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Q. Farooq Akram and Ragnar Nymo

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# Model selection for monetary policy analysis – Importance of empirical validity\*

Q. Farooq Akram

Research Department, Norges Bank

Ragnar Nymoen

Department of Economics, University of Oslo

December 13, 2006

## Abstract

We investigate the importance of employing a valid model for monetary policy analysis. Specifically, we investigate the economic significance of differences in specification and empirical validity of models. We consider three alternative econometric models of wage and price inflation in Norway. We find that differences in model specification as well as in parameter estimates across models can lead to widely different policy recommendations. We also find that the potential loss from basing monetary policy on a model that may be invalid, or on a suite of models, even when it contains the valid model, can be substantial, also when gradualism is exercised as a concession to model uncertainty. Furthermore, possible losses from such a practice appear to be greater than possible losses from failing to choose the optimal policy horizon to a shock within the framework of a valid model. Our results substantiate the view that a model for policy analysis should necessarily be empirically valid and caution against compromising this property for other desirable model properties, including robustness.

**Keywords:** *Model uncertainty; Econometric modelling; Economic significance; Robust monetary policy.*

**JEL Codes:** *C52, E31, E52*

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# 1 Introduction

Model dependence of monetary policy analysis is well known, as is the multiplicity of models. Several criteria can be used when choosing among models. Common criteria for choosing among models include consistency with some economic theory and data. In addition, one may evaluate models on the basis of how easily they would enable one to communicate their mechanisms and functioning to a wider community, including users of models within the model-developing institution. Accordingly, one may use criteria such as the wider community's familiarity with a model, its similarity with models already in use, and its transparency. Parsimony of a model is another sought-after property, as it enhances a model's transparency and facilitates its updating.

One may also select a model because its policy implications seem robust to different forms of potential model misspecifications. The literature on robust monetary policy addresses the issue of model choice and policy design when several models are available, and when a model may potentially fail to adequately represent features of an economy. The strategy advised depends on the extent of missing information about the appropriate model and its features.

The main approach to dealing with severe model uncertainty, when e.g. making a probability distribution on relevant models and/or their features is considered too bold, is the minmax approach proposed by [Hansen and Sargent \(2001\)](#). Accordingly, the policy choice should be informed by the least fault-tolerant model, i.e. the model in which a deviation from the optimal policy has the most severe consequences. When it is appropriate to limit the model or parameter space and specify probability distributions on its elements, the Bayesian approach is advocated; see e.g. [Levin and Williams \(2003\)](#). Accordingly, the preferred policy depends on a defined space of models or parameters.

Model selection often involves a trade-off between desirable characteristics of a model since a model may perform well on one set of criteria and poorly on another set. An economic theory may prefer a different model than available evidence suggests, while different statistical tests may favour different models; cf. [Pagan \(2003\)](#). One may also encounter cases where a model that is overwhelmingly supported by available evidence is more demanding to understand and/or communicate than a model that is not fully data-consistent. In such cases, one might decide to base policies on the latter model. One may also support such an approach by arguing that data are often measured with errors and are revised substantially over time. Furthermore, in the face of model and data uncertainty, one may opt for the apparently most robust model, even though its validity is empirically questionable. Alternatively, one may refrain from selecting one model and decide to base policy on a suite of models consistent with e.g. the Bayesian approach.

However, [Granger \(1992, 2001\)](#) emphasize that consequences of one's decision regarding model choice for policy analysis should be evaluated in terms of their economic significance. Accordingly,

possible loss from choosing one model specification ahead of another should not be assessed in terms of only e.g. predictive power forsaken, or in terms of other desirable statistical properties, but also in terms of potential economic/welfare loss. We essentially follows the recommendations of Granger in this paper.

We investigate empirically whether it would matter much for economic performance and policy implications which model is chosen, i.e. which set of criteria is used to select a model. Moreover, we investigate the potential costs of basing monetary policy (unknowingly) on an invalid model or a suite of models, for whatever good reasons. In particular, we shed light on the potential losses from implementing robust policies based on a single robust model and a suite of models. In this context, we also investigate to what extent one can mitigate the potential losses from choosing an invalid model by following the Brainard principle for policy making in the face of uncertainty; see [Brainard \(1967\)](#) for details. This principle often seems to guide monetary policy practice. In its popular version, one should find out how much interest rates need to be changed in given circumstances and then do less as a concession to different forms of uncertainty. Widely observed gradualism in interest rate setting is often considered a reflection of the Brainard principle; see e.g. [Sack and Wieland \(2000\)](#), [Tetlow and von zur Muehlen \(2001\)](#) and the references therein.

We find that differences in model specification and even differences in estimates of key parameters across similar models may suggest widely different economic performance and policy implications in the face of shocks. Hence, we find substantial losses from choosing a model other than the one that represents the economy, or imposing invalid parameter restrictions. We also find that robust policies need not contribute much to reducing such losses, also when policy is based on a suite of models containing the valid model, or when a policy is guided by the Brainard principle. Furthermore, the potential loss from basing policy on an invalid model or a suite of models appear to be larger than losses from conducting suboptimal policies based on the valid model.

Hence, there seem to be large gains from efficiently exploiting available information to derive the appropriate model for policy analysis. The substantial losses from selecting an invalid model suggest that a model used for monetary policy analysis should necessarily be empirically valid and calls for caution when compromising this property for other desirable model properties, including robustness. A comprehensive econometric evaluation of competing models of relevance for policy analysis may help one to narrow down the choice to the most data-coherent model, given available information.

We proceed as follows. The next section presents three alternative econometric systems of wage and price inflation for Norway. They may be considered alternative blocks of the supply side in a macroeconomic model for medium-term analysis. One of the systems is derived in the light of open economy models of imperfect competition in product markets and a wage-bargaining framework. The other two systems consist of Phillips curves for prices and wages, where one of

them specifies vertical Phillips curves for wage and price inflation through parameter restrictions. The apparently small differences between the two systems of Phillips curves are especially useful in demonstrating the model dependency of monetary policy rules. This section undertakes an econometric evaluation of the three systems to examine their congruence with data and demonstrates that available data are helpful in choosing among them.

Section 3 investigates the monetary policy implications of the three systems in the face of demand and supply shocks. We assume that the central bank primarily targets the inflation rate but, without prejudice to this objective, also pursues output stability. The latter objective is pursued by choosing an appropriate horizon for achieving the inflation target. Previous studies assuming an hierarchy of monetary policy objectives include [Smets \(2003\)](#) and [Driffill and Zeno \(2004\)](#). This way of characterizing monetary policy seems consistent with the actual practice of leading central banks; see e.g. [Meyer \(2004\)](#), [Heikensten \(2005\)](#) and [Giavazzi and Mishkin \(2006\)](#).<sup>1</sup> In order to implement this approach, we follow the procedure suggested by [Akram \(2006\)](#) which is briefly outlined in Section 3.1.

Section 4 investigates the potential costs of basing monetary policy on an invalid model, or a suite of models. We conduct the analysis by embedding, in turn, the three wage and price systems representing the supply side in a well documented macroeconomic model of Norway; see [Bårdsen et al. \(2003, 2005\)](#) and [Akram et al. \(2006\)](#). This model is part of the suite of models maintained by Norges Bank. A number of researchers have called for monetary policy analysis using models that are actually used in policy making institutions rather than simplified models used for illustrations; cf. [Goodhart \(2001\)](#). Our use of the macroeconomic model is motivated by this call.

Section 5 presents our main conclusions while an appendix contains precise definitions of the time series of the variables.

## 2 Alternative systems of prices and wages

This section develops and evaluates three alternative empirical systems of Norwegian wage and price inflation. The three systems are derived from a common VAR model by imposing restrictions in the light of relevant economic theories and following a "general to specific" modelling strategy.<sup>2</sup>

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<sup>1</sup>For the ECB "The Treaty establishes a clear hierarchy of objectives for the Eurosystem. It assigns overriding importance to price stability.", which is defined as "a year-on-year increase in the Harmonised Index of Consumer Prices (HICP) for the euro area of below 2%." and "Without prejudice to the objective of price stability" support the achievement of e.g. "high level of employment" and "sustainable and non-inflationary growth"; see [www.ecb.int](http://www.ecb.int).

The Bank of England 1998 Act also expresses an hierarchical ordering between similar objectives; see <http://www.bankofengland.co.uk/about/legislation/1998act.pdf>.

<sup>2</sup>A Pc-Give batch file and a data file that can be used to replicate the results in detail can be downloaded from <http://folk.uio.no/rnymoen/>.

## 2.1 Time series of key variables

The models are based on quarterly time series for the mainland economy of Norway, i.e. exclusive of its offshore sector. They are estimated on a data set that covers the period 1972q4-2001q4. The data are seasonally non-adjusted and the time series are defined more precisely in the appendix.

The variables of main interest to us include natural logs of average hourly wages ( $w$ ), the consumer price index ( $p$ ), productivity ( $pr$ ), an import price index ( $pb$ ) and the unemployment rate ( $u$ ). In addition, payroll and indirect tax rates,  $\tau_1$  and  $\tau_3$ , log of standard working hours ( $h$ ) and an index of electricity prices ( $pe$ ) appear as explanatory variables in the systems of wages and prices.

## 2.2 System of error correction models (ECMs)

The following long-run relationships for wages and prices in Norway are consistent with open economy models of imperfect competition in product markets and a wage-bargaining framework:

$$w_t = p_t + \gamma_{w1}pr_t - \gamma_{w2}u_t + \gamma_{w0} + \varepsilon_{w,t}, \quad (1)$$

$$p_t = \gamma_{p1}(w_t + \tau_1t - pr_t) + (1 - \gamma_{p1})pb_t + \gamma_{p2}\tau_3t + \gamma_{p0} + \varepsilon_{p,t}, \quad (2)$$

where the slope coefficients are non-negative and  $\gamma_{w0}$  and  $\gamma_{p0}$  are intercepts. A detailed rationalization is given in [Bårdsen \*et al.\* \(2005, Ch 5\)](#) based on the assumption that  $w_t$ ,  $p_t$ ,  $pr_t$  and  $pb_t$  are variables that are integrated of degree one, but cointegrated. The tax and unemployment rates are assumed to be without unit roots, while they may display deterministic non-stationarity due to shifts in their mean rate over time; i.e. discrete tax rate changes in the case of  $\tau_3t$ . Therefore,  $\varepsilon_{w,t}$  and  $\varepsilon_{p,t}$  represent stationary deviations from the two long-run relationships. [Bårdsen \*et al.\* \(2003\)](#) show that (1) and (2) represent identified cointegrating relationships.<sup>3</sup>

Equation (1) is interpreted as a steady-state wage equation, which is implied by a bargaining framework where wages are determined by domestic prices and productivity, while the rate of unemployment affects the mean level of the implied wage share:  $w_t - p_t - pr_t$ . Equation (2) is interpreted as a steady-state price equation which incorporates both the effects of mark-up pricing behaviour (captured by the elasticity  $\gamma_{p1}$ ), and a separate long-run elasticity of  $(1 - \gamma_{p1})$  for import prices. Since the price variable  $p_t$  is the consumer price index, it is also affected by a measure of indirect taxes,  $\tau_3$ .

