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by

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What horizon for targeting inflation?

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December 7, 2007

Abstract

We investigate optimal horizons for targeting inflation in response to different shocks and their properties under alternative preferences of an inflation-targeting central bank. Our analysis is based on a well specified macroeconometric model of Norway, but we examine how alternative specifications of its key equations would affect our results. We find that the optimal horizon is highly shock-specific, precluding general conclusions for demand and supply shocks. An extension of the horizon with concern for output and/or interest rate fluctuations beyond some shock-specific level proves counterproductive. The size of a given shock does not affect the horizon unless the central bank cares about interest rate volatility, while its sign does not matter unless the model is non-linear. The optimal horizon in response to a combination of shocks cannot be derived from those for each of the shocks, as different shocks may amplify or modify the effects of each other. In this case, however, sources of shocks as well as their sizes and signs become relevant, leading to complex dynamics of inflation and output. Successful inflation targeting in such cases may require a complex interest rate response. The optimal horizon generally increases with the degree of persistence in a shock and decreases with the strength of stabilisation mechanisms in the model.

Keywords: *Monetary policy, Inflation targeting, Horizon.*

JEL Codes: *C53, E31, E52.*

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1 Introduction

The horizon for achieving the inflation target is a key element in the design of monetary policy under an inflation-targeting regime. The horizon determines the monetary policy response to shocks. It is especially important for deriving an interest rate path consistent with the preferred inflation path towards its target; a small but increasing number of central banks publicly announce such interest rate paths. Moreover, communication of the horizon is crucial for anchoring inflation expectations at the target in the medium run and the accountability of monetary policy authorities.

Inflation-targeting central banks tend to adopt short rather than long horizons, partly to avoid compromising their credibility as inflation targeters. Many inflation-targeting central banks have either preannounced a fixed horizon of 1 or 2 years or a variable horizon of 1–3 years; see Roger and Stone (2005). Some central banks including Norges Bank, however, refrain from quantifying the horizon and state that they will seek to bring inflation close the target in the 'medium run', which is commonly understood to extend not too far in the future. Choice of a fixed relatively short horizon or range is often based on estimated time lags from interest rate changes to their main effects on inflation.

The relevant literature, however, suggests that the horizon should also depend on the nature of shocks and their properties, particularly size and persistence. It also suggests that the horizon should depend on the extent to which the central bank pursues other policy objectives in addition to the inflation target; see Svensson (1997) and Ball (1999). It is often argued that the optimal policy horizon becomes longer the greater the weight is placed on secondary objectives like smoothing output and/or interest rate fluctuations in the authorities' objective function. It follows that, due to differences in preferences for output stabilisation, the optimal horizon in response to a shock may vary across economies even if they become exposed to the same shock.

The small number of existing empirical studies do not seem to be particularly helpful in pinpointing the optimal horizons in response to different shocks and preferences for output stabilisation. So far, mostly relatively small VAR models and systems of equations for aggregate demand, aggregate supply, and (occasionally) the exchange rate have been used to derive the optimal horizons in the face of demand and supply shocks; see e.g. Batini and Nelson (2001) and Smets (2003). A drawback of using such highly aggregate models is that one can only derive optimal horizons for a few aggregate shocks. A disaggregate model allowing for different kinds of demand and supply shocks is required to estimate the corresponding optimal horizons, since the trade-off between inflation and output volatility may differ across shocks. Hence, if the optimal horizon is shock-dependent, and there are large costs associated with deviating from the optimal horizons, as suggested by e.g. Smets (2003), it may prove costly to infer the optimal horizons corresponding to various types of demand and supply shocks from those for the aggregate demand and supply shocks.

Second, optimal horizons corresponding to different shocks have been shown to be highly model-dependent; see e.g. Batini and Nelson (2001) for evidence based on the UK data. Therefore, one may argue that optimal horizons in response to different shocks should be derived from credible empirical models.

Third, optimal horizons suggested by some studies also seem rather long to be reconciled with horizons actually communicated by inflation-targeting central banks; see Roger and Stone (2005). In e.g. Smets (2003), where the evidence is based on the Euro-area data, the optimal horizon (in the face of shock to prices) ranges from a few years to infinity depending on assumed concern for output and interest rate fluctuations.

Finally, one may also question the realism of a monotonic increase in optimal horizons with concern for e.g. output fluctuations. When disturbed by a shock, an economy may be able to adjust and reach its equilibrium over time through several built-in stabilisation mechanisms. Intuitively, the adjustment period should not exceed the life spans of different forms of rigidities, especially those of nominal rigidities. An active monetary policy may help the economy reach its equilibrium at a faster pace than on its own through appropriate changes in nominal interest rates. One may therefore not expect optimal horizons to exceed the life spans of different rigidities. Otherwise, monetary policy would be prolonging the economic disequilibrium caused by shocks beyond their own "life spans" which can seem inconsistent with strong preferences for output stabilisation. The evidence of a monotonic increase in the optimal horizons beyond reasonable time spans could be an artefact of models employed with weak if any stabilisation mechanisms besides that of monetary policy itself.

We investigate the optimal policy horizons and their properties in the face of different shocks using an econometrically well specified model of the Norwegian economy based on quarterly data.[1] We assume that the central bank is a flexible inflation targeter, such as Norges Bank; see Norges Bank (2007). Specifically, it is assumed that the central bank decides on an interest rate path that minimizes variability in deviations from the inflation target and the variability in the output gap, while ensuring that inflation will reach its target in the foreseeable future. The primacy of achieving the inflation target in the 'medium run' while accepting short-run deviations from the inflation target to promote output stability seems consistent with the practice of many inflation targeting central banks; see e.g. Tuladhar (2005), Smets (2003), Meyer (2004), Blinder (2006) and Giavazzi and Mishkin (2006).

That is, such central banks seem to accommodate concern for output stabilisation by choosing

[1] The model used is a version of the model presented in Bårdsen *et al.* (2003, 2005) which is documented in Akram and Eitrheim (2006). The 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 this macroeconometric model is partly motivated by this call.

an appropriate horizon for achieving an implicit or explicit inflation target. Accordingly, one may define the optimal target horizon as the time at which it is least costly, for a given loss function, to bring inflation back to target after a shock; cf. Batini and Nelson (2001).

To derive optimal horizons within such a monetary policy framework using the econometric model, we employ the procedure suggested in Akram (2007). This procedure seems to characterise the actual process of deriving interest rate and inflation rate paths quite well and makes it easy to conduct such analyses when employing macroeconometric models, irrespective of their size. This procedure focuses on the optimal policy horizon, which is defined as the time at which it is least costly to bring the nominal policy rate back to its neutral rate. In practice and in the model used, the optimal policy horizon is closely linked to the optimal target horizon, as defined above.[2]

The model employed is more extensive than the models used in most of the previous studies. It therefore enables us to investigate optimal horizons associated with several kinds of demand and supply shocks. In addition, the quarterly base of our model makes it possible to derive the optimal horizons more precisely than models based on annual data. Such precision is important if there are relatively large costs associated with deviating from an optimal horizon. Our model also pertains to a relatively more open economy than e.g. the UK and the Euro area, which are the subjects of two notable studies Batini and Nelson (2001) and Smets (2003), respectively. If the exchange rate channel plays a relatively stronger role in our model, the optimal policy horizons for different shocks are likely to be shorter than those reported by these studies.

Moreover, our model has more built-in stabilisation mechanisms than models used in much of the previous work on the topic. Ours is an equilibrium-correction model characterising dynamic adjustment of endogenous variables to their long-run equilibrium paths. This feature may also contribute to relatively shorter horizons. On the other hand, our model does not have forward-looking features. This may contribute to relatively longer horizons than implied by models with forward-looking features.

We use the model to investigate several issues in addition to those studied earlier. We investigate effects of the source, size, sign and persistence of single as well as combined shocks on the optimal policy horizon. The investigation also shed lights on how concern for output stabilisation and/or interest rate volatility affects optimal policy horizons. Moreover, we illustrate the model dependence of the optimal horizons by altering key equations of the model rather than limiting such an exercise to changes in specific parameters, as in previous studies. This exercise highlights the role of adjustment mechanisms in the model and their influence on optimal policy horizons.

Our analysis brings forth the important role of the transmission lags of shocks relative to those of monetary policy. The horizon is often chosen on the basis of transmission lags from a

[2] Monetary Policy Reports of e.g. Norges Bank and Sveriges Riksbank typically show that forecasts of inflation and policy interest rates converge with the target inflation and some level of the neutral interest rate, respectively, at about the same time.

monetary policy shock to the economy, while transmission lags from shocks to the economy are often neglected. Our study suggests that both kinds of lags must be viewed in relation to each other, to better synchronise stabilising effects of monetary policy to destabilising effects of shocks.

Our results regarding optimal horizons for transitory shocks are consistent with those usually communicated by central banks while those for relatively persistent shocks call for substantially longer horizons than 3–4 years. It appears that evidence of relatively long (optimal) horizons reported by some previous studies can be reproduced if we weaken or switch off the equilibrium-correction features of our model. Our results do not support a generally positive relationship between optimal horizons and the degree of concern for output stability. Specifically, optimal horizons becomes invariant to concern for output stability above some shock-specific degrees.

Finally, our results support the view that monetary policy need not always prove to be stabilising; cf. Friedman (1961). The intuition behind this result is that when there are numerous shocks with different signs and sizes, their combined effects on the economy can be relatively complex. In such cases, a rather simple monetary policy response, e.g. a contractionary or expansionary monetary policy followed by a gradual return to a neutral monetary policy stance, can prove counterproductive, as it can turn out to e.g. amplify the effects of the shocks in some periods. Such a policy response can also be unnecessary if the effects of different shocks outweigh each other. Accordingly, we find that monetary policy turns out to be counterproductive in a non-negligible number of cases, and warrants a lot of information and fine-tuning to get the response right. This is consistent with Friedman's argument that monetary policy in the face of e.g. "long and variable lags" can prove to be destabilising.

The paper is organised as follows. Section 2 characterizes the monetary policy framework. Section 3 sets out a stylised version of the macroeconometric model. Sections 4–7 present our results and analysis while Section 8 concludes. The appendix includes data definitions and alternative wage and price systems.

2 Monetary policy objectives and the interest rate rule

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

$$L_\tau = V(\pi_t - \pi^*) + \lambda V(y_t), \tag{1}$$

subject to the constraint that the conditional mean of inflation in period $\tau + H$ is close to its constant target rate, π^*:

$$\mathsf{E}_\tau \pi_{\tau+H} \approx \pi^*. \tag{2}$$

$V(\cdot)$ is a variance function while $\pi - \pi^*$ denotes the inflation gap, y denotes the output gap and λ indicates the degree of concern for fluctuations in the output gap relative to that for fluctuations in inflation; t is a period indicator. The loss function is a reformulation of a quadratic loss function assuming that the discount factor is close to one. E_τ is an expectation operator conditional on the information at time τ.

We use H to represent the policy horizon, which we define as the number of periods of appropriate length, here quarters, during which the policy *interest rate* will deviate from its neutral value and stimulate or cool off the economy. H can take on any discrete value from zero onwards. Thus, the precise policy horizon, when measured as the number of periods, would be $H + 1$, because $H \geq 0$.

