible explanation is that $\psi_{F,t}$ was intended to capture all deviations from the law of one price in Monacelli’s model. This interpretation is based on the assumption that foreign goods enter directly into the consumption basket, and are not used as intermediary goods by domestic firms. However, Monacelli’s interpretation may not hold for the empirical counterpart of $\psi_{F,t}$, since most countries, including Finland, use foreign intermediary goods. From an empirical point of view, the relevant information contained within $\psi_{F,t}$ is $q_t$.

Due to these reasons, attention is restricted to models 1 and 4 in the remaining analysis. The deviations from the law of one price are assumed to be captured by the real exchange rate, i.e. $\psi_{F,t} = -q_t$, in model 4.

6.2 Model 1

The results in section 5 suggested $r = 3$ in model 1. Table 5 reports the results of testing the necessary conditions of equations (1) and (2). The table also tests some additional hypotheses on $\hat{\beta}^*$ that are motivated below. The first

<table>
<thead>
<tr>
<th>Equ</th>
<th>$\hat{\beta}_{\Delta p}$</th>
<th>$\hat{\beta}_i$</th>
<th>$\hat{\beta}_m$</th>
<th>$\hat{\beta}_y$</th>
<th>$\hat{\beta}_{y_n}$</th>
<th>$\hat{\beta}_t$</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_{111}^*$</td>
<td>1</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>$d_{121}^*$</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>-0.20</td>
<td>0.20</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>$d_{112}^*$</td>
<td>1</td>
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<td>0</td>
<td>-0.034</td>
<td>0</td>
<td>0</td>
<td><strong>0.36</strong></td>
</tr>
<tr>
<td>$d_{122}^*$</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>-1</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>$\mathcal{H}_1$</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>0.036</td>
<td>-0.036</td>
<td>-0.015</td>
<td><strong>0.28</strong></td>
</tr>
<tr>
<td>$\mathcal{H}_2$</td>
<td>0</td>
<td>0</td>
<td>-0.05</td>
<td>-0.31</td>
<td>1</td>
<td>-0.4</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 5: Tests of various hypotheses on the estimated cointegration space of model 1. The rows labeled as $d_{ij}$ are tests of the condition $d_i^* \in sp(\hat{\beta})$, provided by equation and restrictions $j, i = 1, 2$ (see table 4). The rows labeled $\mathcal{H}_k$ tests hypotheses (indexed by $k$) on the cointegration space that are of interest. Each relation is arbitrarily normalized on the largest estimated coefficient and the coefficients on the linear trends are multiplied by 100 to facilitate the exposition.

Each row in the table tests if the $d_i^*$ implied by the purely theoretical form of the IS curve (1) is in the cointegration space. This condition corresponds to testing
if the real short-term interest rate is stationary. The hypothesis is rejected, implying that the necessary condition does not hold or equivalently that the real interest rate is not stationary. The second row tests the stationarity of the $d^*_1$ implied by the pure NKPC. The hypothesis is rejected. Note that the sign on the output gap is wrong in terms of $d^*_1$ in table 4. The third row corresponds to the hybrid version of the IS curve, $d^*_1$. The hypothesis that $d^*_1 \in \text{sp}(\hat{\beta}^*)$ is not rejected. The magnitude of the coefficient on $\hat{\beta}_y$ indicates that the deviation from $\varphi_{11} + \varphi_{13} = 1$ is small but important since $d^*_1$ was rejected. The relationship is stable over the whole sample period and invariant to the choice of model. The fourth row corresponds to the hybrid NKPC, with the additional restriction $\varphi_{21} + \varphi_{23} = 1$. The hypothesis tests whether the output gap is stationary. The hypothesis is rejected and implies strong persistence in the Finnish business cycle, in particular during the severe crisis in the beginning of 1990’s (see figure 2).