We find support for the following estimates of the long-run elasticities:  $\gamma_{w1} = 1$ ,  $\gamma_{w2} = 0.15$ ,  $\gamma_{p1} = 0.6$  and  $\gamma_{p2} = 0.5$ . The estimates of the intercept terms,  $\gamma_{w0}$  and  $\gamma_{p0}$ , are close to the sample means of the cointegrating relationships defined by the elasticity estimates. These estimates are consistent with those found in a number of previous studies using data samples of different lengths,

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<sup>3</sup>See the section on cointegration analysis in the provided PcGive batch file for documentation.

periods and level of aggregation; see e.g. Nymoer (1991), Johansen (1995), Bårdsen *et al.* (1998), Bårdsen and Nymoer (2003), Bårdsen *et al.* (2003), Bårdsen *et al.* (2005, Ch 9) and Boug *et al.* (2002, Ch 5).

We derive a system of structural error correction models of wages and prices, (3), to represent wage-price dynamics consistent with (1) and (2) being long-run cointegrating relationships. Here, we also condition on a number of explanatory variables that have been found relevant in earlier econometric models of Norwegian inflation. These variables are: changes in standard working hours,  $\Delta h_t$ , which capture wage compensation for reductions in the length of the working day; see Nymoer (1989). Second, the rate of change in aggregate demand,  $\Delta y_t$ , is included to represent short-term inflationary pressure in the product markets directly. Third, the rate of change in electricity prices,  $\Delta pe_t$ , is an important exogenous explanatory variable for *cpi*-inflation (due to Norway's hydroelectric-based energy system). Fourth, given that incomes policies and direct price regulations have been in operation on several occasions in the sample period, we control for their effects on wages and prices by employing the dummy variables  $W_{d,t}$  and  $P_{d,t}$ , respectively.<sup>4</sup> Finally, the system includes three seasonal dummies and intercept terms for the two structural equations of the system. We employ the FIML method to estimate the system.<sup>5</sup>

$$\begin{aligned} \Delta w_t = & -\frac{0.11}{(0.01)}[w_{t-3} - p_{t-1} - pr_{t-1} + 0.1u_{t-2}] + \frac{0.16}{(0.07)}\Delta w_{t-1} \\ & + \frac{0.06}{(0.02)}\Delta pb_t - \frac{0.54}{(0.12)}\Delta h_t - \frac{0.02}{(0.002)}W_{d,t} \end{aligned} \tag{3}$$

$$\begin{aligned} \Delta p_t = & -\frac{0.06}{(0.01)}[p_{t-3} - 0.6(w_{t-3} - pr_{t-1} + \tau 1_{t-1}) - 0.4pb_{t-1} + 0.5\tau 3_{t-1}] \\ & + \frac{0.16}{(0.05)}\Delta p_{t-1} + \frac{0.21}{(0.03)}\Delta w_t + \frac{0.13}{(0.03)}\Delta w_{t-1} + \frac{0.04}{(0.02)}\Delta_2 y_{t-1} \\ & - \frac{0.01}{(0.01)}\Delta pr_t + \frac{0.03}{(0.01)}\Delta pb_t + \frac{0.06}{(0.01)}\Delta pe_t - \frac{0.01}{(0.001)}P_{d,t} \end{aligned}$$

The equation for wages in system (3) shows that nominal quarterly wage growth,  $\Delta w_t$ , equilibrium corrects with respect to deviations from the steady-state relationship in (1).<sup>6</sup> The ‘*t*-value’ associated with the equilibrium correction coefficient is  $-11$ , suggesting that one of the main im-

<sup>4</sup>The specification of  $W_{dum}$  and  $P_{dum}$  is given in the appendix together with the definition and sources of the other variables. In addition, we refer to the downloadable PcGive batch and data for automatic and full documentation.

<sup>5</sup>The seasonal dummies and intercepts are suppressed from the equation, while coefficient standard errors are given below their respective coefficients.

<sup>6</sup>The 3-quarter lag in wages and the 2-quarter lag in unemployment only affect how the dynamics is parameterized, not the interpretation of  $[w_{t-3} - p_{t-1} - pr_{t-1} + 0.1u_{t-2}]$ , which is an equilibrium correction term consistent with (1). The detailed lag-specification of the variables that make up the equilibrium correction term is a feature of the dynamic specification process which is helpful in achieving parameter parsimony. It does not affect their economic interpretation.

plications of the underlying theoretical framework is strongly supported by the evidence. The remainder of the equation first shows that there is a tendency of negative autocorrelation in the quarterly wage growth rate which is mainly because most wages are adjusted in the second and third quarters. The last part of the wage equation contains effects of imported inflation ( $\Delta pb_t$ ) and wage compensation for changes in standard working hours ( $\Delta h_t$ ).

The price equation in system (3) shows that also the hypothesized price equilibrium correction is supported by the data; the estimate of the equilibrium correction coefficient has a '- $t$ -value' of 6. The other variables also have straightforward interpretations: There is a statistically significant positive autoregressive coefficient consistent with commonly observed inflation persistence. Actually, the autoregressive coefficient would have been larger without the inclusion of the other explanatory variables in the model. Wage growth has a strong effect with an elasticity of 0.34 over two quarters. There is also a small positive effect of product demand growth if sustained over two quarters. The short-run effects of productivity and import prices, though statistically significant, are quite small when compared with the corresponding long-run elasticities in the equilibrium correction term. In contrast, the estimated elasticity of electricity prices ( $\Delta pe_t$ ) is numerically significant, since they fluctuate widely;  $\Delta pe_t$  varies in the range of  $\pm 25\%$ .

### 2.3 Systems of Phillips curves

We derive the two systems of Phillips curves from the same information set and VAR model as the system of error correction models (ECMs). Specifically, they originate from the same unrestricted reduced form, which corresponds to a VAR in levels with cointegration restrictions imposed.

The system of Phillips curves favoured by data is reported in (4):

$$\begin{aligned} \Delta w_t = & \underset{(0.07)}{-0.20} \Delta w_{t-1} + \underset{(0.13)}{0.27} \Delta p_t + \underset{(0.13)}{0.28} \Delta p_{t-1} \\ & \underset{(0.04)}{} \\ & - \underset{(0.004)}{0.01} \Delta u_t - \underset{(0.001)}{0.01} u_{t-1} - \underset{(0.002)}{0.016} W_{d,t} \\ & \hspace{15em} (4) \\ \Delta p_t = & \underset{(0.07)}{0.10} \Delta p_{t-1} + \underset{(0.06)}{0.20} \Delta p_{t-2} + \underset{(0.05)}{0.31} \Delta w_t + \underset{(0.04)}{0.16} \Delta w_{t-1} + \underset{(0.01)}{0.05} \Delta_2 y_{t-1} \\ & + \underset{(0.01)}{0.03} \Delta pb_t + \underset{(0.01)}{0.07} \Delta pe_t - \underset{(0.001)}{0.01} P_{d,t} \end{aligned}$$

This system is consistent with an open-economy triangular model of inflation, whereby inflation is determined by demand-pull, cost-push and expectations inherent in the wage-price spiral; see e.g. Calmfors (1977), Gordon (1997), Stock and Watson (1999) and Bårdsen *et al.* (2002). The long-run Phillips curve implied by this system is downward sloping, however, since the equation has been found to be not homogenous in the price and wage inflation terms. In the short run,

effects of contemporaneous inflation ( $\Delta p_t$ ) appear in the wage equation, and of lagged inflation ( $\Delta p_{t-2}$ ) in the price equation. This is in contrast to the system of wage-price ECMs, (3), but not unexpected since inflation (and its lagged value) is correlated with both of the two equilibrium correction terms in (3), which by the definition of Phillips curves are omitted from the current system.

The following system entails a vertical long-run Phillips curve:

$$\begin{aligned} \Delta w_t = & \underset{(-)}{-0.18} \Delta w_{t-1} + \underset{(0.12)}{0.58} \Delta p_t + \underset{(0.12)}{0.60} \Delta p_{t-1} \\ & \underset{(0.006)}{-0.01} \Delta u_t - \underset{(0.0013)}{0.003} u_{t-1} - \underset{(0.003)}{0.017} W_{d,t} \end{aligned} \tag{5}$$

$$\begin{aligned} \Delta p_t = & \underset{(0.07)}{0.21} \Delta p_{t-1} + \underset{(0.06)}{0.26} \Delta p_{t-2} + \underset{(-)}{0.26} \Delta w_t + \underset{(0.03)}{0.16} \Delta w_{t-1} + \underset{(0.01)}{0.07} \Delta_2 y_{t-1} \\ & + \underset{(0.01)}{0.04} \Delta p b_t + \underset{(0.01)}{0.07} \Delta p e_t - \underset{(0.001)}{0.01} P_{d,t} \end{aligned}$$

This system has been obtained by imposing homogeneity restrictions on the combined effects of wages and prices in both of the equations in system (4).

A notable difference between system (4) and system (5) is that the coefficient estimate of  $u_{t-1}$  is much lower in the latter.<sup>7</sup> The price equation in (5), however, does not differ much from that in (4). This suggests that the homogeneity restrictions of the long-run Phillips curve model are largely data-consistent, especially in the price equation.

## 2.4 Evidence-based model selection

In the following, we examine the econometric properties of the three systems and demonstrate that available evidence is helpful in choosing among the three systems.

The overall explanatory power of all of the models is fairly high and does not seem to differ much across models. In particular, both the systems of Phillips curves, (4) and (5), provide nearly the same level of fit to actual wage and price growth over the sample period; see Figure 1.

More precisely, Table 1 shows that the overall explanatory power, as measured by the standard deviations of the equation residuals, which are denoted  $\hat{\sigma}_{\Delta w}$  and  $\hat{\sigma}_{\Delta p}$ , is less than 1 percent for (growth in) wages and less than 0.5 per cent for prices. This may be reckoned as quite satisfactory since the data are seasonally unadjusted. The explanatory power of the three systems, especially that of the systems of Phillips curves, is lower than that of the unrestricted VAR. For wages, the system with the vertical Phillips curve, (5), has lower explanatory power than the system with

<sup>7</sup>One can set this estimate at some preferred value and re-estimate the model. However, the econometric performance of the resulting model becomes inferior to that of system (5).