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, as shown in Section 4.2.1.[3] Inflation will typically converge asymptotically to its target rate in the wake of a shock in a dynamic model. Hence, imposing an exact target horizon is generally not meaningful.[4] We assume that when the policy interest rate has almost converged with its reference value in period H, the inflation target will be largely achieved. This seems to be consistent with published future paths of interest rates and inflation, as noted earlier. Also, our approach would not lead to overly gross approximations of the optimal target horizons, in comparison with those based on alternative suggestions in the literature; cf. Batini and Nelson (2001).[5]

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 (2) for different policy horizons, i.e. H values. Then, from this set of interest rate paths, it selects and implements the interest rate path, and the corresponding policy horizon, that would minimise the loss function (1).

However, there can be numerous interest rate paths that satisfy the constraint (2) for every possible value of H. By only considering interest rate paths that adhere to some reasonable pattern, however, the set of relevant interest rate paths can be limited to the number of policy horizons (H

[3] In several studies, including Batini and Nelson (2001), policy horizon is equated with target horizon, as defined here.

[4] Beside its simplicity, the procedure allows us to achieve price stability asymptotically rather than exactly at a particular horizon. The latter is apparently an unrealistic feature of e.g. Smets (2003) who models the price stability constraint as an *exact* forward-looking constraint on either inflation or the price level at a particular horizon. Imposing an exact constraint at a particular horizon also gives rise to unattractive interest rate volatility at that horizon.

[5] Batini and Nelson (2001) suggest two operational definition of an optimal target horizon: an absolute and a relative horizon concept. They define an absolute horizon as the number of periods ahead at which inflation has returned permanently to within a specific target range, i.e. of ± 0.1 percentage point, following a shock today. The relative horizon concept is based on what fraction of a shock's effect policy has succeeded in eliminating. They define the relative horizon as the number of periods ahead at which 90% of the peak effect of the shock on inflation has been extinguished. In contrast to the relative horizon, the absolute horizon depends on the size of the shock. Another way to define target horizon is to associate it with the time period when inflation "first touches-down" at its target rate in the wake of a (positive) shock.

We essentially define policy and target horizons as relative horizons. We use the relative concept for the interest rate as well as the inflation rate, while specifying the convergence criteria explicitly for only the interest rate. The extent of convergence of inflation with its target rate at the policy horizon will depend on the convergence criteria for the interest rate, but varies across shocks.

values) considered by the central bank.

We assume that the central bank initiates changes in the interest rate when the shock occurs at time τ and thereafter allows the interest rate to return gradually towards its neutral rate, (i_0), as commonly observed; see e.g. Sack and Wieland (2000).[6,7] Then, if the model is stable and linear, an interest rate path corresponding to a specific policy horizon H can be obtained from the following interest rate rule:

$$i_{\tau+m} = i_0 + (1-\varrho_H)\frac{\beta_\varepsilon}{(1-\phi)}\varepsilon_\tau + \varrho_H(i_{\tau+m-1} - i_0) \quad ; \; m = \; 0, \; 1, \; 2, ..., H, \; H+1, ... \tag{3}$$

The response coefficient $\beta_{\varepsilon,H} \equiv (1-\varrho_H)\beta_\varepsilon/(1-\phi)$ determines how much the interest rate must deviate initially from the neutral rate to offset inflationary effects of a shock ε_τ. This initial deviation is thereafter eliminated gradually, depending on the value of an interest rate smoothing parameter ϱ_H.[8] Both the response coefficient and the degree of smoothing depend on the policy horizon, as indicated by the subscript H.[9] ϕ 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 requires a stronger initial response $(\beta_{\varepsilon,H})$ than a transitory shock (for which $\phi = 0$) for a given degree of interest rate smoothing (ϱ_H) and β_ε.

The value of β_ε 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; see Akram (2007). β_ε can be considered a constant (shock- and model-specific) parameter, if the transmission mechanism of the shock and interest rate 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, ϱ_H. It is defined as $\delta^{1/(H+1)}$ and takes on a value in the range of $(0, 1)$ depending on H (for a chosen fraction δ). Interest rates are considered converged with the neutral rate when just a fraction δ of the initial interest rate deviation (from the neutral rate remains. δ also determines how close inflation is to its target when monetary policy becomes neutral; cf. constraint (2)).

[6]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.

[7]By restricting movements of the interest rates, one loses some control over the movements of the inflation rate, however. 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 neutral rate. This may seem at odds with stylised facts, though.

[8]Rule (3) can be seen as a special case of the general interest rate rule in Akram (2007) where interest rates are moved gradually away from the neutral rate as well as towards the neutral rate. The general rule allows one to optimally determine the period over which the interest rate should be raised and reduced. For simplicity, however, when implementing rule (3), we assume that the initial increase in the interest rate and the shock occur over four quarters. Our conclusions would not change notably if we determine the horizon for the initial increase optimally for every shock.

[9]This rule resembles a Taylor-type rule with interest rate smoothing except that it is the determinant of (excess) inflation, i.e. ε_τ, that enters the rule rather than inflation itself; see Taylor (1999) and the references therein.

The degree of smoothing increases with the policy horizon in a concave fashion since $\varrho_H = \delta^{1/(H+1)}$. 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 $\varrho_H = \delta^{1/(H+1)} \longrightarrow 1$ when $H \longrightarrow \infty$. The case $H = 0$ refers to the case when the policy maker allows interest rates to deviate from their reference rate in just a single period.

However, 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 $(1 - \varrho_H)\beta_\varepsilon/(1 - \phi) \longrightarrow 0$ when $H \longrightarrow \infty$ since $\varrho_H \longrightarrow 1$. This suggests that if a very long policy horizon is allowed, the interest rate needs to deviate only marginally from its neutral/reference value, but this deviation has to be quite persistent.

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 response coefficient $\beta_{\varepsilon,H}$ becomes equal to β_ε. In contrast, a short horizon may imply a particularly large deviation from the neutral interest rate in the face of a persistent shock.

Clearly, the parameters characterising the interest rate rule depend on the policy horizon (H), ceteris paribus. 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.

It follows that once the rule (3) is implemented in the model, the optimal policy response to a shock can be found by minimising the loss function (1) with respect to H. The optimal value of H will then define the optimal interest rate change, β_{ε,H^*}, the optimal degree of smoothing, ϱ_{H^*}, as well as the optimal level of loss, L, conditional on a given macroeconometric model.

We are particularly interested in analysing the effect of shock ε on the loss L and consequently the policy, represented by the policy horizon (H). We therefore express the loss function (1) as an explicit function of H and ε:

$$L \equiv L(H; \varepsilon). \tag{4}$$

It follows that the optimal policy horizon can be defined as the time at which it is least costly, for a given loss function, to bring interest rates as well as inflation back to their reference values after a shock. The corresponding target horizon can be called optimal because of its close relationship with the optimal policy horizon and the optimal interest rate rule.

In the empirical analysis we focus on the relative loss, $\Delta L(H, \varepsilon)$, to illuminate the effect of policy horizon on the loss $L(.)$ conditional on a given shock. We define the relative loss as:

$$\Delta L(H; \varepsilon) \equiv \frac{L(H; \varepsilon) - L(H^*; \varepsilon)}{L(H^*; \varepsilon)}. \tag{5}$$

Here, $L(H; \varepsilon)$ denotes the level of loss by choosing H conditional on a specific shock ε, while

$L(H^*;\varepsilon)$ expresses the loss under an optimal policy horizon conditional on the shock ε. It follows that $\Delta L(H;\varepsilon) > 0$ for $H \neq H^*$ while $\Delta L(H;\varepsilon) = 0$ when $H = H^*$, assuming the loss function is continuous in H and there is a unique optimum.

3 The model

Our macroeconometric model of Norway is a version of the model developed in Bårdsen *et al*(2003, 2005) that has been documented and employed in several studies including Akram and Eitrheim (2006).[10] The model pertains to the Norwegian mainland economy, i.e. exclusive of its petroleum sector. 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. Monetary policy, represented by short-term nominal interest rates, has direct effects on the three asset prices, credit and aggregate demand, but it is neutral in the long run. The model may be considered a backward-looking model in the sense that the expectations formation process is not explicitly modeled.

The model characterises a stable (economic) system where the effects of transitory shocks eventually die out. The model is (log) linear and estimated on quarterly aggregate data for the period 1972–2001. It is econometrically well specified, with parameters that seems to be invariant to changes in monetary policy over the sample. The model's statistical properties are documented in Akram and Eitrheim (2006) and further evidence on its properties can be found in e.g. Bårdsen *et al.* (2003, 2005). We have also reestimated the model on an extended sample that ends in 2006q4 and not discovered notable changes in the parameter estimates of key equations in the model. 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 (1995). In the following, we assume that the model will remain invariant to the monetary policy decisions we consider, i.e. we consider them too modest to induce noticeable changes in the model; cf. Leeper and Zha (2003).

To highlight the main features of the model, we present a stylised version of it in equations (6)–(13), obtained by following the approach of Bårdsen (2005). Here, effects of exogenous variables such as foreign output, interest rates, oil prices and government expenditures have been suppressed. Our results, however, are based on the complete model, as presented in Akram and Eitrheim (2006), with its rich dynamics and embedded attention to institutional and structural changes in the Norwegian economy since the 1970s.

Below, all variables except nominal interest rates (r) are in natural logarithms. Δ denotes the first difference operator, and foreign variables are denoted by starred superscripts. The nominal

[10] Available from http://www.norges-bank.no/publikasjoner/arbeidsnotater/pdf/arb-2006-07.pdf.

effective exchange rate (in logs denoted e) expresses the number of domestic currency units per unit of foreign currency, while $q \equiv (e + p^* - p)$ denotes the log level of the real exchange rate. ℓ represents (log of) nominal credit demand, while pr denotes labour productivity; see Appendix B for precise definitions of the variables.

$$\text{Aggregate demand: } \Delta y_t = 0.02\Delta(s-p)_t + 0.3\Delta q_t - 0.2\left[y + (r - \Delta_4 p) - 0.5q - 0.1(ph-p)\right]_{t-1}, \tag{6}$$

$$\text{Real credit: } \Delta(\ell - p)_t = 0.1\Delta y_t + 0.05\Delta(ph-p)_t + 0.01\Delta(s-p)_t - 0.05\left[(\ell-p) - 0.5y + 3r - (ph-p)\right]_{t-1}, \tag{7}$$

$$\text{House prices: } \Delta ph_t = 1.1\Delta p_t + 0.05\Delta s_t + 0.2\Delta y_t + 1.0\Delta(\ell-p)_t - 1.4\Delta r_t - 0.1\left[(ph-p) - 0.5y - 0.25(\ell-p) + 4(r-\Delta p)\right]_{t-1}, \tag{8}$$

$$\text{Equity prices: } (\Delta s - r)_t = 0.9(\Delta s^* - r)_t - 5\Delta r_t\ , \tag{9}$$

$$\text{Exchange rate: } \Delta e_t = -0.5\Delta r_t - 0.1(r - r^*)_t - 0.1\left[e - (p - p^*)\right]_{t-1}, \tag{10}$$

$$\text{Unemployment: } \Delta u_t = -0.1u_{t-1} - 2.8\Delta y_t, \tag{11}$$

$$\text{Wages: } \Delta w_t = 0.7\Delta p_t - 0.1[w - p - pr + 0.1u]_{t-1}, \tag{12}$$

$$\text{Consumer prices: } \Delta p_t = 0.4\Delta w_t + 0.05\Delta y_t - 0.06\left[p - 0.7(w - pr) - 0.3(e + p^*)\right]_{t-1}. \tag{13}$$

Aggregate demand (y_t) is characterised in equation (6). Equity prices and house prices, in particular, have wealth effects on aggregate demand; cf. Kiyotaki and Moore (1997). In addition, aggregate demand is affected by the real interest rate ($r - \Delta_4 p$) and the real exchange rate q. Thus, a change in the nominal exchange rate would also directly affect aggregate demand.[11]

Equity prices and house prices have collateral effects on (real) credit demand; see equation (7). Credit demand also depends on income (represented by actual output (y_t)) and interest rates, as in a standard money-demand equation.