Graphical inspection of the inflation rate reveals that during the past 20 years, there has been a downward trend in inflation (see figure 1). This trend cannot be deterministic a priori, although it can be approximated by one in this sample. However, the output gap cannot, by construction, contain a trend. Hence, even if swings in the business cycle can account for some of the variation in inflation it cannot account for the long-run trend, as is confirmed by $d^*_1$ in table 5. It may be possible to study the influence of the output gap on inflation by approximating the long-run stochastic trend in inflation by a deterministic trend. This is done in row five, $H_1$, of table 5. The hypothesis is not rejected so it is indeed the case that the output gap accounts for some of the short-run or medium-run variation in inflation. Note also that the output gap now has the correct sign in terms of table 4. A common finding in the previous literature, for instance in Gali and Gertler (1999), is that the output gap has the wrong sign in terms of the NKPC. This finding does not seem surprising in light of the evidence in this paper. Since the typical data is non-stationary, what has essentially been estimated previously is the cointegration relationship implied by the necessary condition $d^*_1$. However, it is apparent that some important factor accounting for the long-run trends in inflation is still missing. Moreover, if this information is included it may correct the sign on the output gap. This result is in accordance with Sahuc (2006) who argues that trend inflation should be taken into account. The

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13 Similar results were found in Juselius (2006) and Fanelli (2005) for the U.S and the European output gaps.
difference in this paper is that the trend in inflation is viewed as stochastic. The last row, $H_2$, shows a rotation of the cointegration space that is needed to explain potential output. The relationship is hard to interpret and is somewhat unstable over the estimation period. Furthermore, it vanishes if potential output is treated as weakly exogenous.

Finally, the joint hypothesis that the relationships in $d_{112}^*, H_1$ and $H_2$ span the estimated cointegration space is tested. The hypothesis cannot be rejected (p-value 0.46). Thus, the three relationships provide an identified representation of the estimated cointegration space.

Although weak exogeneity of potential output was rejected, it might be imposed on theoretical grounds. Doing so reduces the cointegration rank by one so that $r = 2$ in the partial model. Table 6 reports similar testing as in table 5. The results are virtually identical to those in table 5, with the exception that the strange relationship is no longer present. The joint hypothesis, that the relationships tested in $d_{112}^*$ and $H_1$ span the estimated cointegration space produces a p-value of 0.30. Table 7 reports the estimated system with corresponding loadings (the $\alpha$ matrix in (7)). A few things in the table deserve attention. The first cointegration relation is significant and error correcting in both the equation for (the change in) the interest rate and (the change in) real output. Hence, the rule of thumb necessary condition on $\alpha$ holds and the relationship can be interpreted as an IS curve. The second
Estimated and identified $\beta$ and $\alpha$ vectors of model 1

<table>
<thead>
<tr>
<th></th>
<th>$\hat{\beta}_t$</th>
<th>$\hat{\beta}_i$</th>
<th>$\hat{\beta}_m$</th>
<th>$\hat{\beta}_y$</th>
<th>$\hat{\beta}_y^{n}$</th>
<th>$\hat{\beta}_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\hat{\beta}_1$</td>
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<td>1</td>
<td>0</td>
<td>0.033</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(8.30)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\hat{\beta}_2$</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>-0.039</td>
<td>0.039</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(-4.43)</td>
<td>(4.43)</td>
<td>(9.72)</td>
</tr>
<tr>
<td>$\Delta^2 p_t$</td>
<td>$\Delta i_t$</td>
<td>$\Delta m_t$</td>
<td>$\Delta y_t$</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\hat{\alpha}_1'$</td>
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<td>-0.18</td>
<td>0</td>
<td>-0.93</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(-3.48)</td>
<td>(-5.31)</td>
<td></td>
</tr>
<tr>
<td>$\hat{\alpha}_2'$</td>
<td>-0.71</td>
<td>0</td>
<td>0</td>
<td>-1.40</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(-5.45)</td>
<td>(-5.21)</td>
<td></td>
</tr>
</tbody>
</table>

Table 7: The estimated identified cointegration space of model 1 (with $y_t^n$ weakly exogenous) and corresponding loadings. Zero restrictions are imposed on statistically insignificant variables. The coefficients on the linear trends are multiplied by 100 to facilitate the exposition.