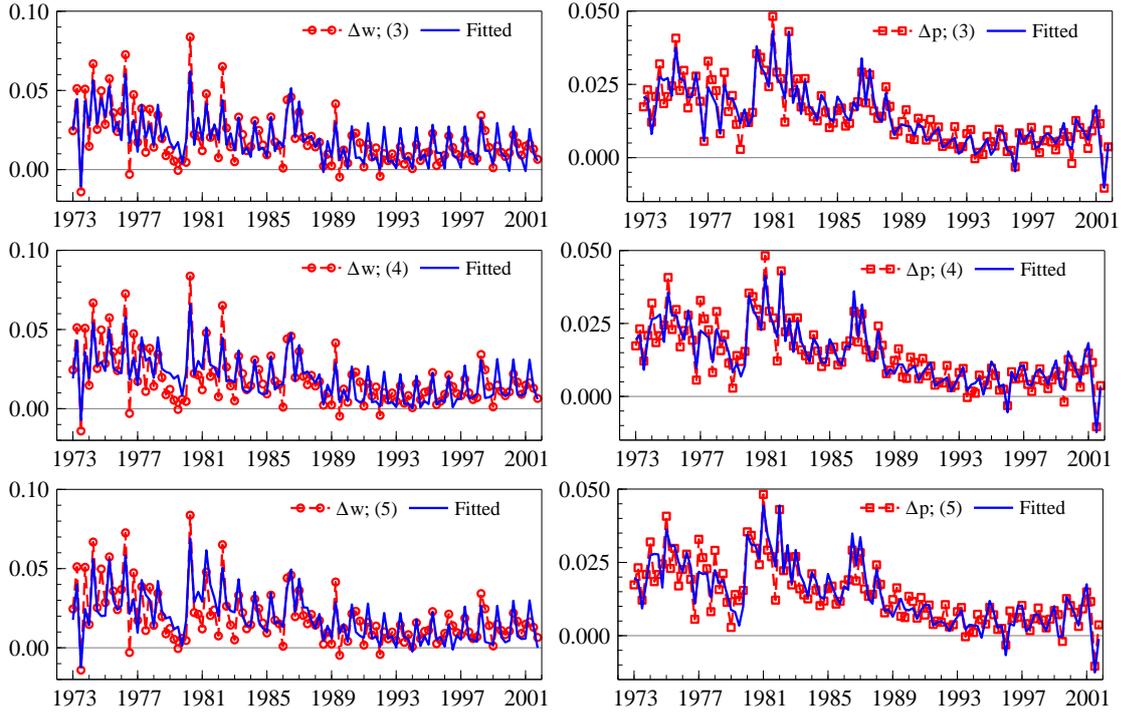


Figure 1: *Explanatory power of the three systems (3)–(5) for (quarterly) growth in wages and prices over the sample period: 1972q4–2001q4. The left-hand column presents the explanatory power of the three systems for growth in wages ( $\Delta w$ ), while the right-hand column presents that for growth in prices. Dashed lines with circles represent actual values of growth in wages, while dashed lines with boxes represent the actual growth in prices. Solid lines represent the corresponding fitted values.*

the downward-sloping Phillips curve, (4), and the system of wage-price ECMs, (3). For prices, however, both systems of Phillips curves provide the same explanatory power, but lower than the ECM of prices.

Table 1: Explanatory power of the VAR and the three systems

| System                    | VAR   | (3)   | (4)   | (5)   |
|---------------------------|-------|-------|-------|-------|
| $\hat{\sigma}_{\Delta w}$ | 0.85% | 0.88% | 0.93% | 0.98% |
| $\hat{\sigma}_{\Delta p}$ | 0.33% | 0.36% | 0.47% | 0.46% |

Notes: The three systems have been estimated by FIML on a sample for the period 1973q1–2001q4. The VAR column shows the diagnostics of the statistical model which has the three economic models/systems as special cases.

Yet, given the relatively high explanatory power of all three models, there may not seem to be any harm in selecting one of them to e.g. facilitate communication with the wider community, including financial markets, politicians, academics and the general public. On such grounds, one could select e.g. the system of the vertical Phillips curve for policy analysis instead of the other two systems: (3) and (4).

However, choosing the system with the vertical Phillips curve, or that of the downward-sloping one, may seem less obvious in the light of a further examination of their econometric properties. One may start by examining the validity of employing the FIML method for estimation since it rests

on specific assumptions regarding residuals; see e.g. [Andreou and Spanos \(2003\)](#). Any violation of these assumptions on available data may signal model misspecification, such as omitted variables and/or wrong functional form. It is also of interest to formally test whether the explanatory power of the three models is comparable to that of the VAR model from which they originate.

Table 2 shows that the evidence is not favourable to the systems of Phillips curves, especially to that of the vertical Phillips curve, while it does not reject the validity of the system of wage-price ECMs. For all three systems, and the VAR model from which they originate, the null hypotheses of normally distributed errors are not rejected by the chi-square distributed test. The corresponding  $p$ -values are well above 10%. However, the hypotheses of no residual autocorrelation and heteroscedasticity are strongly rejected for the system with the vertical Phillips curve (5). The  $F$ -distributed tests of autocorrelation (up to order 5) and heteroscedasticity in the column for system (5) suggest that the two null hypotheses are rejected at even the 1% level of significance. This is not inconsistent with the support for the normally distributed errors, but indicates that misspecification tests have power in different directions. Moreover, the support for normally distributed errors also supports the validity of these tests as they rely on the normality assumption.

Table 2: Diagnostics for the VAR and the three systems

| <b>System</b>             |          | <i>VAR</i> | (3)        | (4)          | (5)           |
|---------------------------|----------|------------|------------|--------------|---------------|
| <i>Autocorrelation</i>    | $F$      | 0.71[0.80] | 1.12[0.33] | 1.41[0.12]   | 2.17[0.00]**  |
| <i>Heteroscedasticity</i> | $F$      | 1.08[0.32] | 0.88[0.76] | 1.32[0.05]   | 1.82[0.00]**  |
| <i>Normality</i>          | $\chi^2$ | 2.98[0.56] | 6.23[0.18] | 0.95[0.92]   | 3.02[0.55]    |
| <i>Overidentification</i> | $\chi^2$ |            | 34.3[0.10] | 69.1[0.00]** | 118.8[0.00]** |

Notes: The number in square brackets are  $p$ -values for the respective statistics, which are adjusted for degrees of freedom. References:

Autorcorrelation test: [Godfrey \(1978\)](#), [Doornik \(1996\)](#); Heteroscedasticity test: [White \(1980\)](#), [Doornik \(1996\)](#); Normality test: [Doornik and Hansen \(1994\)](#); and Overidentification test: [Anderson and Rubin \(1949, 1950\)](#) and [Sargan \(1988, pp 125\)](#).

In contrast to the results for system (5), the  $F$ -tests do not reject the null hypotheses of no autocorrelation and heteroscedasticity at the 5% level of significance for systems (4) and (3). The corresponding tests for the VAR model suggest that it constitutes a valid foundation for deriving the three systems.

We now apply an encompassing test to examine whether the three systems originating from the VAR model explain the data nearly as well as the VAR model itself; cf. [Hendry and Mizon \(1993\)](#). This test supplements the impression gained by comparing the standard deviations of the residuals from the different systems in Table 1. Specifically, we test whether or not the sets of over-identifying restrictions distinguishing each of the three models from the VAR models are accepted by a chi-square distributed test. Table 2 shows that the set of (24) over-identifying restrictions specifying system (4) is strongly rejected; the insignificance of the misspecification tests notwithstanding. As one may expect, system (5) is also strongly rejected. In contrast, the set of (25) over-identifying restrictions specifying system (3) is not rejected at the 5% significance level; the  $p$ -value is 10%.

To test the empirical validity of system (4), and by implication that of system (5), we have also employed a likelihood-ratio test for the null hypothesis that the equilibrium correction terms (which appear in system (3)) are insignificant in system (4). This null hypothesis was strongly rejected by the test on the full sample and different subsamples. On the full sample the test-statistic was 36.2 ( $=\chi^2(2)$ ), with a  $p$ -value of 0.00 per cent. On a subsample starting in 1981q1, the test-statistic was 12.5 ( $=\chi^2(2)$ ), with a  $p$ -value of 0.2 per cent.

#### 2.4.1 Model selection when data are subject to revisions

Data are often measured with errors and revised frequently and substantially over time; see e.g. [Orphanides and Norden \(2002\)](#). One can therefore argue that empirical support of a model may vary across different vintages of data and hence should not be a decisive factor when choosing among models.

However, data revisions and different vintages of data are valuable sources of information that can be used to expose spurious empirical relationships. Genuine long-run relationships between variables are likely to emerge in different vintages of data. Specifically, cointegrating relationships are likely to remain intact in the face of typical data revisions, which corresponds to stationary measurement errors, and hence uncorrelated with integrated variables. Moreover, data revisions that are uncorrelated with stationary variables may not affect estimates of the slope coefficients, which determine the impulse responses to shocks and thereby the monetary policy response. In contrast, spurious long-run and short-run relationships are likely to break down in the face of even minor data revisions. Moreover, changes in estimated relationships in the face of data revisions may indicate that relevant variables have been omitted from the estimated relationship. Therefore, estimation of economic relationships on different vintages of data may reveal information about the adequacy of a model and provide additional evidence on its validity.

A thorough examination of the three systems using different vintages of data is beyond the scope of this study. However, as noted in Section 2.2, the long-run relationships embedded in the system of wage-price ECMs, (3), have been supported by data of different sample lengths and vintages. Moreover, evidence of the wage-price ECMs encompassing the (two versions) of the Phillips curve systems, (4)–(5), has been found on different sample periods. In particular, the strong support for the wage-price ECMs relative to the system (4), and hence also relative to system (5), on the subsample starting in 1981q1 indicates that typical data revisions are unlikely to overturn the evidence favouring the wage-price ECMs. This is because the change in correlation structure resulting from the substantial shortening of the sample is larger than what will usually ensue from a typical data revision.

To summarize Section 2.4, one may say that competing dynamics wage and price equations can be formulated and estimated in such a way that requirements like a reasonable fit and correctly

signed coefficients are met. If a model evaluation ends with checking such properties, one might claim that available data are not sufficiently informative and do not strongly favour one model ahead of another, i.e. show little recalcitrance. However, if one extends model assessment and apply a number of standard misspecification tests, whose properties are well known in the relevant literature, data may be quite recalcitrant, as demonstrated above. Furthermore, data revisions can be utilized to expose the inadequacy of models and to distinguish between genuine and spurious empirical relationships between variables. The next section shows that econometric differences between models are not merely of academic interest but may bear heavily on (model-based) policy recommendations.

### 3 Economic significance of model specification

This section investigates the monetary policy implications of the three systems in the face of demand and supply shocks. We start by outlining our approach to modelling monetary policy and then present the empirical analysis.

#### 3.1 Model dependence of monetary policy

We assume that monetary policy in the face of a shock, directly or indirectly to the inflation rate, primarily aims to ensure that the inflation rate becomes close to its target rate at some specific target horizon. This horizon is determined in the light of the properties of the shock, and the monetary policy authority's concern for output stability, *ceteris paribus*. Below, we briefly outline a convenient procedure for characterizing monetary policy using relatively large macroeconomic models when the central bank has an hierarchy of objectives; see [Akram \(2006\)](#) for details.

To devise an optimal response to an observable shock that occurs at time  $\tau$ , we assume that a forward-looking central bank minimizes the following loss function with respect to an interest rate path  $i_\tau, i_{\tau+1}, i_{\tau+2}, \dots, i_{\tau+H-1}, i_{\tau+H}, i_{\tau+H+1}, \dots$ :

$$L(.) = V_\tau(\Pi) + \lambda V_\tau(Y), \quad (6)$$

subject to the following constraint:

$$E_\tau \Pi_{\tau+H} \approx 0. \quad (7)$$

This constraint implies that the inflation rate must move close to its target in  $H$  periods; cf. [Smets \(2003\)](#).  $\Pi$  denotes deviation from the inflation target while  $H$  represents the policy horizon, i.e. the number of periods during which the policy *interest rate* will deviate from its reference/neutral value and stimulate or cool off the economy. The target horizon, i.e. the number of periods *inflation* will deviate from target, will generally be linked and be close to the policy horizon, but the exact

relationship will be shock- and model-dependent.<sup>8</sup> Typically, inflation will converge asymptotically to its target rate. However, we assume that the policy is set such that the target is largely achieved in period  $H$ , i.e. when the policy interest rate is considered converged with its reference value.  $V_\tau(\cdot)$  is a variance function conditional on information at time  $\tau$ .  $\lambda$  indicates the degree of concern for fluctuations in the output gap,  $Y$ .