House prices in real terms are mainly determined by income, interest rates and credit; see equation (8). Equity prices also have some short-run effects on house prices. Credit affects the economy through its effects on house prices.

Nominal equity prices are modeled in light of the capital asset pricing model (CAPM) by treating the Norwegian stock market portfolio as a "single" asset and the international stock market portfolio as the "market portfolio". The relationship obtained in equation (9) suggests

[11] We have not found any significant direct effect of oil prices on aggregate demand (of the mainland economy). However, oil prices indirectly affect aggregate demand through their positive effects on equity prices and the nominal exchange rate; see the complete equations in Akram and Eitrheim (2006). One reason for the absence of direct oil price effects could be that the effects of oil prices are already taken into account by the government consumption variable, which is exogenous (and hence is suppressed in equation (6), but appears explicitly in the detailed documentation of the model in Akram and Eitrheim (2006)). Norwegian oil revenues are invested abroad while the return on the petroleum assets abroad is used by the government in accordance with a fiscal policy rule.

that excess returns on the Norwegian stock market portfolio $(\Delta s - r)_t$ move closely with excess returns on the international market portfolio. There is a strong negative relationship between changes in interest rates and excess returns on the domestic stock market. In addition, an increase in oil prices (here suppressed) has a positive effect on equity prices, and thereby on aggregate demand, credit growth and house prices; see equations (6)–(8).

The nominal exchange rate appreciates when the interest rate and/or the interest rate differential increases, ceteris paribus; see equation (10). It also reacts to correct deviations from PPP and thereby contributes to stabilising the real exchange rate. Also, a rise in oil prices (here suppressed) tends to appreciate the nominal exchange rate in the short run. In the long run, the nominal exchange rate reflects the difference between domestic and foreign prices and any difference between domestic and foreign interest rates. Accordingly, domestic inflation becomes fully reflected in the nominal exchange rate in the long run.

The unemployment rate u_t follows output growth in the short run, as in an Okun's law relationship; see equation (11). In addition, it reverts slowly towards its equilibrium rate, which also depends on an intercept term (here suppressed).

There is a partial pass-through of consumer price inflation to nominal wage growth (Δw) in the short run; see equation (12). In each period, nominal wages adjust towards their long-run relationship where there is a full pass-through of consumer prices and productivity. However, the mark-up of wages on prices and productivity falls with the unemployment rate.[12]

In the short run, consumer price inflation varies with changes in aggregate demand and nominal wage growth; see equation (13). In addition, it adjusts to correct deviations from the long-run relationship for consumer prices. In the long run, consumer prices reflect a weighted average of domestic and imported costs, represented by unit labour costs and import prices $(e + p^*)$.

3.1 Transmission lags from policy changes and shocks

In our monetary policy framework, the success of stabilisation policy depends on whether one is able to synchronise the (stabilising) effects of monetary policy impulses with those of shocks. Monetary policy can prove to be destabilising if its (offsetting) effects on inflation and output are asynchronous with the effects of shocks. An optimal policy horizon will ensure as much synchronisation as possible between the effects of monetary policy and the shocks on inflation and output, depending on the preferences; see Section (2). Consequently, long (short) lags from shocks to inflation and output will favour long (short) policy horizons.

Also, if it is not possible to obtain a close synchronisation between the effects of monetary policy and those of the shocks through monetary policy actions, the economy may actually be better off

[12] The constant mark-up term is suppressed. In the full econometric model, productivity pr is also an endogenous variable that depends on real wages $w - p$, unemployment u and a deterministic trend.

by adjusting on its own over time, without policy interventions, through built-in stabilisation mechanisms. That is, keeping nominal interest rates at their neutral rate can prove to be more stabilising than making them deviate from the neutral rate for short or long periods.

Therefore, impulse responses of different shocks as well as of monetary policy help to understand the empirical results to follow. The impulse responses show that there are variable lags from different shocks to aggregate demand and inflation; see Appendix A for details. Some of the shocks have quite long lags, which exceed those of a monetary policy shock. For example, the impulse responses reveal the following overall effects on the output gap and inflation when the model is exposed to e.g. a partial shock to short-term interest rates, aggregate demand, consumer prices, the nominal exchange rate or house prices.

First, a transitory rise in short-term interest rates over a year affect output almost contemporaneously. This is because of the contemporanous effects of interest rates on asset prices, i.e. the nominal exchange rate, stock prices and house prices, which affect aggregate demand. However, inflation is affected with a lag of about two quarters, mainly because of lags in the pass-through from imported prices, wages and in effects of changes in aggregate demand.

Second, a shock to aggregate demand affects inflation with a lag of a quarter. The transitory shock has its peak effect on aggregate demand after a year, and on inflation after two years. The policy interest rate is kept unchanged to display the stabilising properties of the model. It is shown that the variables equilibrium correct towards their steady-state values after the shock.

Third, inflation starts converging towards its reference value immediately after the shock to inflation. Output falls immediately because of the real exchange rate appreciation. However, due to a short-term increase in house prices following higher inflation, aggregate demand increases temporarily, but thereafter starts falling as this short-run wealth effect diminishes and the effect of the real exchange rate appreciation becomes more important.

Fourth, a shift in the nominal exchange rate has stronger and more immediate effects on inflation and output growth than house prices and equity prices. This is partly because the nominal exchange affects inflation and aggregate demand directly in contrast to house prices and equity prices. Short-run effects of inflation on house prices partly explain the non-monotonous convergence of the output gap to zero.

Fifth, there are relatively long lags from changes in house prices to their effects on inflation, while the lags from changes in house prices to aggregate demand are relatively short. The effect of a shift in house prices on inflation peaks after three years, while the effect on output peaks after two years. Hence, the lags from house prices to these variables are longer than those from a change in interest rates to these variables.

Finally, the different shocks do not have long-run effects on inflation and real output (or other variables such as unemployment and the real exchange rate).

4 Shock properties and policy horizons

In this section, we first investigate variation in the policy horizon across different kinds of shocks in detail and demonstrate that there may exist a close relationship between optimal policy horizons and optimal target horizons. Thereafter, we investigate possible effects on optimal policy horizons of size, sign and persistence of shocks.

Our empirical analysis is based on the following assumptions, unless otherwise stated. The monetary policy response to a shock is characterised by (3). Values of ϱ_H for different policy horizons are obtained from $\varrho_H = \delta^{1/(H+1)}$, where we set δ at say 0.1 to define convergence of interest rates with the neutral interest rate i_0. That is, we would consider an interest rate deviation from i_0 eliminated when the deviation is not more than 1/10 of the initial deviation from i_0. Alternative values of δ do not bring about substantially different results. Estimates of the horizon-specific response coefficients $\beta_{\varepsilon,H}$ for a given shock can be obtained from its formula: $(1 - \varrho_H)\beta_\varepsilon/(1 - \phi)$, for different degrees of persistence in the shock and interest rates, ϕ and ϱ_H, respectively. Finally, values of the loss function (4) are based on λ equal to 0.5. Implications of alternative values of λ are discussed in Section 6.

4.1 Demand and supply shocks

4.1.1 Monetary policy response to transitory demand and supply shocks

In the following, we present our estimates of $\beta_{\varepsilon,H}$ and ϱ_H pertaining to transitory demand and supply shocks, respectively, for different policy horizons in the range 0–20 quarters. Here, the transitory demand shock refers to an increase in the residual in the aggregate demand equation (ε_y) such that growth in aggregate demand initially increases by one percentage point over a year. The transitory supply shock refers to an increase in the residual in the (consumer) price equation (ε_{cpi}) such that price inflation increases by one percentage point over a year.

The left and the middle frames of Figure 1 display values of the response coefficient for the (transitory, $\phi = 0$) demand shock and the supply shock, respectively. The horizontal axes present policy horizons. The right frame of Figure 1 depicts the degree of interest rate smoothing ϱ_H implied by the different policy horizons. Before analysing 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 1. 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, ϱ_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

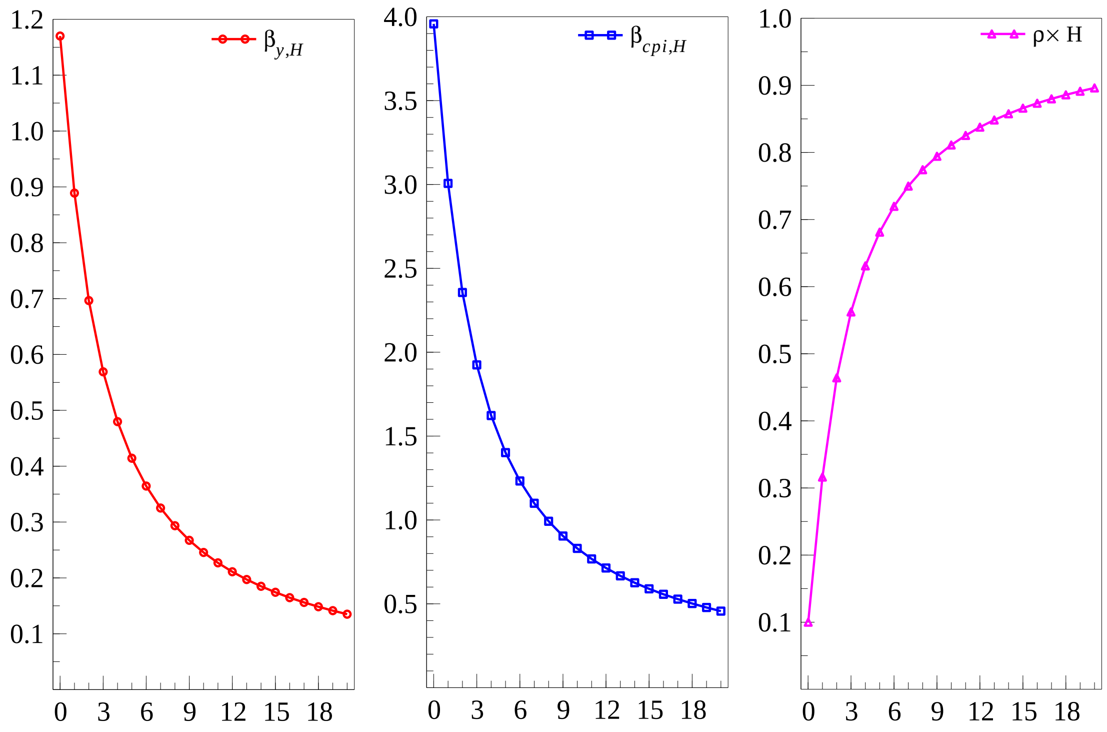

Figure 1: *Left: Initial interest rate responses to the demand shock (in percentage points) implied by different policy horizons (horizontal axes), $\beta_{y,H}$. Middle: Initial interest rate responses to the supply shock (in percentage points) implied by different policy horizons, $\beta_{cpi,H}$. Right: Interest rate smoothing, ϱ_H, associated with different policy horizons.*

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.

Notably, the response coefficients in the face of the demand shock and the supply shock are comparable to typical response coefficients in simple Taylor rules, especially when the horizon is around 3 quarters. Then, the response coefficient in response to the demand shock is about 1.5, while that in response to the supply shock is 0.5. At this horizon or higher, the implied degree of interest rate smoothing is also comparable to that found on many data sets; see e.g. Brian and Wieland (2000). The right frame shows that the degree of interest rate smoothing is close to 0.6 for horizons around 3 quarters.