The relationship is significant and error correcting in (the change in) inflation and, hence, the rule of thumb condition also hold for this equation. The relationship is consistent with the Phillips curve, apart from the deterministic linear trend. Note, also that this relationship is significant in the (the change in) real output equation. However, real output is not error correcting in this relationship as can be seen from the signs. This feature probably reflects the boom-crisis years of the late eighties and early nineties and does not reflect any real explosiveness in the model, as can be confirmed by the roots of the companion matrix.

The results of this section indicate that both the IS curve and the Phillips curve are important empirical long-run relationships, providing explanations of inflation and output fluctuations. However, since the RE restrictions of the NKM were rejected it is not possible to determine to which extent they reflect forward-looking behavior.

### 6.3 Model 4

The results from section 5 suggests that $r = 3$ and that $q_t$ and $i_t'$ are weakly exogenous in model 4. Table 8 reports the results from testing the necessary conditions of equations (1), (2), (5), (4), and some additional hypotheses, $H_k$. The results are, with minor modifications, similar to what was found in
Table 8: Tests of various hypotheses on the estimated cointegration space of model 4. The rows labeled as $d_{ij}$ are tests of the condition $d_{ij} \in sp(\hat{\beta})$, provided by equation and restrictions $j, i = 1, 2$ (see table 4). The rows $H_k$ test hypotheses on the cointegration space that are of interest. Each relation is arbitrarily normalized on the largest estimated coefficient and the coefficients on the linear trends are multiplied by 100 to facilitate the exposition.

For instance, ignoring the trend in the Phillips curve relationship, $d_{121}$, produces the wrong sign on the output gap. However, the open economy NKPC, $d_{111}$, produces the correct sign although this relationship is rejected as well. However, as in section 6.2, the relationship is not rejected if a linear trend is included. This hypothesis is tested in $H_3$. The open economy IS curve specification, $d_{112}$, is not rejected when the natural interest is treated as a constant, while it is rejected when expressed in terms of the interest rate differential, $d_{152}$. The last relationship in $H_4$ is similar to that in $H_2$ and is again needed to explain the change in potential output. As before, the relationship disappears if $y^n_t$ is treated as weakly exogenous. Weak exogeneity of $y^s_t$ is not imposed here since it was rejected in table 2, although the main results remains unchanged even if it is imposed.

The joint hypothesis, that the relationships tested in $d_{112}$, $H_3$ and $H_4$ span the estimated cointegration space produces a p-value of 0.43. Table 9 reports the estimated system with corresponding loadings. As before, the rule of thumb necessary condition on $\alpha$ holds for both the IS curve and the
Table 9: The estimated identified cointegration space and corresponding loadings of model 4, with $q_t$ and $i_t$ weakly exogenous. Zero restrictions are imposed on statistically insignificant variables. The coefficient on the linear trend is multiplied by 100 for clarity of exposition.

NKPC.

Overall, the gains of going from a closed economy model to an open economy model are moderate. The main advantages appear to be, more parameter stability, confirmation of the “no role for money” result, and a slightly better fit.

7 Conclusions

This paper analysed Finnish inflation from the perspective of the new Keynesian model. The restrictions implied by closed and open economy specifications of the NKM were tested by the Johansen and Swensen method. The restrictions were rejected on all models and specifications.