This constrained optimization approach implies that the central bank do not compromise its inflation-targeting objective. It is willing, however, to trade off the (conditional) variance of inflation against that of the output gap in accordance with its value of  $\lambda$ , i.e. the relative weight it put on reducing output fluctuations relative to reducing inflation fluctuations. It follows that we characterize the hierarchical objectives of the central bank by assigning overriding importance to the mean of the inflation rate while its variance is given a relatively lower importance, since the central bank may trade off a reduction in the variance of inflation for that in the output gap. This perspective is consistent with what [Faust and Henderson \(2004\)](#) regard as best-practice monetary policy.<sup>9</sup>

We envision that in the face of a shock, the central bank derives a set of interest rate paths, each of them satisfying the constraint (7) for different policy horizons  $H$ s. Then, from this set of interest rate paths, it selects and implements the interest rate path, and the corresponding policy horizon, that would minimize the loss function (6).

However, there can be numerous interest rate paths that satisfy the constraint (7) for every possible policy horizons. By only considering interest rate paths that obey some reasonable pattern, however, the set of relevant interest rate paths can be limited to the number of relevant policy horizons  $H$ s.

We need to assume that the central bank initiates changes in the interest rate when the shock occurs at time  $\tau$  and thereafter allow the interest rate to return gradually towards its reference value/neutral rate, ( $i_0$ ), as commonly observed in practice; see e.g. [Sack and Wieland \(2000\)](#) and [Qvigstad \(2005\)](#).<sup>10,11</sup> Then, if the model is linear, an interest rate path satisfying the constraint (7) for a specific policy horizon  $H$  can be obtained from the following interest rate rule:

$$i_t = i_0 + (1 - \rho_H) \frac{\beta_\varepsilon}{(1 - \phi)} \varepsilon_\tau + \rho_H (i_{t-1} - i_0) \quad ; \quad t = \tau, \tau + 1, \tau + 2, \dots \quad (8)$$

<sup>8</sup>In several studies including [Batinin and Nelson \(2001\)](#) policy horizon is equated with target horizon, as defined here.

<sup>9</sup>Accordingly, “...best-practice policy can be summarized in terms of two goals: First, get mean inflation right; second, get the variance of inflation right.”, but “...getting the mean right may be the goal of greatest importance”; see [Faust and Henderson \(2004, pp. 117–118\)](#).

<sup>10</sup>It is quite common in the relevant literature to rule out interest rate paths that seem unreasonable. In contrast to our approach, this is typically obtained by including a measure of volatility in interest rates in the objective function of the central bank; see e.g. [Smets \(2003\)](#), [Taylor \(1999\)](#) and the references therein.

<sup>11</sup>By restricting movements of the interest rates, however, one loses some control over the movements of the inflation rate. Consequently, the inflation rate can e.g. fluctuate around its target rate before settling down to it instead of converging with it gradually in a geometric fashion. To make the inflation rate e.g. converge gradually with its target rate, the interest rate may need to move excessively around its reference/neutral rate. This may seem at odds with facts, though.

The response coefficient  $(1 - \varrho_H)\beta_\varepsilon/(1 - \phi) \equiv \beta_{\varepsilon,H}$  determines how much the interest rate must change initially to counteract the inflationary effects of a shock  $\varepsilon_\tau$ .<sup>12</sup> This initial deviation is thereafter eliminated gradually, depending on the value of an interest rate smoothing parameter  $\varrho_H$ . It appears that both the response coefficient and the degree of smoothing depend on the policy horizon.<sup>13</sup>  $\phi$  denotes the degree of persistence in the shock and is assumed to be positive and less than one:  $0 \leq \phi < 1$ . It follows that a persistent shock (for which  $\phi > 0$ ) requires a stronger initial response ( $\beta_{\varepsilon,H}$ ) than a transitory shock for a given degree of interest rate smoothing ( $\varrho_H$ ) and  $\beta_\varepsilon$ .

The value of  $\beta_\varepsilon$  depends on the shock and the model. It is a derived parameter whose value increases with the inflationary effects of the shock over a specific period, but declines with the effectiveness of interest rates in checking inflation. It is convenient to estimate  $\beta_\varepsilon$  by taking the ratio of the accumulated impulse responses of the shock over the simulation horizon to that of a monetary policy shock.<sup>14</sup>  $\beta_\varepsilon$  can be considered a constant (shock- and model-specific) parameter, if the transmission mechanism of the shocks is super exogenous with respect to the policy changes considered; see [Engle \*et al.\* \(1983\)](#).

The policy horizon enters the interest rate rule through the interest rate smoothing parameter.  $\varrho_H$  is defined as  $\delta^{1/(H+1)}$  and takes on a value in the range of  $(0, 1)$  depending on the policy horizon  $H$  (for a given  $\delta$ ).  $\delta$  is a sufficiently small fixed parameter of choice that indicates when the interest rate may be considered converged with its reference value; in principle, the interest rate will converge asymptotically with its reference value.

The degree of smoothing increases with the policy horizon in a concave fashion. In particular,  $H = 0$  will lead to (almost) no interest rate smoothing ( $\varrho_H = \delta$ ), while large values of  $H$  will imply a high degree of interest rate smoothing since  $\varrho_H = \delta^{1/(H+1)} \rightarrow 1$  when  $H \rightarrow \infty$ . The case  $H = 0$  refers to the case when the policy-maker only allows interest rates to deviate from their reference rate in a single period at time  $\tau$ .

However, the initial response becomes stronger with a short policy horizon than with a relatively longer policy horizon. The value of the response coefficient  $\beta_{\varepsilon,H} (\equiv (1 - \varrho_H)\beta_\varepsilon/(1 - \phi))$  declines (in a geometric fashion) with the policy horizon or degree of interest rate smoothing. In particular,  $(1 - \varrho_H)\beta_\varepsilon/(1 - \phi) \approx \beta_\varepsilon/(1 - \phi)$  when  $H = 0$ , while  $(1 - \varrho_H)\beta_\varepsilon/(1 - \phi) \rightarrow 0$  when  $H \rightarrow \infty$ ; since  $\varrho_H \rightarrow 1$ . This suggests that if a very long policy horizon is allowed, the interest rate needs to deviate only marginally from its reference value, but this deviation has to persist for a long time.

A long horizon would help subdue the required initial response to a relatively persistent shock. In particular, if persistence in a shock is matched by persistence in interest rates, i.e.  $\varrho_H = \phi$ , the initial response becomes equal to  $\beta_\varepsilon$ . In contrast, a short horizon may imply a particularly large

<sup>12</sup>One may also think of  $\varepsilon_\tau$  as a vector of shocks at time  $\tau$  and  $\beta_{\varepsilon,H}$  as the corresponding vector of response coefficients.

<sup>13</sup>This rule resembles a Taylor-type rule with interest rate smoothing except that it is the determinant of (excess) inflation, i.e.  $\varepsilon_\tau$ , that enters the rule rather than inflation itself; see [Taylor \(1999\)](#) and the references therein.

<sup>14</sup>An implication of such an estimate is that inflation targeting can become effectively equal to price-path targeting; see [Akram \(2006\)](#) for details.

deviation from the neutral interest rate in the face of a persistent shock.

Clearly, the parameters characterizing the interest rate rule depend on the policy horizon ( $H$ ), in a given model and a given  $i_0$ . By varying  $H$ , one can vary the interest rate rule and thus the complete interest rate path as well as the level of the loss  $L(\cdot)$ .

It follows that once the rule (8) is implemented in the model, the optimal policy response to a shock can be found by minimizing the loss function (6) with respect to  $H$ . The optimal value of  $H$  will then define the optimal interest rate change,  $\beta_{\varepsilon, H^*}$ , the optimal degree of smoothing,  $\varrho_{H^*}$ , as well as the optimal level of loss,  $L(\cdot)$ , conditional on a given (version of) the macroeconomic model,  $\mathcal{M}$ .

We are particularly interested in analyzing the effect of model choice on the loss  $L(\cdot)$  and consequently the policy, represented by the policy horizon ( $H$ ). We therefore express the loss function (6) as an explicit function of  $H$  and  $\mathcal{M}$ :

$$L(\cdot) \equiv L(H, \mathcal{M}). \quad (9)$$

Optimal loss is defined by the optimal policy horizon,  $H^*$ , for a given model,  $\mathcal{M}$ .  $H^*$  will depend on the degree of concern for fluctuations in the real economy ( $\lambda$ ). Thus,  $\beta_{\varepsilon, H^*}$  and  $\varrho_{H^*}$ , will also depend on  $\lambda$ .

### 3.2 Monetary policy implications of the models

We investigate differences in economic and policy implications of the three alternative wage and price systems in response to demand and supply shocks. To this end, we embed them, in turn, in a macroeconomic model of Norway. This way we are able to almost close the wage and price system. For the sake of brevity, we refer to the three versions of the macroeconomic model, which would differ from each other only by the wage and price system included, as ‘ECM’, ‘PCM’ and ‘PCMr’, respectively. Specifically, ECM includes the system of wage-price ECMs, (3); PCM includes the system of Phillips curves (4) while PCMr includes the system with the vertical Phillips curve (5), which is a restricted version of (4).

The difference between the three versions of the macroeconomic model essentially consists of difference in restrictions on the overall equilibrium correction behaviour. The version with the wage-price ECMs has more equilibrium correction mechanisms than the version with the downward-sloping Phillips curve; which in turn is more equilibrium correcting than the version with a vertical Phillips curve system. In the following, we briefly present the macroeconomic model and further details about the analysis before presenting our main results.

### 3.2.1 Macroeconometric model

The macroeconometric model is a version of the model developed in Bårdsen *et al.* (2003, 2005) which has been documented and employed in several studies, including Akram *et al.* (2006). The model is (log) linear and estimated on quarterly aggregate data for the period 1972–2001. In addition to a system of wages and prices, the model contains equations for aggregate demand, unemployment, import prices, labour productivity, credit demand, and three asset prices: house prices, domestic equity prices and the nominal exchange rate. Foreign variables and domestic government expenditures and electricity prices are treated as exogenous variables.

In particular, short-run fluctuations in aggregate demand are determined by the real exchange rate, real interest rate and wealth effects from house prices and equity prices. Thus, a change in consumer prices affects aggregate demand through its effect on the real exchange rate and the (ex-post) real interest rate. However, an increase in domestic prices mainly depresses aggregate demand because of the dominating effect of the real exchange rate appreciation that follows. The unemployment rate follows growth in output in the short run, as in an Okun’s law relationship. In addition, it exhibits reversion towards its equilibrium rate over time.

Monetary policy, represented by short-term interest rates, has direct effects on the asset prices, credit and aggregate demand, but is neutral in the long run. The model may be considered a backward-looking model in the sense that it does not make the expectations formation processes explicit. The whole model may be considered econometrically well-specified, when system (3) is included, with apparently invariant parameters with respect to changes in monetary policy over the sample; see Bårdsen *et al.* (2003, 2005) for documentation. The lack of evidence for significant parameter instability in the face of shifts in monetary policy is in line with Ericsson and Irons (1995) and Rudebusch (2005). In the following, we assume that the model will remain invariant to the monetary policy decisions we consider.