Figure 2 displays interest rate paths over time suggested by the policy rule (3) in response to a supply shock for three different policy horizons: 3, 6 and 12 quarters. The policy rule has been specified by reading the corresponding values of the response coefficients and the degree of interest rate smoothing from Figure 1.

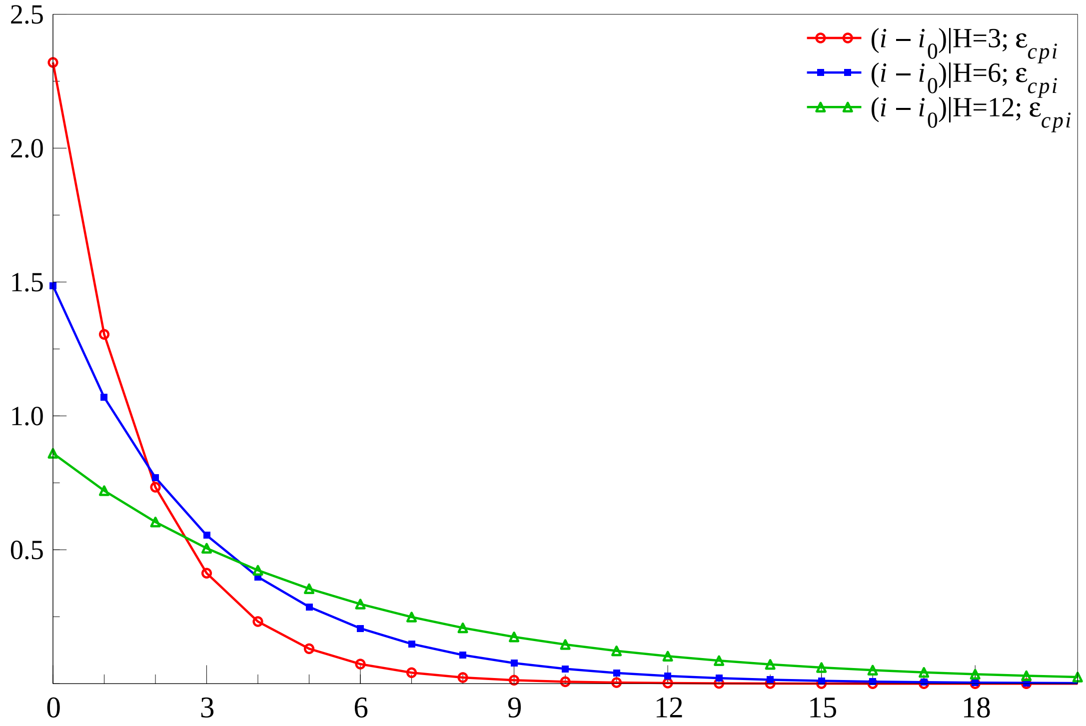

Figure 2: *Interest rate paths over time (in quarters) implied by three different policy horizons in the face of the supply shock. The three interest rate paths are associated with the policy horizons of 3, 6 and 12 quarters, respectively. The interest rates are measured as deviation from the reference interest rate, i.e. the neutral rate, in percentage points.*

4.1.2 Optimal policy horizons

Figure 3 sets out the economic performance conditional on different horizons in the face of the demand and supply shocks. The economic performance associated with every policy horizon is measured by the standard deviations of the output gap and inflation. We present values of the loss functions under different policy horizons relative to their value under the optimal policy horizon (H^*) for a given shock (ε); see equation (5) for the definition.

As expected, there is no conflict between the objectives of price stabilisation and output stabilisation in the case of the demand shock; see Figure 3, left panel. Moreover, it appears that both objectives can be promoted by reducing the policy horizon. 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 $H = 0$. This finding is consistent with the bulk of studies suggesting that demand shocks should be counteracted as aggressively as possible, since inflation can be stabilised jointly with output.

Figure 3 also presents the economic performance of (optimal and suboptimal) policies employed in response to the supply shock. The right panel of the figure shows that there is a trade-off between price and output stabilisation for different ranges of policy horizons. Specifically, there is a trade-off in the range of 0 to 6 quarters. Policy horizons that are longer than 6 quarters appear inefficient

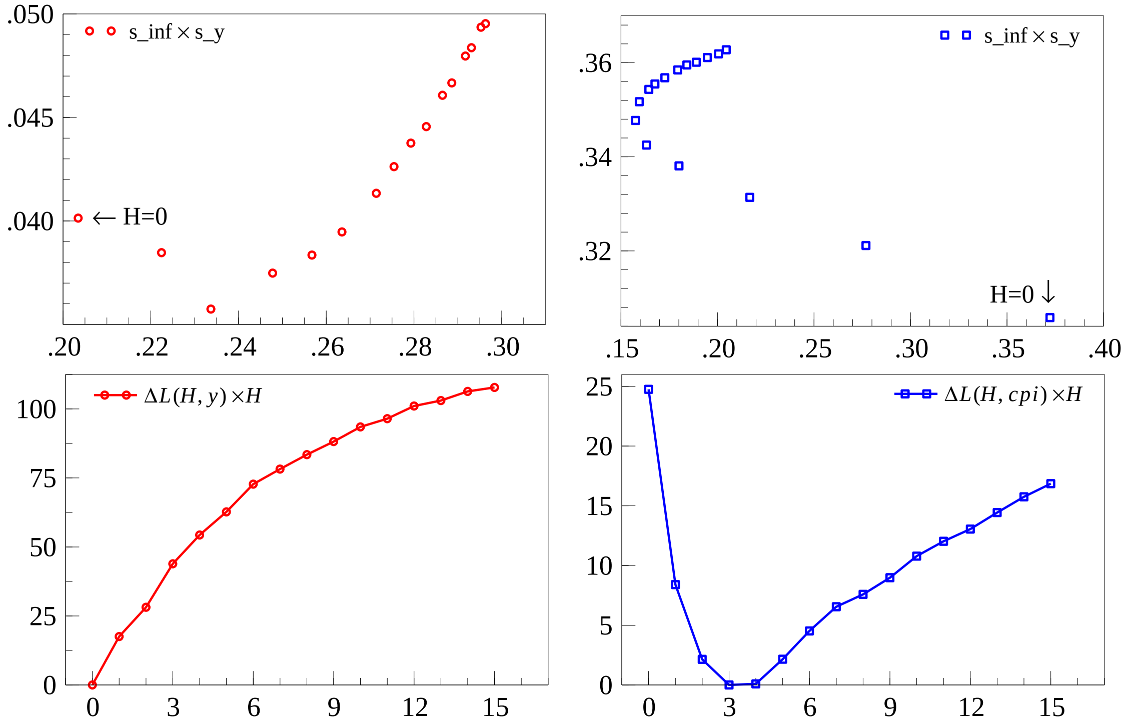

Figure 3: *Top: Performance of the policy rules associated with different policy horizons in the face of the demand shock (left-hand side) and the supply shock (right-hand side), respectively. The policy rules are associated with policy horizons (Hs) in the range of 0-15 quarters. We only indicate the performance of the interest rate rule defined by H =0, while that of the interest rate rule defined by H = 1 is depicted next to it and so on. Bottom: plots of the values of the relative loss function (in %),* $\Delta L(.)$*, against different policy horizons in the case of the demand shock (left-hand side) and the supply shock (right-hand side). The policy horizon is optimal when* $\Delta L(.) = 0$.

as both price and output stabilisation can be improved by shortening the policy horizon. The optimal policy horizon is 3 quarters in the case of the supply shock.

It also appears that there are substantial costs associated with choosing a suboptimal policy horizon. The costs of deviating from the optimal horizon are larger in the case of the demand shock than the supply shock. Second, the increase in the costs seem to decline with the policy horizon. The case of the supply shock also suggests that the costs of deviating from the optimal horizon are asymmetrically distributed around the optimal. Specifically, the costs of choosing a longer than optimal horizon seem to be lower than those from choosing a shorter than optimal horizon. This asymmetry is because of the concave relationship between the degree of interest rate smoothing and the policy horizon, and not due to any asymmetry in the loss function. Nevertheless, the evidence is apparently consistent with that presented in Smets (2003).

4.2 Different kinds of demand shocks

The above section suggests that one should offset effects of a demand shock as soon as possible and adopt a relatively aggressive response. However, in the following we show that relatively

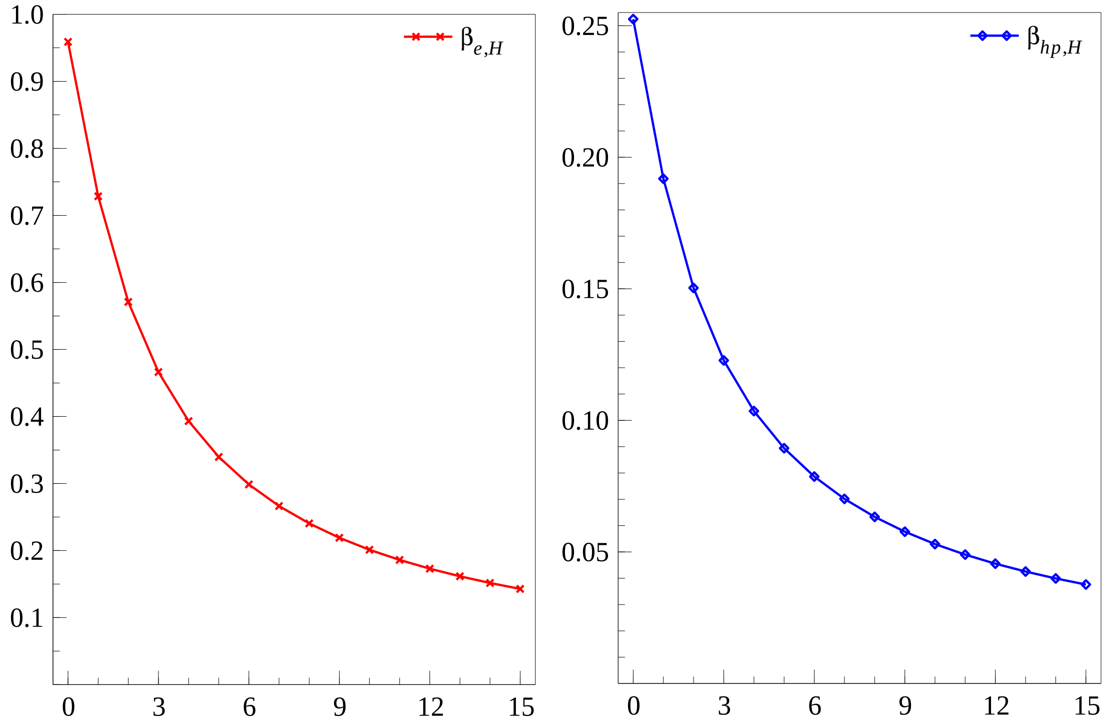

Figure 4: *Left: Initial interest rate responses to the nominal exchange rate shock (in percentage points) implied by different policy horizons (horizontal axes),* $\beta_{e,H}$*. Right: Left: Initial interest rate responses to the house price shock (in percentage points) implied by different policy horizons,* $\beta_{hp,H}$*.*

aggregated models may provide a distorted view of the appropriate horizon in the case of different demand shocks. This is because different demand shocks affect the economy with different lags. Hence, if one offsets the effects of all shocks that are commonly classified as demand shocks with a rather short horizon, monetary policy may prove inefficient and even counterproductive. In the following, we show that optimal policy horizons may vary considerably across shocks even when they are of the same type. We consider the cases of an exchange rate shock and a house price shock which in our model can be interpreted as demand shocks. Similar results can be obtained for the case of different supply shocks such as productivity shocks or wage growth shocks.