Following the formal rejections of the models, less strict tests of the NKM were performed. In particular, necessary conditions on cointegration implied by the different versions of the model were investigated. Several interesting findings emerged. First, the standard output gap cannot fully explain the long-trend in inflation and if this trend is not accounted for the gap will have
the “wrong” sign in the NKPC. However, if this trend is accounted for, or at least approximated by a linear trend, the sign will be according to theory and the empirical necessary condition of the NKPC will hold. Extending, the model to account for open economy effects offers a slight improvement, but does not resolve the issue. These, results suggests that the standard NKM framework is too simple to provide an adequate explanation of inflation. Extensions of the model, for example by including labor market rigidities, may prove useful.

The optimizing IS curve, performed much better in terms of the necessary condition. The data supported a clear IS curve relationship. However, the overall restrictions of the IS curve were rejected. There are at least two reasons for this result. The first and most straight forward, is that the restrictions on the short-run parameters of the model do not hold. If this is the case, one might feel comfortable using the IS curve for purposes of analysing the long-run paths of output, while recognizing that the short-run dynamics are not fully worked out yet. The second possibility is more severe. Since the empirical necessary conditions are consistent with both forward and backward looking models, the reason for the failure of the overall restrictions may be related to the formation of expectations in the model.

Finally, although the open economy extension of the NKM offered an improvement it nevertheless was disappointing in terms of new results. However, by extending the model in this way I found support for the theoretical result that money does not matter.

A Data

The data used in the analysis was mainly collected from two different sources, the OECD and ETLA data-bases. The quarterly sample is 1982:1-2005:3.

\[ p_t = \text{The (log of) GDP deflator and the (log of) CPI, base year 2000, collected from ETLA and OECD (Economic Outlook) respectively. The measures are fairly similar, and the results of the analysis is insensitive to the choice between them. The results using CPI are reported throughout the paper.} \]

\[ r_t = \text{The short-term interest rate, constructed from 3 month market rates such as the 3 month HELIBOR before the EMU period. Available} \]
\[ m_t = m_t^c - p_t, \text{ where } m_t^c \text{ is the (log of) nominal monetary aggregate M3 in millions of EUR, available from ETLA. A sensitivity analysis was conducted by using M2 as well, but the results were similar, apart from a slightly better fit with M3.} \]

\[ y_t = y_t^c - p_t, \text{ where } y_t^c \text{ is (log of) nominal GDP in millions of EUR, available from ETLA.} \]

\[ y_t^a = \text{(log of) Potential real output constructed using production function based method described in Giorno et al. (1995). A sensitivity analysis was conducted with Hodric-Prescott filtered real GDP (using scale parameters 400, 1600).} \]

\[ q_t = \text{(log of) The real effective exchange rate available from OECD (Main Economic Indicators).} \]

\[ p_{F,t} = \text{(log of) Domestic currency price of imports, available from OECD (Economic Outlook).} \]

\[ i_t = \text{Long-term interest rates, market yield on government 10 year bonds. available from OECD (Economic Outlook).} \]

Finally, although the results are not reported in the main text, the analysis was also conducted by using labor’s share as a proxy for marginal costs, i.e. \[ x_t = w_t - y_t. \] \[ w_t = w_t^c - p_t, \text{ where } w_t^c \text{ is the log of total nominal wages and salaries, available from ETLA.} \]

\section*{B Optimization}

This appendix describes the methods used to obtain the coefficient estimates of the unknown parameters in the \( c_i \) matrices of section 3. As noted by Johansen and Swensen (1999), as long as the functions of the parameters are smooth, numerical optimization techniques can be applied to maximize the likelihood function. To this end both grid search and the quasi Newton optimization algorithm by Broyden-Fletcher-Goldfarb-Shanno (BFGS) were used.
In some of the cases there were several local maxima, in which case a grid search over reasonable starting values were conducted. The reported parameters correspond to the maximum. The other local maxima produced very low values of the likelihood and very extreme values of the parameters.

Restricting the parameters to the unit interval was conducted by setting $\varphi_{ij} = \frac{1}{1+|V_{ij}|}$ and maximizing over $V_{ij}$, and by grid search over the unit intervals. The hypotheses were strongly rejected in all cases.

References