### 3.2.2 Demand and supply shocks

The monetary policy response to a shock is characterized by rule (8), where the response coefficient ( $\beta_\varepsilon$ ) is entirely model- and shock-dependent. We derive the (absolute) value of the response coefficient in response to a shock for a given model by taking the ratio of the accumulated impulse responses of the shock to that of a monetary policy shock; see Akram (2006) for details. The impulse responses of the two shocks are accumulated over a simulation horizon of six years, when effects of the shocks (approximately) die out.<sup>15</sup>

In details, to derive the value of the response coefficient in the face of a transitory demand shock ( $d$ ),  $\beta_d$ , conditional on a version of the macroeconometric model, we temporarily raise the residual in the aggregate demand equation such that growth in aggregate demand initially increases by

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<sup>15</sup>The results are invariant to the choice of the simulation period since the model is linear.

one percentage point over a year, and record the implied impulse response of inflation over time. Thereafter, we raise the short-term interest rate over a year by one percentage point and record its effects on inflation over time. The ratio of the accumulated impulse responses of the demand shock to that of the monetary policy shock leads to the estimate of the response coefficient  $\beta_d$ . Similarly, to derive the values of the response coefficients in the face of a supply shock for the three model versions, we raise the residual in their (consumer) price equations such that price inflation increases by one percentage point over a year. The response coefficient in face of the supply shock ( $s$ ),  $\beta_s$ , implied by a given model is then derived as the ratio of the accumulated impulse response of inflation to the supply shock to that of the interest rate shock.

Values of  $\varrho_H$  for different policy horizons are obtained from  $\varrho_H = \delta^{1/(H+1)}$ , where we set  $\delta$  to say 0.1 to define convergence. That is, we would consider an interest rate deviation (of e.g. one percentage point) from the reference rate converged with the reference rate when it deviates not more than 1/10 of the initial deviation from the reference rate. Alternative values of  $\delta$  do not bring about substantially different results.

Estimates of the horizon-specific response coefficients  $\beta_{\varepsilon,H}$  for a given model and shock can be obtained from the formula:  $(1 - \varrho_H)\beta_\varepsilon / (1 - \phi)$ , for different degrees of persistence in the shock and interest rates,  $\phi$  and  $\varrho_H$ , respectively. Obviously,  $\varrho_H$  and thus  $\beta_{\varepsilon,H}$  vary with the policy horizon.

The left and the middle frames of Figure 2 display values of the response coefficient for the (transitory,  $\phi = 0$ ) demand shock and the supply shock, respectively, associated with the three model versions: ECM, PCM and PCMr. The values of the response coefficients are presented for different policy horizons in the range 0–12 quarters. The right frame of Figure 2 depicts the degree of interest rate smoothing  $\varrho_H$  implied by the different policy horizons. Before analyzing the results for each of the two shocks, we make the following general observations.

First, an increase in the policy horizon reduces the required initial interest rate response to a shock, but raises the degree of interest rate smoothing, *ceteris paribus*; see Figure 2. For example, the required initial interest rate response declines substantially if the policy horizon is increased from 0 to 8 quarters. This must, however, be accompanied by an increase in interest rate smoothing,  $\varrho_H$ , from 0.1 to 0.77 (right frame). And second, an increase in the policy horizon from a low level leads to a larger reduction in the response coefficient than an increase in the policy horizon from a relatively high level. This is due to the concave relationship between the degree of interest rate smoothing and the policy horizon, since  $\varrho_H = \delta^{1/(H+1)}$ , which in turn leads to a convex relationship of geometric form between the response coefficient and the policy horizon. A linear relationship between the degree of interest rate smoothing and the policy horizon would have implied a linear relationship between the response coefficient and the policy horizon. However, the results presented would not have changed qualitatively.

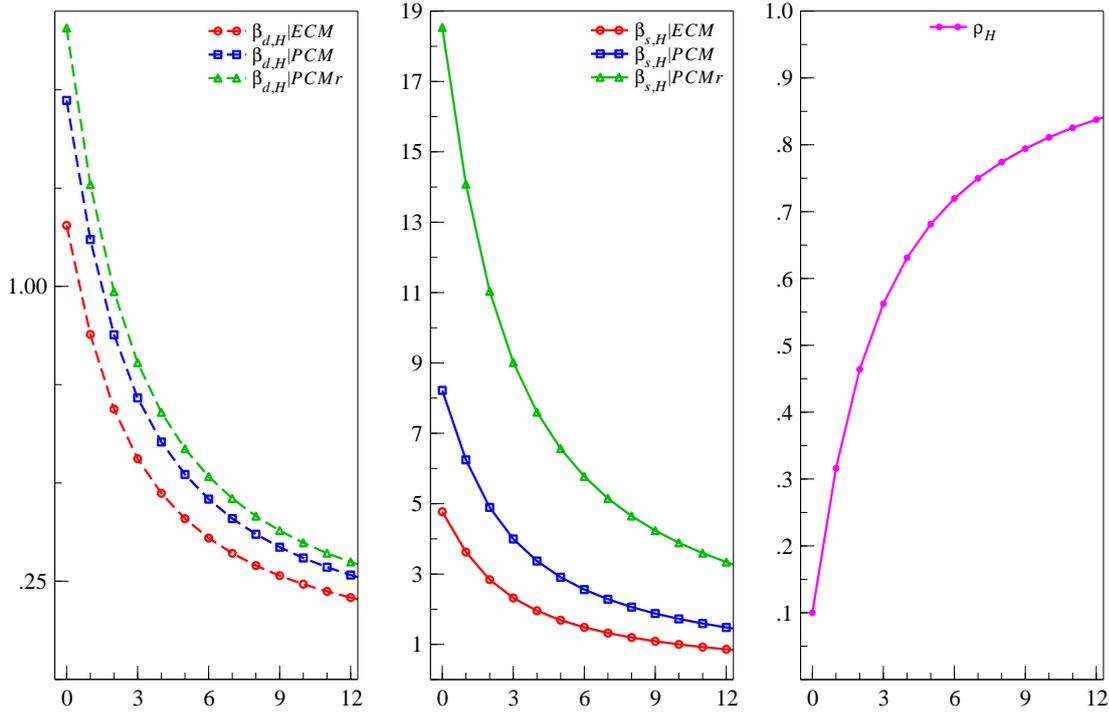


Figure 2: *Left: Initial interest rate responses to the demand shock (in percentage points) implied by different policy horizons (horizontal axes),  $\beta_{d,H}$ . They are suggested by the three versions of the macroeconomic model: ECM, PCM and PCMr. Middle: Initial interest rate responses to the supply shock implied by different policy horizons,  $\beta_{s,H}$ , suggested by the three model versions. Right: Interest rate smoothing,  $\rho_H$ , associated with different policy horizons (horizontal axes).*

### 3.2.3 Economic and monetary policy implications

Figure 2 shows that both PCM and PCMr suggest a stronger response to both shocks than ECM, at all horizons. In particular, PCMr suggests a stronger response to both shocks than PCM and ECM. However, Figure 2 reveals substantial differences between the monetary policy response to the two shocks across the three model versions.

In the case of the demand shock, the interest rate response is relatively low varying in the range of 0.25–1.75 percentage points across the three models. The differences across the three models are relatively small. This reflects that the interplay of the wage and price system with the rest of the model, particularly with aggregate demand and unemployment, is not that different across the three wage and price systems. A demand shock has relatively larger inflationary effects, while a monetary policy shock has relatively stronger deflationary effects in PCM and especially in PCMr, relative to ECM. This is also reflected in the response coefficients, but to a smaller extent since the ratio of the accumulated inflationary effects to that of the deflationary effects is affected to a smaller extent.

Figure 3 sets out the economic performance of the policies in the face of the demand shock suggested by the three models. The economic performance associated with every policy horizon

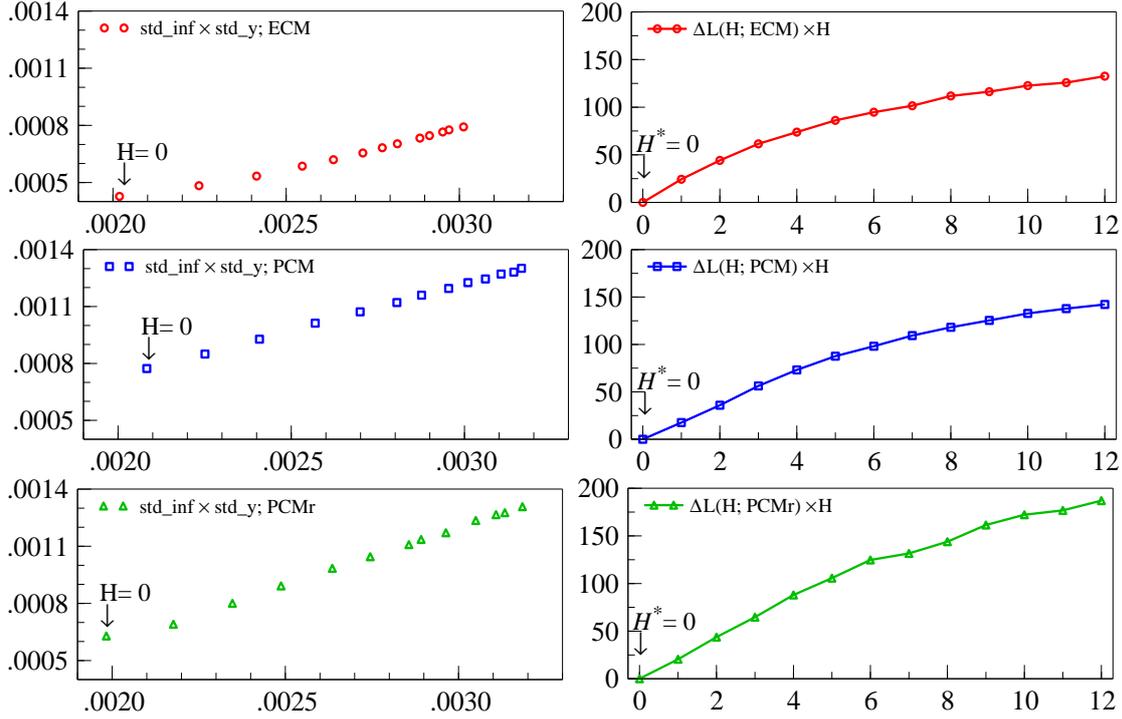


Figure 3: *Economic performance and optimal policy suggested by three models in the face of the demand shock. Left column: Trade-offs between standard deviations of inflation gap and output gap (horizontal axis) associated with different (policy) horizon-specific rules in response to the demand shock. The trade-offs are plotted for rules associated with policy horizons ( $H$ ) in the range of 0–12 quarters. Here and elsewhere, the trade-offs associated with different horizons follow each other, where that one for  $H=0$  is indicated. Right column: Values of the relative loss function (in %), defined by equation (10), at the different policy horizons (horizontal axis).*

is measured by the standard deviations of the output gap and inflation. A policy horizon fully describes the interest rate rule for given values of the response coefficient,  $\beta_d$ ; see Section 3.1. Hence, the optimal policy is found by minimizing the loss function (6) with respect to the policy horizon. We assume that the parameter reflecting concern for output gap fluctuations,  $\lambda$ , is equal to 0.5. We present values of the loss functions under different policy horizons relative to their value under the optimal policy horizon ( $H^*$ ) for a given model version ( $\mathcal{M}$ ).

We define the relative loss,  $\Delta L(H; \mathcal{M})$ , as:

$$\Delta L(H; \mathcal{M}) \equiv \frac{L(H; \mathcal{M}) - L(H^*; \mathcal{M})}{L(H^*; \mathcal{M})}. \quad (10)$$

Here,  $L(H; \mathcal{M})$  denotes the level of loss by choosing  $H$  conditional on a specific model (version)  $\mathcal{M}$ , while  $L(H^*; \mathcal{M})$  expresses the loss under optimal policy horizon conditional on model  $\mathcal{M}$ . It follows that  $\Delta L(H; \mathcal{M}) > 0$  for  $H \neq H^*$  while  $\Delta L(H; \mathcal{M}) = 0$  when  $H = H^*$ , when the loss function is continuous in  $H$  and there is a unique optimum.