Figure 4 shows the response coefficients associated with the different horizons in response to an exchange rate shock and a house price shock. In the latter case, the response coefficients are relatively smaller in comparison with those in the case of the exchange rate shock. This is because the inflationary effects of a house price shock are considerably smaller than those of an exchange rate shock, as noted in Section 3.1. As noted above, the lags from the house price shock to output and inflation are also longer than those in the case of the exchange rate shock. This is reflected in the corresponding optimal policy horizons. The effects of the exchange rate shock are actually comparable to those of the supply shock.

Figure 5 depicts the efficiency frontiers for different horizons. It appears that the optimal

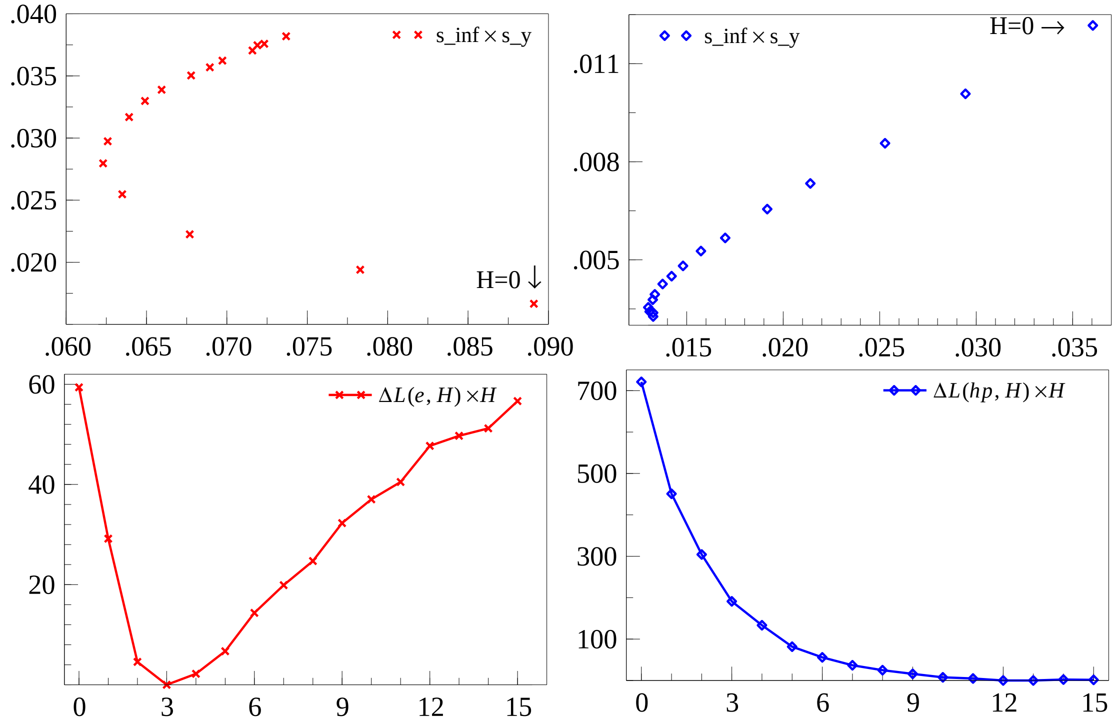

Figure 5: *Top: Performance of the policy rules associated with different policy horizons in the face of the exchange rate shock (left-hand side) and the house price shock (right-hand side), respectively. The policy rules are associated with policy horizons (Hs) in the range of 0-15 quarters. See* Figure *3 for more details.*

horizons in the case of both the exchange rate shock and the house price shock are longer than in the case of the shock to the aggregate demand equation. In particular, the optimal horizon in the latter case is about 12/13 quarters, which is even longer than in the case of the supply shock considered above. In these two examples, the optimal policy horizons are close to or longer than that for the supply shock.

4.2.1 Optimal target horizons

Below, we present some examples suggesting that there is a close relationship between the optimal policy horizon and the target horizon. Hence, the optimal policy horizon can be considered a close indicator of the optimal target horizon. In general, the relationship between policy and target horizons is shock- and model-dependent. In a dynamic model, the target horizon is likely to be somewhat longer than the policy horizon as the effects of monetary policy stimulus may remain effective for some time after interest rates have converged to their neutral rate.

The optimal target horizon associated with a shock can be defined as the time it takes for inflation to almost converge with its target rate after the shock under the corresponding optimal interest rate rule, as defined by the optimal policy horizon associated with the shock. We would consider inflation to be converged with its target rate when it first 'touches' its target after the shock. Even though it can display complicated dynamics after the first 'touch', we would consider that to be largely dependent on the dynamic properties of the model.[13].

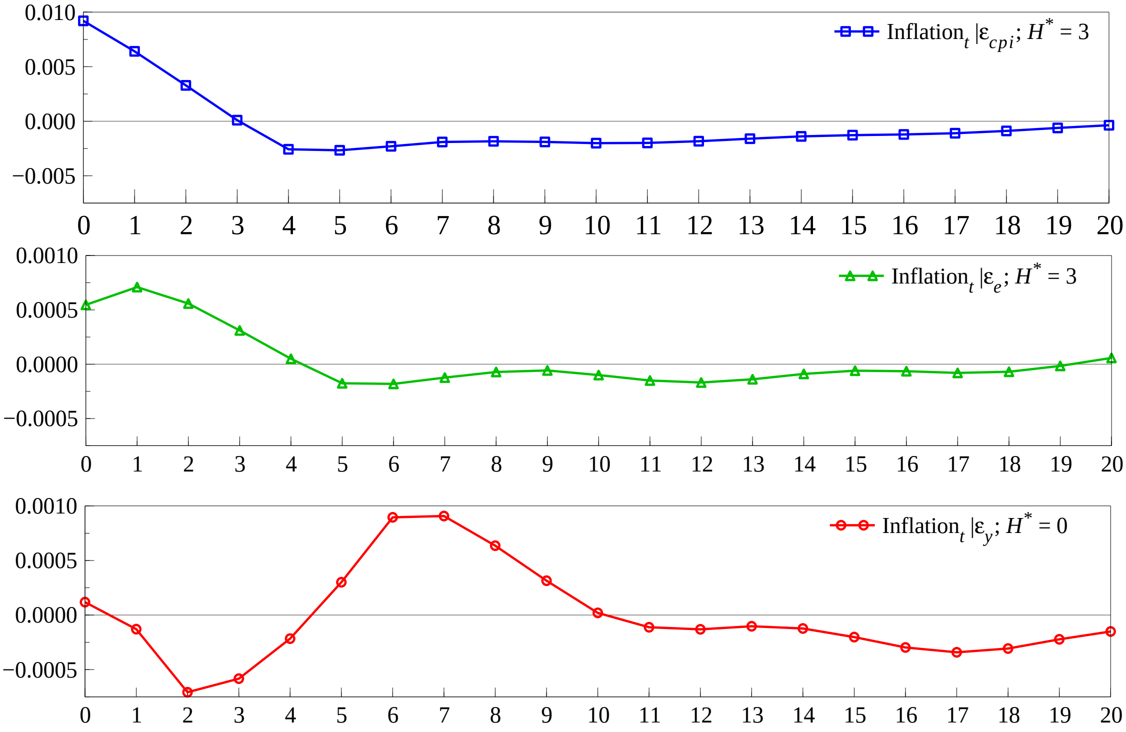

Figure 6: *Convergence of inflation to its target rate in response to different shocks under the corresponding optimal policy rules, which are represented by the optimal policy horizons H^*. Optimal target horizons are suggested by the first 'touch down' of inflation to its target rate, indicated by zero on the vertical axes. The horizontal axes indicate the time periods in quarters.*

To obtain the precise target horizons in the case of different shock, we simulate the model under corresponding optimal interest rate rules defined by the associated optimal policy horizons. Figures 6.a–c show the optimal target horizons in the case of the supply shock, exchange rate shock and the aggregate demand shock, respectively. Obviously, inflation converges gradually to its target rate after the first "touch down". Nevertheless, it appears that the first 'touch downs' are remarkably close to the optimal policy horizons.

In particular, in the case of the supply shock, the optimal policy horizon is equal to the optimal target horizon, i.e. 3 quarters. In the case of the exchange rate shock, the optimal target horizon exceeds the policy horizon by just one quarter, and is equal to 4 quarters. In the case of the aggregate demand shock, the optimal target horizon is approximately equal to the optimal policy horizon. We note that the optimal target horizon is about 1/2 of a quarter in this case, while the

[13]There are also alternative definitions of optimal target horizons, e.g. the relative measure, which are influenced by the pattern of convergence to the target in the aftermath of a shock. This measure appears, however, to be influenced too much by properties such as the size of the shock and the dynamic properties of a given model. For example, the relative measure implies optimal target horizons that would also depend on the size of the shock and suggests that the horizon is short in the case of small shocks but long in the case of large shocks. Moreover, convergence becomes too lengthy in the case of all shocks in a dynamic model. Thus, differences between optimal target horizons become less pronounced. Hence, such measures seem not only to overestimate the optimal target horizons in general, but also underplay differences in them across shocks.

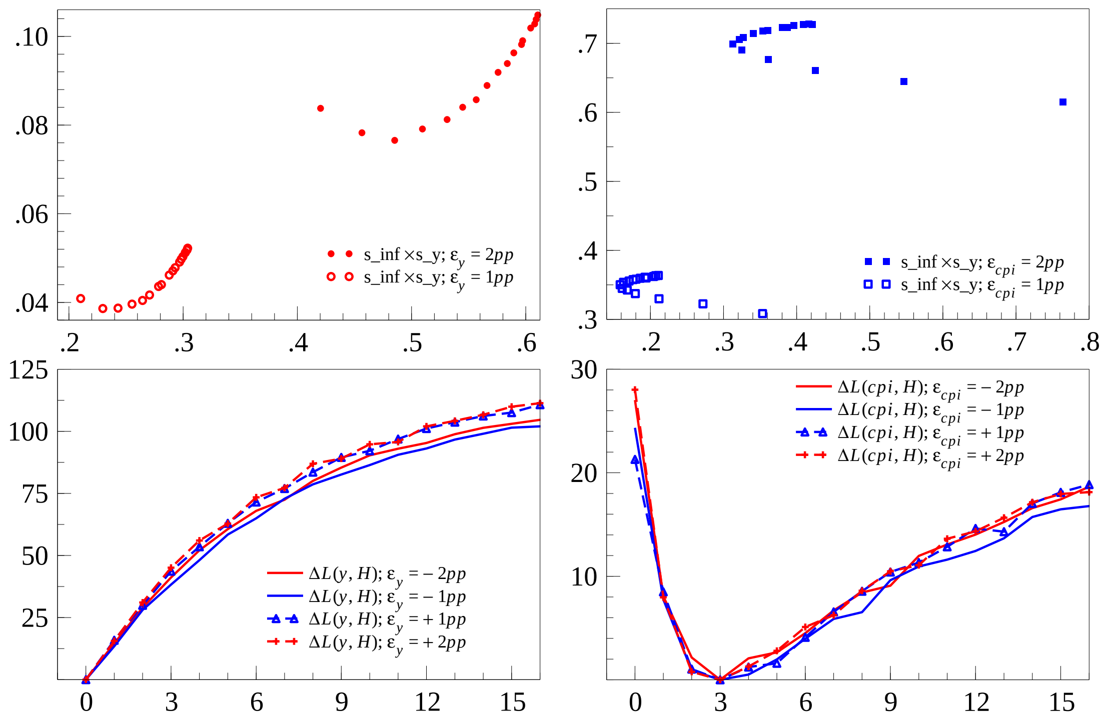

Figure 7: *Performance of the policy rules associated with different policy horizons in the face of demand shocks of different sizes and signs (left-hand side) and that of different sizes and signs of the supply shock (right-hand side), respectively; see Figure 3 for more details. 1pp and 2pp denote shocks implying 1 and 2 percentage points direct initial changes in the variable of interest, e.g. output growth or inflation, respectively. The results for shocks implying -1pp and -2pp changes in the graphs at the top are left out since their results were identical to those for shock sizes 1pp and 2pp.*

optimal policy horizon is equal to zero, i.e. contemporaneously with the shock.