As expected, there is no conflict between the objectives of price stabilization and output stabilization in the case of the demand shock; see Figure 3, left column. Moreover, it appears that both

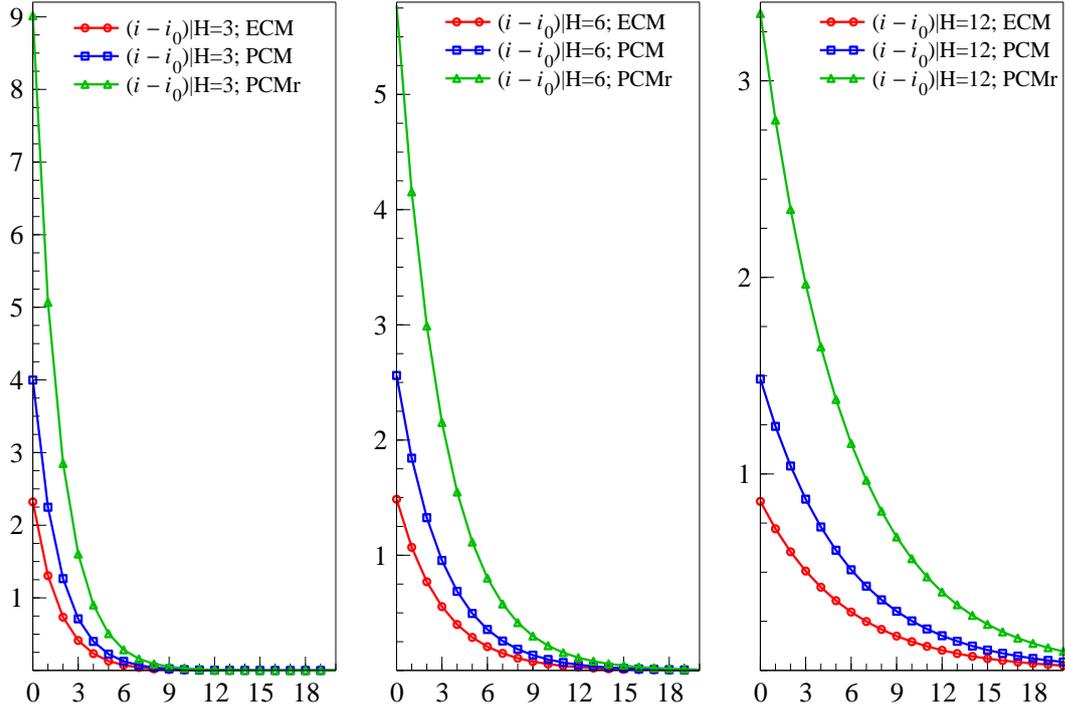


Figure 4: Interest rate paths over time suggested by three models in the face of the supply shock. The three frames shows interest rate paths associated with the policy horizons of 3, 6 and 12 quarters, respectively. The interest rates are measured as deviation from the reference interest rate in percentage points, while the horizontal axes depict periods in quarters.

objectives can be promoted by reducing the policy horizon as much as possible. Hence, a policy horizon of zero appears as the most efficient one. The values of the relative loss functions are zero, i.e. at their optimal level, for  $H=0$ ; see right column. Hence, the optimal policy horizon would be zero irrespective of which wage and price system we implement in the model. This finding is consistent with the bulk of studies suggesting that demand shocks should be counteracted as aggressively as possible, since inflation can be stabilized jointly with output.

In the case of the supply shock, however, the implied monetary policy response is much stronger and differs widely across the three models; see Figure 2, middle frame. Figure 4 depicts the interest rate paths implied by the three models for three different policy horizons: 3, 6 and 12 quarters. These paths exhibit clearly the differences in monetary policy response implied by the three models. Moreover, the gap in policy implications of PCM and PCMr is wider than the gap between those of PCMr and ECM. Notably, if there was an exogenously provided fixed policy horizon, the three wage and price systems, particularly the two systems of Phillips curves, would have suggested substantially different monetary policy responses to the supply shock. Hence, one may say that seemingly minor parameter restrictions can alter the policy implications of a model fundamentally.

The large differences in the response coefficients across the three models can be ascribed to the associated wage and price systems, specifically to differences in the autoregressive coefficients

across the three systems and to the effect of the unemployment term. The autoregressive coefficients largely determine the degree of persistence in the inflationary effects of the supply shock, i.e. how fast the inflationary effects of the transitory supply shock are exhausted. The larger the persistence, the more lasting the inflationary effects and the stronger the required interest rate response will be. The relatively weak effect of unemployment on the wage growth in system (5), relative to those in systems (3) and (4), the monetary policy becomes less effective in PCMr, than in ECM and PCM. Hence, a relatively larger change in the interest rate is required in the case of PCMr than in the cases of ECM and PCM.

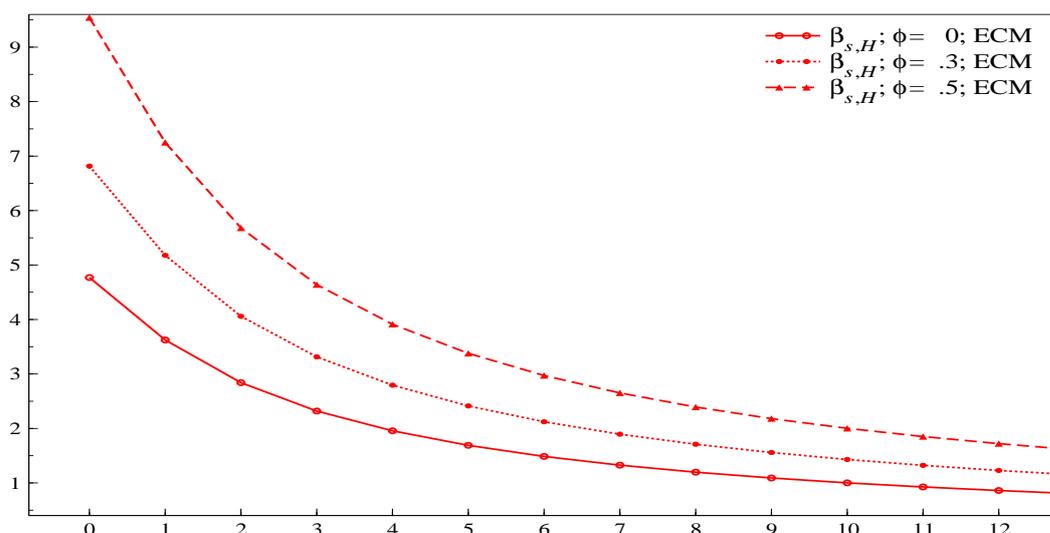


Figure 5: *Initial interest rate response suggested by ECM to supply shocks with different degrees of persistence,  $\phi$ . The initial interest rate response is implied by policy horizons in the range 0–12 quarters (horizontal axis).*

For example, the degree of persistence implied by the lagged and contemporaneous terms of wages and prices in system (5) is higher than that implied by system (4), which in itself implies higher persistence than system (3). Consequently, the inflationary effects of the transitory supply shock are more lasting in the case of PCMr than in the case of PCM, which in itself implies more lasting effects than ECM. Accordingly, the required interest rate response is higher in the case of PCMr than in the case of PCM and relatively low in the case of ECM.

The systems of Phillips curves, (4) and (5), which have relatively stronger autoregressive effects than the system of wage-price ECMs, (3), effectively make the transitory supply shock a more persistent one than the system of ECMs. In the system of ECMs, a certain degree of persistence is modelled by lagged wage and price growth variables *and* equilibrium correction terms in the levels of variables. In terms of a VAR in levels, this entails that some of the characteristic roots are on the unit circle, while others are on the stable side of the unit circle. The system of the downward-sloping Phillips curve (4), however, implies a reduction in the number of stable roots

since the direct equilibrium correction in wage and price setting is omitted, and as a consequence, an increase in the degree of persistence of any shock. The system of vertical Phillips curve system (5), has even more in-built persistence, because extra unit-roots are implied by the homogeneity restrictions; cf. [Bårdsen and Nymoen \(2006\)](#).

The analytical expression for the required interest rate response suggests that an increase in the degree of persistence in a shock increases the required interest rate response; see equation (8). Figure 5 suggests that the required interest rate responses in the case of ECM can become comparable to those implied by PCM and PCMr if we raise the persistence in the supply shock.

Figure 6 presents the economic performance of (optimal and suboptimal) policies employed in response to the supply shock. The left column of the figure shows that there is a trade-off between price and output stabilization for different ranges of policy horizons. Specifically, in the case of ECM and PCM there is a trade-off in the range of 0 to 8 quarters. Policy horizons that are longer than 8 quarters appear inefficient as both price and output stabilization can be improved by shortening the policy horizon. The opposite is the case for PCMr. In this case, the trade-off curve is associated with policy horizons that are longer than 6 quarters, while policy horizons shorter than 6 seem inefficient.

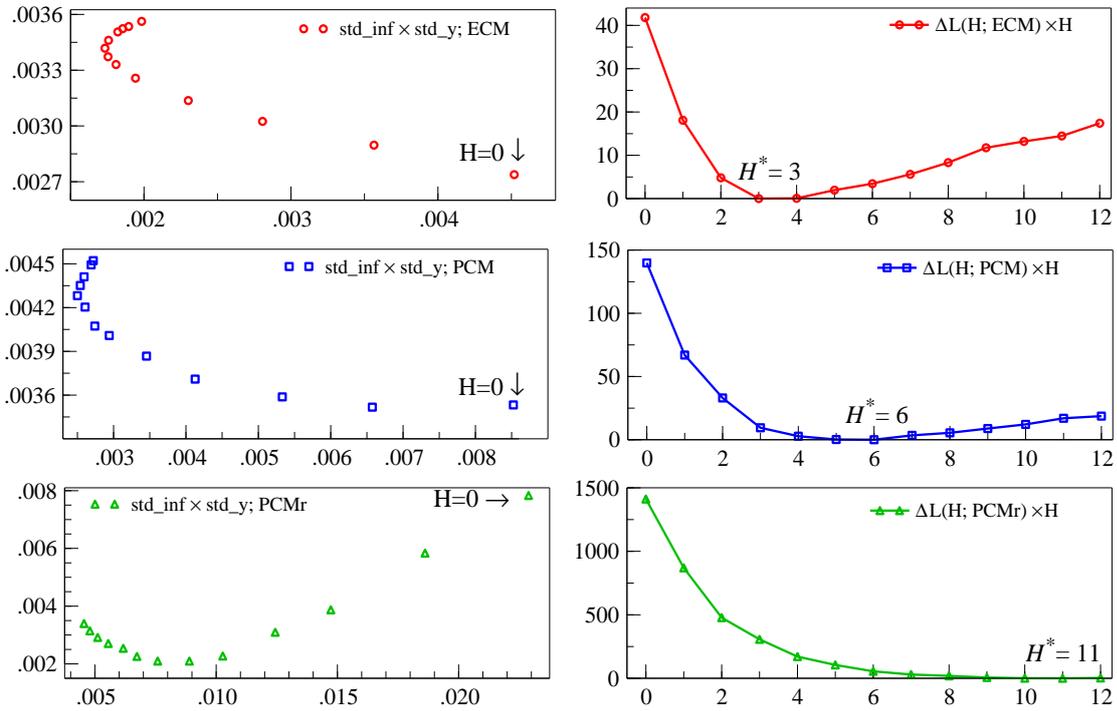


Figure 6: *Economic performance and optimal policy suggested by three models in the face of the supply shock. Left column: Trade-offs between standard deviations of inflation gap and output gap (horizontal axis) associated with different (policy) horizon-specific rules in response to the supply shock. The trade-offs are plotted for rules associated with policy horizons ( $H$ ) in the range of 0–12 quarter, where that for  $H = 0$  is indicated. Right column: Values of the relative loss function (in %), defined by equation (10), at the different policy horizons (horizontal axis).*

Figure 6 shows, in right column, that the three models recommend substantially different policy horizons. Even though the efficiency frontiers for ECM and PCM are defined by almost the same policy horizon, the optimal horizon is 3 quarters conditional on ECM, but 6 quarters in the case of PCM. In the case of PCMr the policy horizon is 11 quarters. (An increase in the value of  $\lambda$  from 0.5 would have increased the optimal policy horizons in all three models.)

The largely different optimal policy horizons imply widely different interest rate paths. They can be seen from Figure 4, where the interest rate path favoured by ECM appears in the left frame, that by PCM in the middle frame, while that favoured by PCMr would be comparable to that for  $H=12$  in the right frame. Both ECM and PCM suggest about the same initial interest rate increase for  $H=3$  and  $H=6$ , respectively; 2.25 and 2.5. However, the degree of interest rate smoothing associated with  $H=6$  is relatively higher, i.e. 0.72, which makes monetary policy contractionary over a relatively longer period than when  $H=3$ . PCMr suggests an initial interest rate increase of about 4 for  $H=11$ , while the implied interest rate smoothing is 0.83. Hence, PCMr suggests a more aggressive as well as a more prolonged contractionary monetary policy stance than the other two models.

In sum, the more persistent the inflationary effects are in a model, the longer is the preferred policy horizon. Both a higher degree of persistence in the inflationary effects of the shocks and the implied policy response, which increases with the degree of persistence, contribute to relatively large economic fluctuations, i.e. high standard deviation of prices and the output gap. This is especially the case at especially short policy horizons. A relatively long horizon leads to a less aggressive policy response and a more prolonged contractionary policy. This helps to achieve a better synchronization between the destabilizing effect of the persistent inflationary effects with the stabilizing effect of monetary policy. Monetary policy thereby becomes more effective in stabilizing the economy.

The above results underscore the importance of imposing valid coefficient estimates when conducting monetary policy analysis. As demonstrated, restrictions on parameter values can have a more profound effect on monetary policy than alterations in model specification. The differences in suggested policy horizons can be mainly ascribed to the alteration in the degree of persistence by the different model specifications and to the estimates of unemployment on wages. Figure 7 shows that ECM would have produced similar results if the shock had been more persistent. For example, if the persistence in the shock had been 0.3, ECM would have suggested an optimal policy horizon of 6 quarters, and of 12 quarters if the persistence had been 0.5. It follows that imposing seemingly weak restrictions to make the model e.g. more presentable may not be an innocuous act.

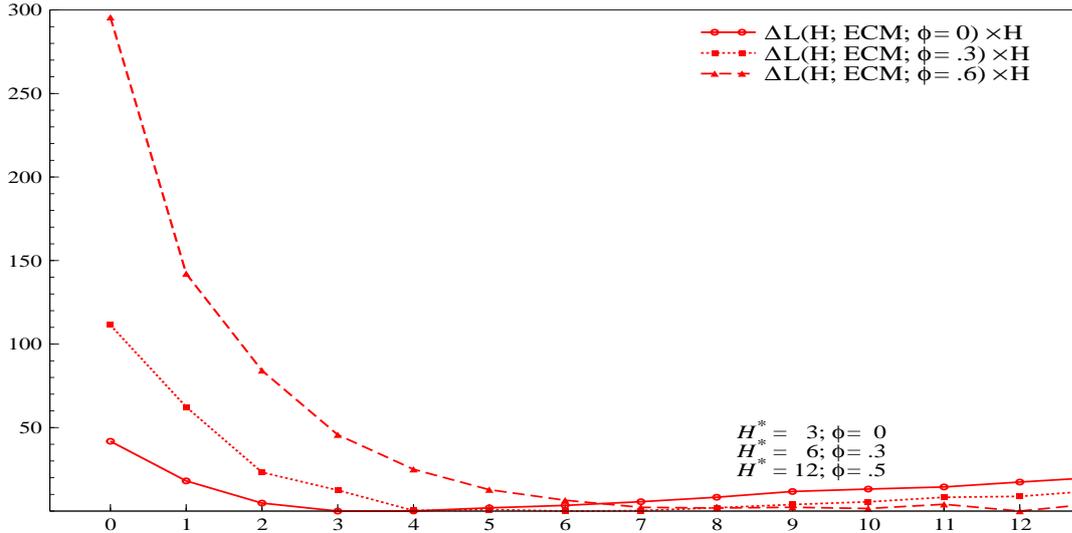


Figure 7: *Relative losses at different policy horizons, 0–12, when monetary policy responds to supply shocks with different degrees of persistence. The relative losses (in %), defined by (10), are based on ECM.*

## 4 Costs of an invalid model and robust policies

In the following we investigate potential costs of selecting an invalid model for policy analysis or of basing policy on a suite of models. It is shown that such costs can be substantial, even when robust policies are adopted.

### 4.1 Costs when an invalid model is selected

Let us suppose that we choose to implement a monetary policy rule that is optimal in one of the models considered. We might have selected this rule because our analysis could have suggested that this policy rule is the most robust rule, i.e. it will perform better than any of the other rules if the valid model turns out to be different than the one implying the rule; cf. Hansen and Sargent (2001). An invalid model and the implied policy rule may also be adopted (unknowingly) if e.g. criteria such as transparency and parsimony of a model are emphasized at the expense of a model's data consistency.

Figure 8 examines the potential costs of choosing rules that are optimal in PCM and in PCMr in response to the supply shock when ECM is by assumption the valid model; the former rules are referred to as the PCM-rule and the PCMr-rule, respectively.<sup>16</sup> The upper frame of Figure 8 depicts the outcomes in terms of standard deviations of inflation and the output gap when the PCM-rule and PCMr-rule are implemented in ECM. For comparison, the outcomes under (suboptimal and optimal) rules based on ECM itself, referred to as ECM-rules, are also plotted. The lower frame of

<sup>16</sup>For the sake of brevity, we do not present results for the cases where PCM and in PCMr are assumed to be valid models.

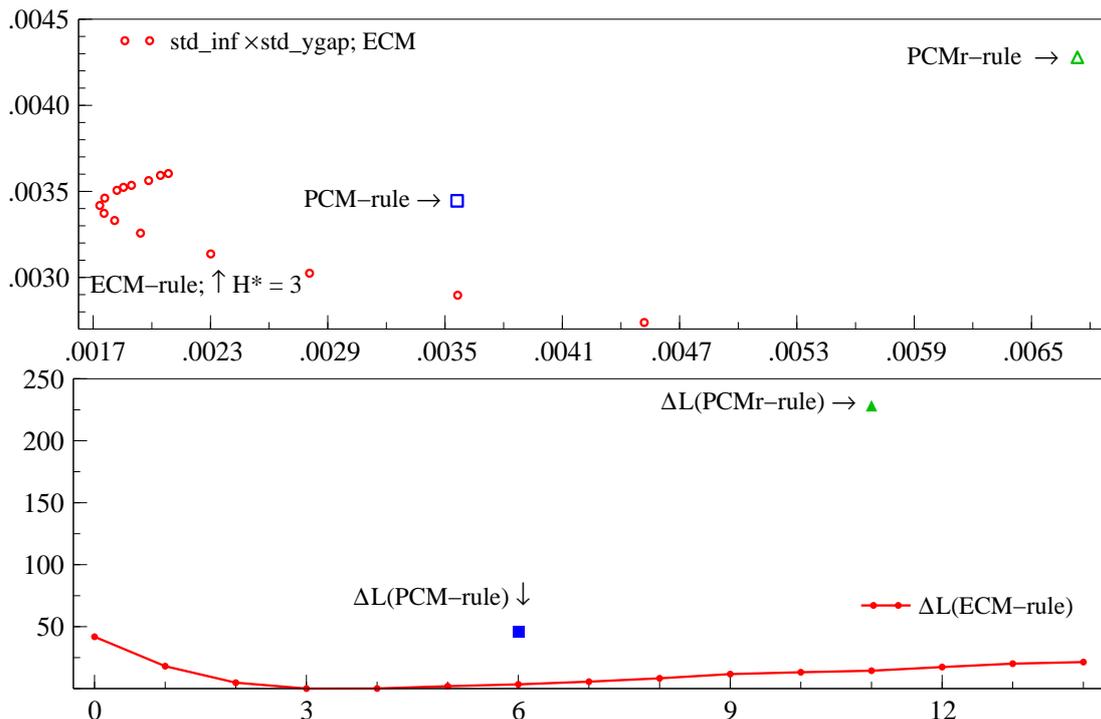


Figure 8: *Economic performance and relative losses (in %) under different rules in response to the supply shock when ECM is the valid model. In the upper column, we plot outcomes in terms of standard deviations of the inflation gap (vertical axis) and output gap conditional on rules that would have been optimal if PCM or PCMr was the valid model. For comparison, we also reproduce the outcomes associated with (policy) horizon-specific rules based on ECM itself; cf. Figure 6. The policy horizon is varied in the range of 0-14; thus outcomes under 15 rules based on the valid model itself are reported. In the lower frame, we report values of the relative loss function (in %) under the optimal rules assuming the validity of PCM and PCMr. The relative losses are calculated relative to the optimal loss if the optimal rule based on ECM itself was implemented; cf. (11) for a definition. The lower frame also reproduces values of the relative loss for different policy horizons under ECM itself; cf. Figure 6.*

the figure presents the relative losses under the ECM-rules as well as under the (optimal) PCM-rule and PCMr-rule. The losses are measured relative to the level under the optimal ECM-rule:  $L(\text{ECM-rule}; \text{ECM})$ , defined by  $H = 3$ . For example, the relative loss under the PCMr-rule is defined as:

$$\Delta L(\text{PCMr-rule}) \equiv \frac{L(\text{PCMr-rule}; \text{ECM}) - L(\text{ECM-rule}; \text{ECM})}{L(\text{ECM-rule}; \text{ECM})}, \quad (11)$$

where  $L(\text{PCMr-rule}; \text{ECM})$  expresses that the value of the loss function (6) has been obtained by implementing the rule that is optimal in PCMr, in ECM. As shown above,  $H^* = 11$  defines the optimal rule conditional on PCMr, while  $H^* = 3$  defines the optimal rule conditional on ECM. As above, we calculate the losses assuming  $\lambda = 0.5$ ; cf. equation (10).

Figure 8 shows that if ECM is the valid model, while the policy rules are based on PCM and PCMr, both inflation and the output gap will become relatively more unstable, especially if the PCMr-rule is implemented. We note that under the PCM-rule, the loss would be 46% higher

relative to that under the optimal ECM-rule. Under the vertical PCM-rule, however, the relative loss would be much higher: 228%.

It also seems that choosing the valid model and the corresponding rule is much more important than choosing the optimal policy horizon, and thereby the corresponding interest rate path. The lower frame of the figure shows that the relative losses under both the PCM-rule and particularly under the PCMr-rule are higher than under rules that are based on ECM but are defined by policy horizons that differ from the optimal policy horizon, 3. It can be shown that, at least for policy horizons within the range of 0–20 quarters, the relative loss under such rules never exceeds 42%, which is for  $H=0$ .