In contrast to the case of the supply shock and the exchange rate shock, inflation displays quite complex dynamics after the first touch down before it settles down to the inflation target. In the former cases, inflation converges relatively smoothly towards the target over the 5-year period (20 quarters). These three shocks also illustrate that if we had defined the optimal target horizon as the time it would take before inflation settles down to its target, there would not be much difference in optimal target horizons across different shocks.

4.3 Size and sign of shocks

The sign of a given shock is not expected to have an effect on the optimal policy horizon when the model is linear and the loss function is quadratic. Figure 7 confirms this intuitive result. It shows that the optimal policy horizon is the same irrespective of the signs of the shocks.

Figure 7 also shows that the size of a shock does not affect the optimal policy horizon. This is because only the location of the efficiency frontier changes when we vary the size of the shock, while its shape remains the same. The left panel shows that the optimal policy horizon remains

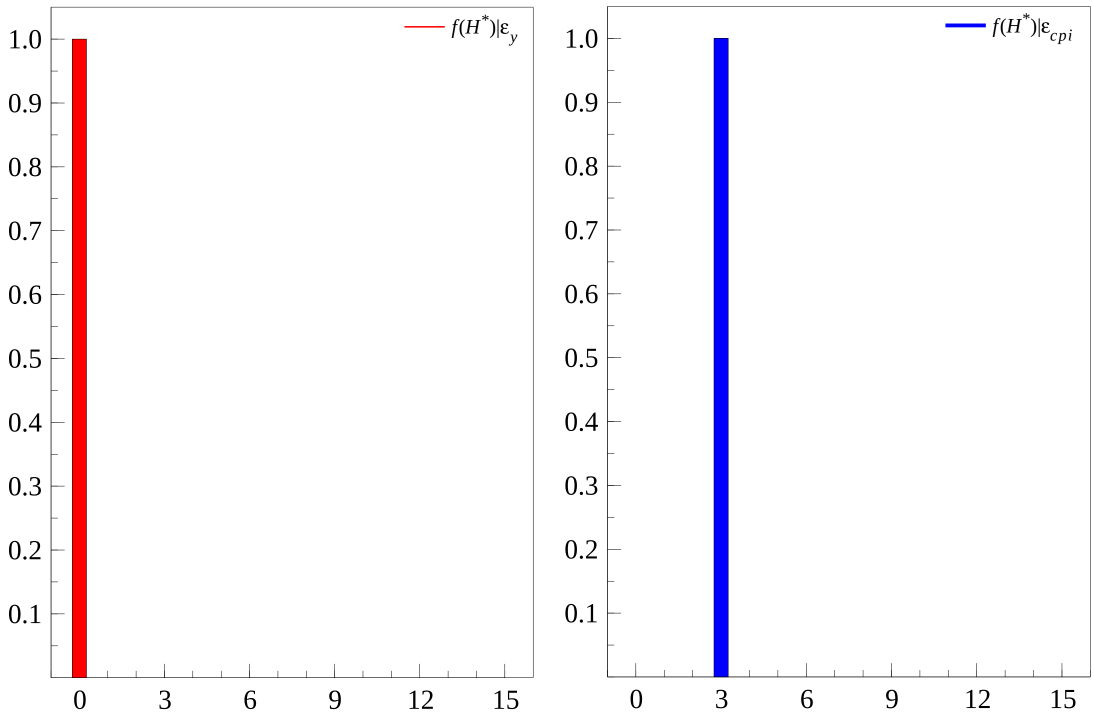

Figure 8: *Distribution of the optimal policy horizon in the case of demand shocks of different sizes and signs is presented on the left-hand side and that in the case of supply shocks of different sizes and signs is presented on the right-hand side. Value of "1" on the vertical axis suggest that 100% of the shocks of a given kind have optimal horizon at the level indicated on the horizontal axis (in quarters).*

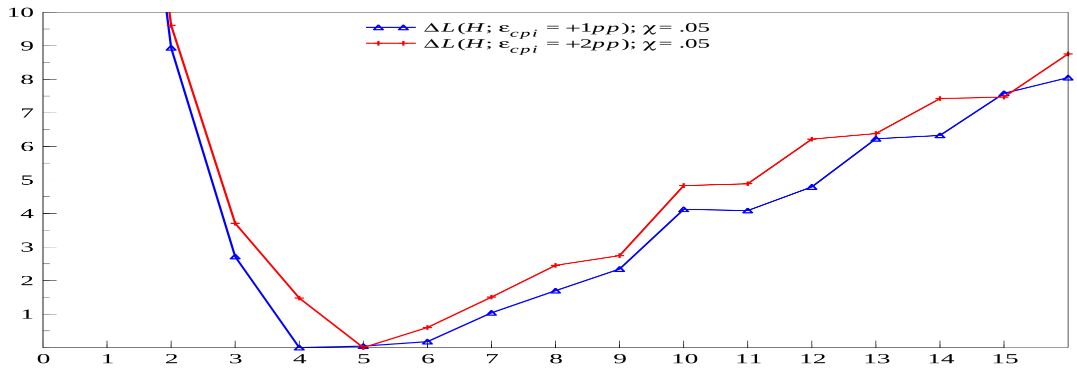

Figure 9: *Plots of the values of the relative loss function ($\Delta L(.)$) (in %) at different policy horizons in the case of supply shocks of different sizes. The loss function has been modified to incorporate concern for interest rate volatility which is measured by χ and its value has been set to 0.05. The policy horizon is optimal when $\Delta L(.) = 0$.*

zero in the case of demand shocks while it remains 3 quarters in the case of supply shocks, when λ is 0.5. This is further confirmed by Figure 8, which reports the optimal horizons in the face of numerous demand and supply shocks of different sizes and signs. It shows that all of the demand shocks have an optimal policy horizon equal to zero while all of the supply shocks have an optimal policy horizon equal to 3 quarters.

In our approach, the optimal policy horizon seeks to synchronise the effects of the shock with those of the monetary policy response as much as possible. The degree of synchronisation is independent of the size of the shock in our linear model. Thus, a counteraction of the effects of a shock only requires a rescaling of the monetary policy response in accordance with the size of the shock. The optimal policy horizon therefore remains invariant to the size of the shock.

However, the required interest rate changes can be particularly large in the face of relatively large shocks. Thus, if we had allowed for a concern for interest rate volatility in the loss function, the optimal policy horizon would have increased with the size of the shock. For example, Figure 9 shows that the optimal horizon increases by one quarter, from 4 to 5 quarters, when the size of the shock is increased from 1pp to 2 pp, under the assumption that the central bank is averse to interest rate volatility. This is defined as variance of Δr and the degree of aversion, represented by χ, is set at 0.05. In the benchmark case, where χ is zero, the optimal policy horizon is 3 quarters. Higher degrees of aversion (χ) are expected to bring about a larger extension in the optimal policy horizon when the shock size is increased.

Figure 7 also suggests that if the shock is correctly identified, the costs of choosing the wrong horizon are independent of the size and signs of the shocks if the central bank only cares about output stability. This is mainly because the monetary policy response is otherwise attuned to the shock.

However, when the economy is exposed to a combination of shocks, their signs as well as sizes influence the optimal policy horizons. The results for combinations of shocks are presented in Section 5.

4.4 Persistent shocks

In the following we analyse effects of persistence in shocks on the optimal policy horizons. For simplicity, we assume that a shock (to an equation in the model) follows an AR(1) process with degree of persistence denoted by ϕ:

$$\varepsilon_\tau = \phi\varepsilon_{\tau-1} + \upsilon_\tau \tag{14}$$

We shock the model conditional on a specific ϕ value and then implement the rule (3) for different H-values, to derive the optimal policy horizon. The interest rate rule (3) implies that the interest rate response increases in a non-linear fashion with the degree of persistence.

In the following, we present the results for the demand and supply shocks with different degrees of persistence. The estimated response coefficient at different H-values for these shocks can be learned from Figures 10 and 11, and then adjusted for different degrees of persistence to obtain implementable rules. For comparison, we also plot the results in the case of the transitory shocks presented in Figure 10.

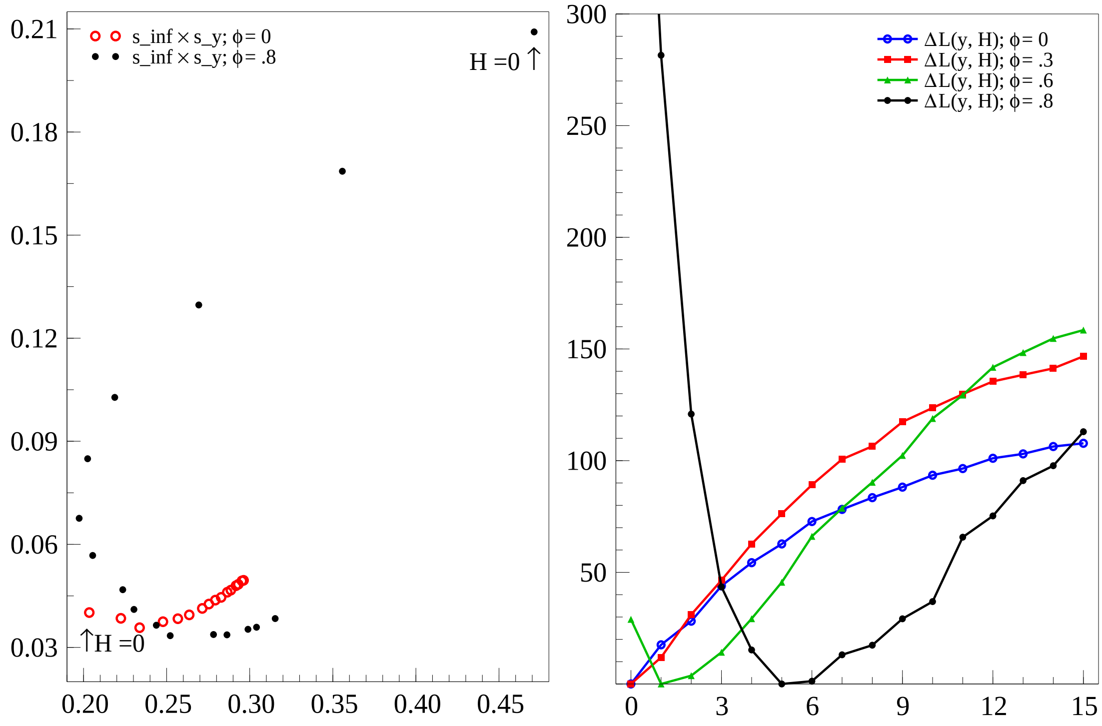

Figure 10: *Left-hand side: Performance, represented by cross plots of standard deviations of inflation and output gaps, of horizon-specific interest rate rules in the case of the demand shocks of different degrees of persistence (ϕ). Right-hand side: Values of the corresponding relative loss functions (in %) at different policy horizons (horizontal axis).*

Figures 10 and 11 show that both the location and the shape of the efficiency frontiers vary with the degree of persistence. For example, in the case of the demand shock, interest rate rules associated with relatively short horizons become inefficient at relatively high degree of persistence. This is mainly because effects of persistent shocks are distributed over a relatively longer horizon than those of transitory shocks. Thus, if a relatively short policy horizon is chosen, the implied contractionary monetary policy effects required to offset the effects of shocks will be asynchronous to those of the shocks. Hence, monetary policy will not be as stabilising as it can be by adopting to the degree of persistence in the shock by taking a longer horizon.