Even if we follow the Brainard principle, the loss owing to the model being invalid would be considerable. For example, if the PCMr-rule was a suboptimal rule defined by e.g.  $H=20$  quarters, rather than 11 quarters, while conditioning on PCMr, and the PCM-rule was a suboptimal rule defined by  $H=8$  quarters conditioning on PCM, costs owing to implementing them in ECM would have been lower, but still considerable. The relative loss would be 157% under the PCMr-rule defined by  $H=20$  and 37% under the PCM-rule defined by  $H=8$ . By choosing 20 and 8 quarters, instead of 11 and 6, respectively, one chooses a relatively longer horizon, higher degree of smoothing, and accordingly a weaker initial response.<sup>17</sup> In addition to costs captured by the relative loss function, there could be possible additional costs in the form of credibility loss owing to inflation not being close to the target at the policy horizons preferred by invalid models.

## 4.2 Costs when policy is based on a suite of models

We now assume that the economy is adequately characterized by one of the three models considered. However, we do not distinguish between the models and consider them equally probable, and hence also the associated monetary policy rules as equally relevant. Therefore, instead of implementing one specific monetary policy rule in the face of a given shock, we implement an ‘average-rule’. Specifically, we define the required interest rate response,  $\beta_s$ , in the rule (8) as 1/3 of the sum of the  $\beta_s$ s implied by the three models and then determine the response for different horizons by (8), as above, for a transitory shock  $\phi = 0$ . This is consistent with a Bayesian approach to formulating a robust policy in the face of model uncertainty.

Figure 9 presents the outcome of the average-rule *if* the economy is actually characterized by ECM. For comparison, we also present the performance under the “valid rule”, i.e. the rule implied by ECM. The upper frame depicts the curves presenting the trade-off between stability in inflation and output gap, while the lower frame depicts the loss under both rules relative to the loss under the optimal ECM-rule, defined in Section 4.1.

<sup>17</sup>The policy horizon of 20 and 8 would be the optimal horizons in the hypothetical case where we had to derive the initial interest rate responses using PCMr and PCM, respectively, and implement the resulting rules in ECM.

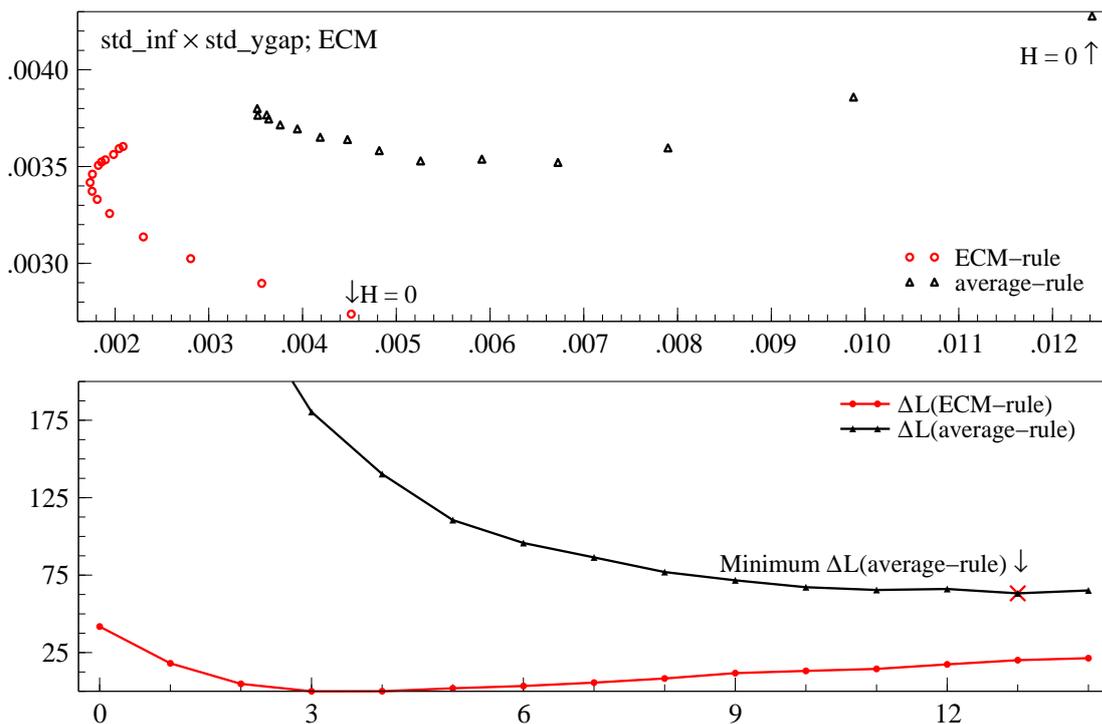


Figure 9: *Economic performance and relative losses (in %) under the ‘average-rule’ in response to the supply shock when ECM is the valid model. In the upper column, we plot outcomes in terms of standard deviations of the inflation gap (vertical axis) and output gap conditional on the average-rule for different policy horizons (horizontal axis). For comparison, we also reproduce the outcomes associated with (policy) horizon-specific rules based on ECM itself; cf. Figure 6. The policy horizon is varied in the range of 0–14; thus outcomes under 15 rules based on the average-rule as well as ECM itself are reported. In the lower frame, we report values of the relative loss function under the average-rule as well as the ECM itself. The relative losses are calculated relative to the loss if the optimal rule based on ECM itself was implemented; cf. equation (11) for a definition.*

It appears that an average-rule will lead to much higher variation in both inflation and the output gap than under an ECM-rule, irrespective of the policy horizon; in the figure this is shown only for policy horizons in the range of 0–14 quarters. Under average-rules, which can be defined by different policy horizons, there is a trade-off between price and output stability for policy horizons above 4 quarters. The poor performance of average-rules is mainly because they suggest a much stronger policy response than favoured by the valid model, by assumption, ECM. Relatively short policy horizons under an average-rule are especially destabilizing because they suggest relatively strong immediate interest rate hikes; cf. Figure 2. A comparison of the trade off curves in Figure 9 suggests that the performance of an average-rule will be considered inferior to that of an ECM-rule, irrespective of preferences for output stabilization.

The lower frame of Figure 9 shows relative values of the loss function under both (suboptimal and optimal) ECM-rules and average-rules. The difference between relative losses indicates the costs of implementing the average-rule relative to that of implementing ECM-rules. It appears that the loss will be higher, the lower is the policy horizon under an average-rule. Notably, if

we implement an average-rule, the loss when ECM is valid will tend to decrease with the policy horizon. Thus, even though we choose the policy horizon for which the loss under an average-rule will be at a minimum, which is at  $H=13$ , the relative loss under the average-rule will be ca. 63% higher than that under the optimal ECM-rule, defined by  $H=3$ . In addition, it must be borne in mind that if an average-rule consistent with one's preferences is implemented, by choosing one of the policy horizons considered, it will generally make inflation deviate from its target rate. Also, possible costs of basing policy on a suite of models may become higher if the suite does not include the valid model.

As observed above, it also seems more important to choose the rule consistent with the valid model than choosing the optimal policy horizon. We note that under an ECM-rule defined by  $H \neq H^* = 3$ , the relative loss does not exceed that under an average-rule even when the relative loss under an average-rule is at its minimum, i.e. when  $H=13$ .

## 5 Conclusions

This paper sheds light on the importance of selecting the valid model for monetary policy analysis. A model can be selected on the basis of several desirable model properties, including how well a model's properties and functioning can be communicated to a wider audience and the robustness of a model's policy implications to potential deficiencies of a model. Model choice may involve trading off one set of desirable properties with another. However, our empirical analysis suggests that letting an empirically invalid model influence monetary policy can lead to policy mistakes that may have substantial costs. Hence, the analysis suggests that a model for policy analysis should necessarily be empirically valid and calls for caution when compromising this property for other desirable model properties, including robustness.<sup>18</sup>

The empirical analysis in this paper is based on three alternative econometric systems for wage and price inflation for Norway that have been embedded as the supply side in a macroeconomic model for medium-term analyses. We have undertaken an extensive econometric evaluation of the three systems to check their congruency with available data. It has been shown that such an evaluation can enable one to choose a model that is more likely to present a valid characterization of the economy under study than models that appear at odds with available evidence. We have also argued that data revisions should not be considered a nuisance, but sources of information that can be utilized to expose the inadequacy of models and to distinguish between genuine and spurious empirical relationships between variables.

We find that econometric differences bear heavily on (model-based) policy recommendations and are thus not merely of academic interest. First, our empirical analysis suggests that differences

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<sup>18</sup>This is consistent with e.g. [Granger \(1992\)](#) who states that "...it should be generally agreed that a model that does not generate many properties of actual data cannot be claimed to have any 'policy implications'..."

in model specifications and even in parameter values across models can lead to widely different policy implications. Interestingly, it appears that imposing a set of parameter restrictions may have stronger influence on policy implications than choosing a different functional form of the model. And second, monetary policy based on a model that turns out to be an invalid characterization of the economy under study may lead to substantial losses in terms of economic performance, even when policy is guided by gradualism in line with the Brainard principle. Moreover, basing policy on a suite of models can also lead to relatively large losses, even when the suite of models contains the valid model by assumption. Actually, possible losses from basing policy on such practice appear greater than possible losses from choosing a suboptimal policy horizon and the associated interest rate path in the face of a shock.

Estimates can always be contested in economics. Thus, further research using alternative models and alternative ways of characterizing monetary policy would be useful in assessing the robustness of our results. Nevertheless, it seems reasonable to conclude that there may be huge gains from utilizing empirical evidence efficiently to select the valid model and parameter estimates. In this endeavour, there may also be large gains from improving data quality and timely availability of data as well as further research on improving tools for the efficient use of available information.

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## A Data definitions

### A.1 Notes

1. Unless another source is given, the time series have been extracted from databases maintained by Norges Bank (The central bank of Norway).
2. The variables are precisely defined in Rikmodnotat 140, Norges Bank, Research department, 19th April 1999. The variables are named as indicated in hard brackets [.] below.
3. Several of the variables refer to the *mainland economy*, defined as the total economy excluding oil and gas production and international shipping.
4. In the main text, impulse dummies are denoted  $iy y q x$ , 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 0 in all other quarters.

## A.2 Definitions

*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 base year (1991) prices. Mill. NOK.

*H* Normal working hours per week. [NH]

*P* Consumer price index. 1991 = 1. [CPI].

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

*Y* Total value added at market prices in the mainland economy. Fixed base year (1991) prices. Mill. NOK. [YF].

*PR* Mainland economy value added per man-hour at factor costs, fixed base year (1991) prices. Mill. NOK. [ZYF].

*RS* 3 month Euro-krone interest rate. [RS].

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

$\tau 3$  Indirect tax rate. [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. [UTOT].

*W* Nominal mainland hourly wages. Constructed from time series in the database as:

$$W = WIBA \times TWIBA + WOTVJ \times (TWTV + TWO + TWJ) / TW F$$

*Wdum* Composite dummy for wage freeze: 1 in 1979q1, 1979q2, 1988q2 and 1988q3.

*Pdum* Composite dummy for introduction and removed of direct price regulations. 1 in 1971q1, 1971q2, 1976q4, 1979q1, -1 in 1975q1, 1980q1, 1981q1, 1982q1. Zero otherwise.

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