Figure 10 shows that the optimal horizon increases with the degree of persistence. In the case of the demand shocks, the optimal horizon is beyond 5 quarters for relatively high degrees of persistence in the demand shock. Thus, even demand shocks require that one chooses a relatively long horizon to combat them rather than a short horizon when they are persistent. Otherwise, the effects of the shock and those of the monetary policy will become asynchronous reducing the effectiveness of monetary policy. In the case of the supply shock, the optimal horizon is 10 and 20 quarters when the degrees persistence is 0.6 and 0.8, respectively, but just 3 quarters if the shock is transitory. The optimal policy horizon in the case of the supply shock is, however, more dependent on the degree of persistence than that in the case of the demand shock.

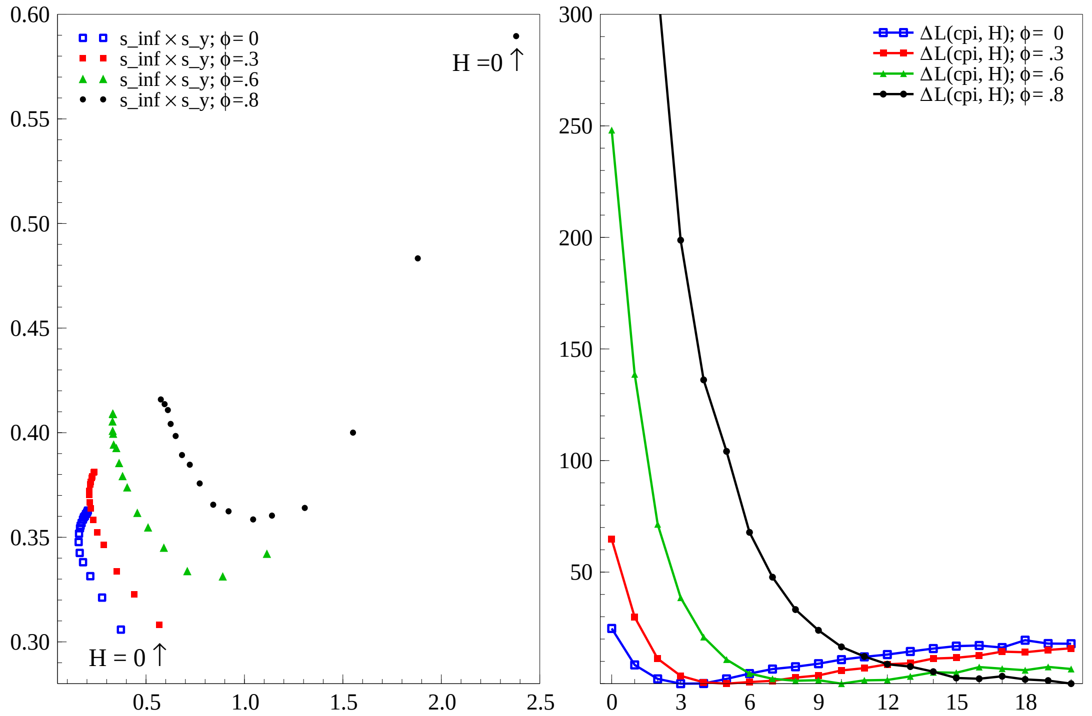

Figure 11: *Left-hand side: Performance, represented by cross plots of standard deviations of inflation and output gaps, of horizon-specific interest rate rules in the case of the supply shocks of different degrees of persistence. Right-hand side: Values of the corresponding relative loss functions (in %) at different policy horizons (horizontal axis).*

To summarise, we find that 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 particularly 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 synchronisation between the destabilising effect of the persistent inflationary effects with the stabilising effect of monetary policy. Monetary policy thereby becomes more effective in stabilising the economy. We also note that the costs of adhering to a fixed horizon of say 4 quarters would be relatively low in the case of transitory shocks, but quite high if the shocks are relatively persistent.

5 Multiple shocks

The optimal policy horizon in the face of a set of shocks with different signs and sizes is difficult to infer from optimal policy horizons for individual shocks. A combination of shocks provides several impulses to the economy. They may amplify or modify each others' effects on the economy. Moreover, impulse responses of e.g. inflation and output when exposed to a combination of

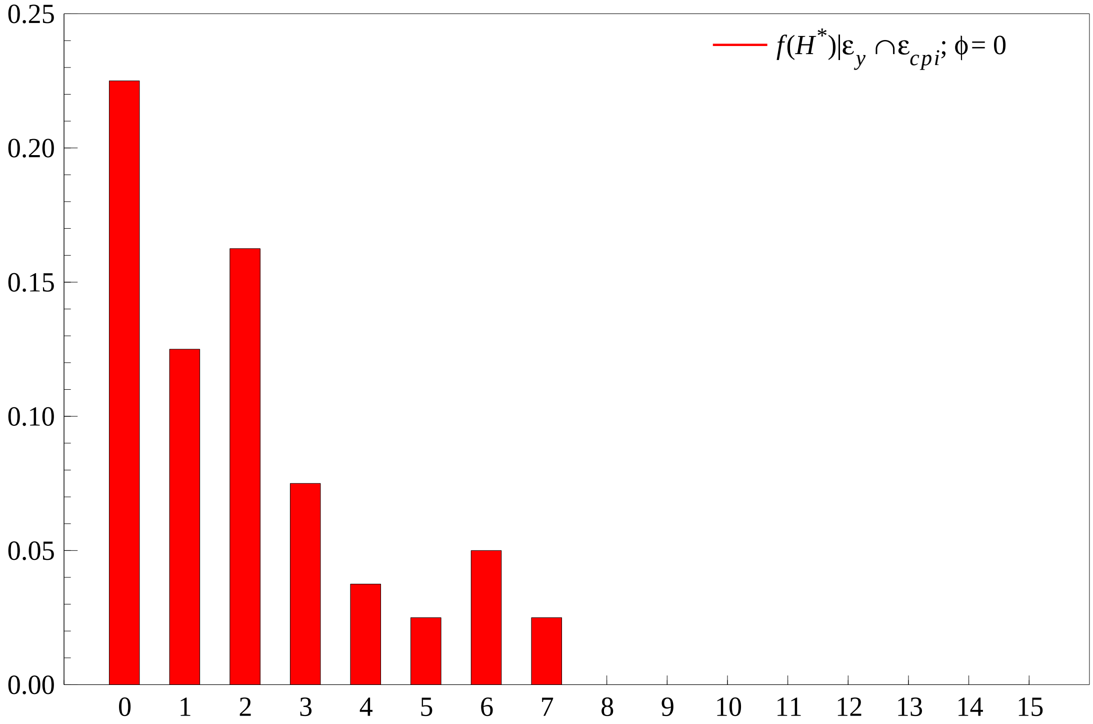

Figure 12: *Distribution of the optimal policy horizons in the case of transitory demand and supply shocks of different sizes and signs. The vertical axis indicates the share of the shocks having an optimal horizon at the level indicated on the horizontal axis (in quarters).*

several shocks may be quite complex depending on the dynamic effects of the shocks. Optimal policy horizons synchronise the monetary policy impulse with those of the net effect of shocks on inflation and output as much as possible. Therefore, the optimal horizon in the face of a set of shocks does not become just a convex combination of the optimal policy horizons corresponding to individual shocks. To show this, we present distributions of optimal policy horizons in the face of different combinations of shocks. It appears that both sign and size become important for a given combination of shocks, even when there is no concern for interest rate volatility.

Figure 12 shows the distribution of optimal policy horizons for different combinations of demand and supply shocks, i.e. shocks to both the *cpi*-equation and the *y*-equation. The shocks are uniformly and symmetrically distributed around zero and take on values within ranges that change inflation and/or output growth by up to 2 percentage points per annum. In order to limit the number of simulations, we let each of the shocks take on 9 different values within their respective ranges. Thus, we consider 81 less one different combinations of the demand and the supply shocks; we overlook the case of zero change in both the demand and the supply shock. We report our findings as distributions of the optimal horizons.

In about 1/4 of the shock combinations, the relatively simple interest rate response pattern, characterised by rule (3), turned out to be destabilising by contributing to more instability than induced by some shock combination alone. Consequently, a relatively long horizon around 20

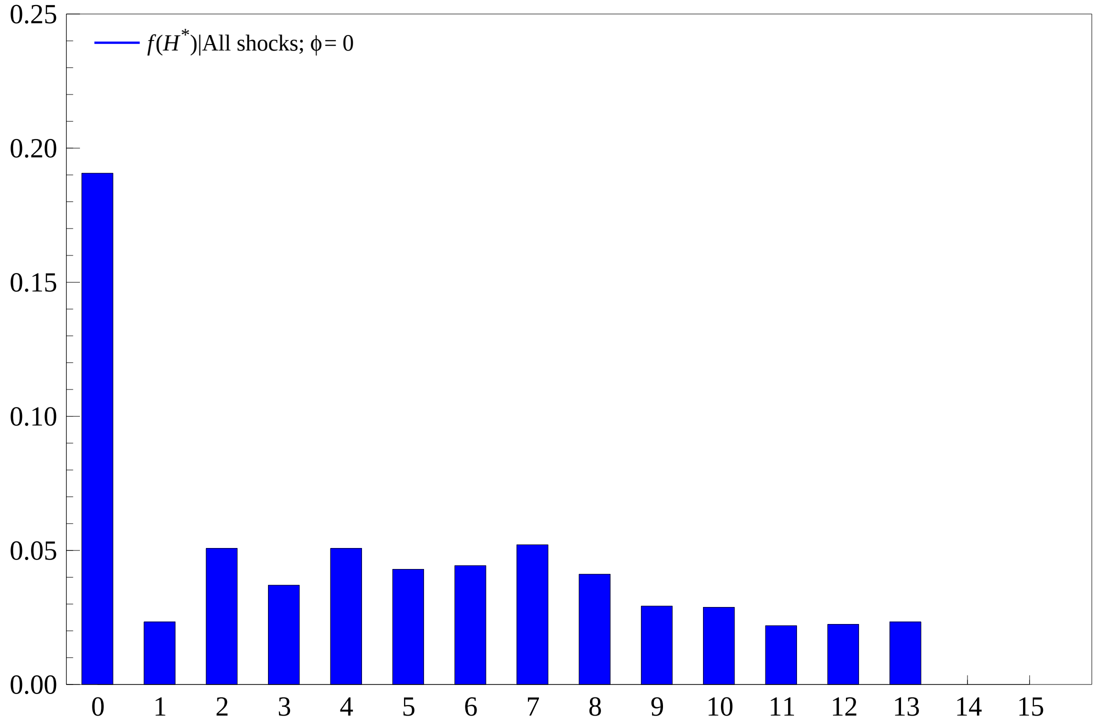

Figure 13: *Distribution of optimal policy horizons in the case of transitory ($\phi = 0$) shocks of all kinds and different sizes and signs. The vertical axis indicates the share of the shocks having an optimal horizon at the level indicated on the horizontal axis (in quarters).*

quarters was preferred. In such cases, the monetary policy impulses became virtually negligible. For monetary policy to be successful in the cases of relatively complex effects of combined shocks, one needs to engineer a quite complex monetary policy rule, which may not even be feasible in practice because of the extent of required information.

Figure 12 suggests that the optimal policy horizon is in the range of 0–7 quarters, in cases where monetary policy has a stabilising effect. In most of the cases, the optimal horizon is in the range of 0–3 quarters, where 0 and 3 are also suggested by individual demand and supply shocks. The mode of optimal policy horizons is 3–4 quarters. In about 15 per cent of the cases, however, the optimal policy horizons are between 4 and 7 quarters. The relatively high frequency of the zero horizon owes to the effect of the demand shocks on the loss function relative to those of the other shocks. Note that deviations from the optimal horizons in the case of demand shocks are more loss-inducing than those of supply shocks; cf. Figure 3.

There are, however, a relatively large number of shocks in the model. Figure 13 presents the distributions of optimal policy horizons when we contemporaneously expose the economy to all of the shocks in the model.[14] This figure shows that in the face of contemporaneous shocks to the whole economy, the optimal horizons fall in the range of 0–13 quarters. The mode of optimal

[14]To reduce the number of possible combinations and simulations we neglect (direct) shocks to equity prices, since their effect is negligible on the rest of the economy. But allowance for them would increase the number of combinations to be considered by 4374 for every every policy horizon, implying 91854 additional simulations.

policy horizons is 6–7 quarters in this case. As above, the dominance of the zero horizon, $H = 0$, can be partly explained by the size of the demand shocks relative to the others, and its effect on the loss function.

In this case, we also let all of the shocks be uniformally and symmetrically distributed around zero in their respective ranges. We let the shocks to the nominal exchange rate, house prices and credit be such that these variables change at most by 10 per cent per annum. The other variables are allowed to change by ± 1 percentage points at most due to the corresponding shocks. These variables include the unemployment rate, wage inflation, output growth and cpi inflation. To limit the number of possible shock combinations, we let each of these variables take on just three values in their ranges, e.g. -1, 0, $+1$, or -10, 0, $+10$. This provides us with 2186 possible shock combinations when we neglect the single case of zero shock to all of the variables. Thereafter, we consider the economic performance conditional on a specific combination for 21 policy horizons in the range of 0–20.

As above, in about 1/4 of the combinations, the simple interest rate response pattern devised by the rule turned out to be destabilising since the shock combinations turned out to have a quite complex effect on the economy, demanding a relatively complex monetary policy response for it to have stabilising effects.

Notably, the above results support the range of inflation targeting horizon up to 1–3 years. This supports the announced target ranges of many inflation-targeting central banks. The next section, however suggests that an optimal horizon up to 3 years may be low in the face of relatively persistence shocks.

5.1 Combinations of persistent shocks

We have also examined how distributions of the optimal policy horizons for different combinations of sizes and signs of shocks are affected by their degree of persistence. Figure 14 presents distributions of optimal policy horizons in the case of (contemporaneous) combinations of demand and supply shocks. As above, the shocks are uniformally and symmetrically distributed around zero and contribute to change inflation and/or output growth by up to ± 2 percentage points. The sizes of the shocks are determined such that each of them makes the corresponding endogenous variable take on 9 possible values within the ± 2 range with step size 0.5, leading to 81 possible combinations. In contrast to the above, however, we let each of the shock follow and AR(1) process as defined in (14).

The figure shows that the range of distributions increases with the degree of persistence in the shocks. We also note that the frequency at which relatively long horizons become optimal increases with the degree of persistence; note the shift in the frequency from short to relatively long horizons. The figure also shows that in the case of relatively high degrees of persistence, 0.8,

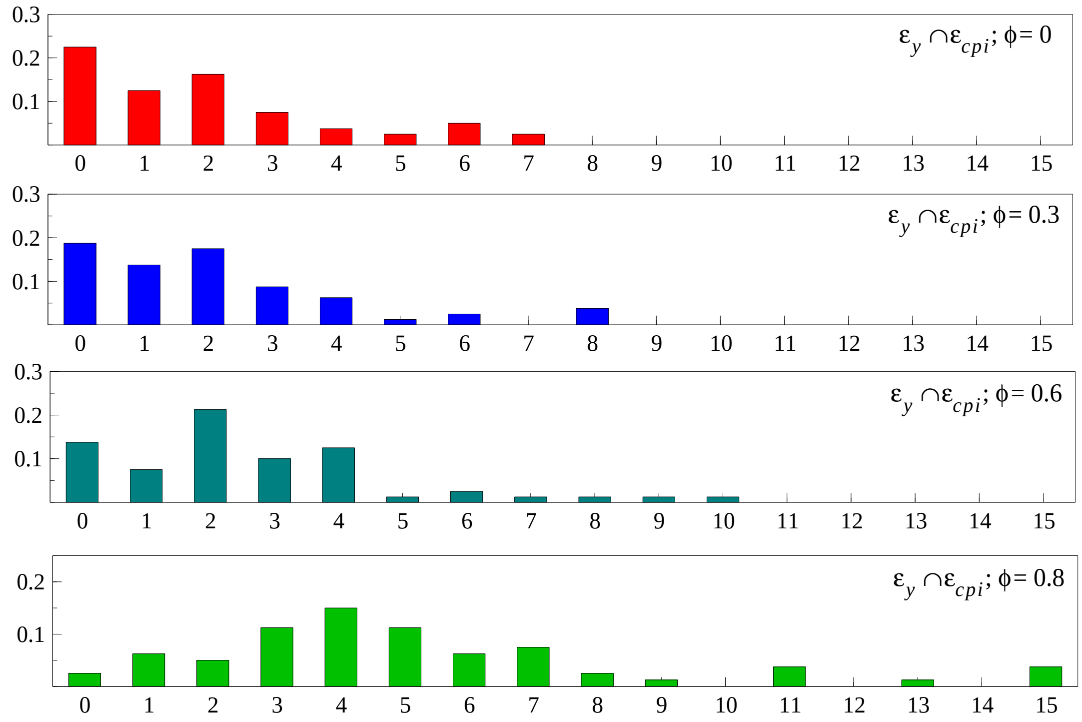

Figure 14: *Distributions of optimal policy horizons in the case of demand and supply shocks of different sizes and signs and degrees of persistence (ϕ). The vertical axis indicates the share of the shocks having an optimal horizon at the level indicated on the horizontal axis (in quarters).*

the optimal policy horizon becomes 15 quarters. For particularly high degree of persistence, close to 1, the optimal policy horizons become quite long, in many cases beyond 5 years, in which case, the term 'medium run' may not seem useful.

As above, however, in about 1/4 of the cases, monetary policy described by the simple rule turns out to be destabilising. This illustrates that a simple response to developments in the economy may not always be beneficial. Furthermore, in such cases, one must fine-tune the monetary policy response to achieve stabilising effects, which can be demanding.

6 Central bank preferences and policy horizon

6.1 Concern for output fluctuations

It is commonly assumed that the optimal horizon in the case of the supply shock increases with a policy maker's concern for output stabilisation. In the following, we show that this need not be the case since a too long horizon can prove counterproductive. Intuitively, if a shock is transitory but one chooses a relatively long horizon, monetary policy can affect the economy for a longer period than the shock itself, i.e. even after the effects of the shock have died out, and thereby cause instability.

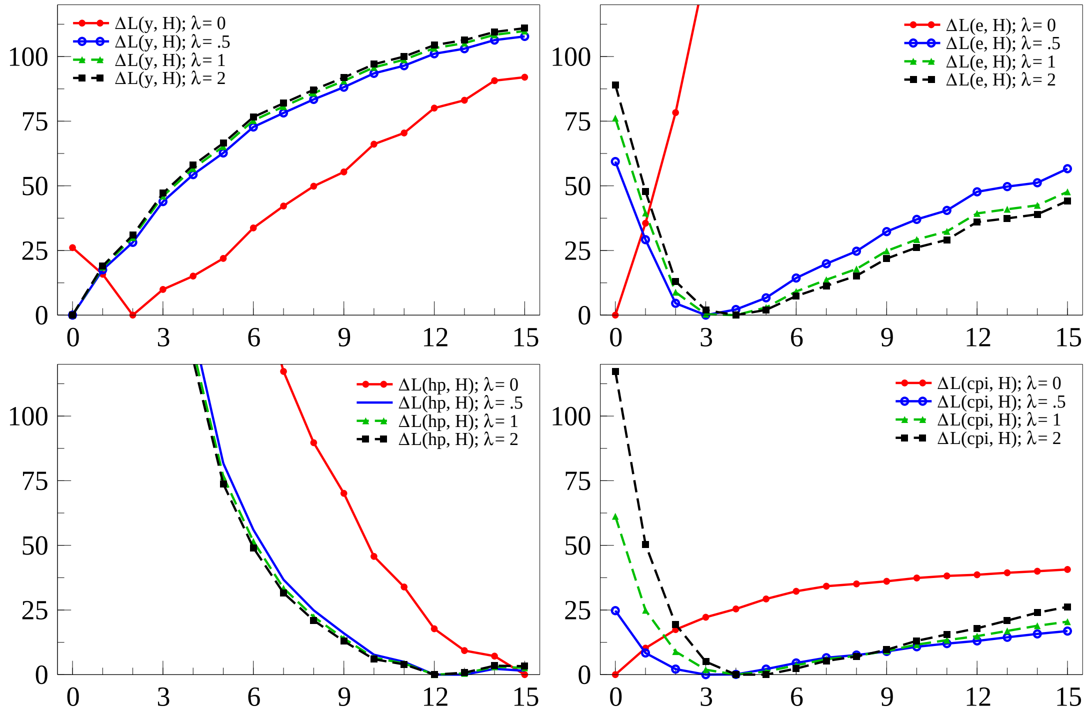

Figure 15: *Top: plots of the values of the relative loss function, $\Delta L(.)$ in %, defined by different λ values against different policy horizons in the cases of the demand shock (left-hand side) and that of the nominal exchange rate shock (right-hand side). Bottom: plots of the values of the relative loss function defined by different λ values against different policy horizons in the cases of the house price shock (left-hand side) and those of the supply shock (right-hand side); see Figure 3 for more details.*

There seems to be a strongly concave relationship between the optimal horizon and lambda (λ); see Figure 15. This shows that the optimal policy horizon increases abruptly from zero to 3 when lambda increases from 0 to 0.5. Thereafter, however, the optimal horizon increases only up to 5 even when lambda becomes 2 or even higher. This is because, increasing the horizon beyond 5 quarters would be inefficient; see Figures 3 and 5. Thus, no matter how much one cares about output, one will not adopt a horizon, and the associated interest rate path, that can be improved on. In particular, the monetary policy rule suggests that choosing a too long horizon can imply a too large reduction of the response coefficient ($\beta_{\varepsilon,H}$) causing a violation of the so-called Taylor-principle. That is, the nominal interest rate can turn out to increase by less than the increase in inflation which could cause a fall in the real interest rate and thereby contribute to instability. This may explain why the optimal policy horizon does not increase with lambda beyond some shock-specific level.

The case for the different demand shocks is notable; see Figure 15. It appears that the optimal horizon is largely invariant to lambda for different kinds of demand shocks. The crucial difference is between the case of strict and flexible inflation targeting, i.e. between the case of $\lambda = 0$ and $\lambda > 0$. In the former case, a relatively long horizon is suggested in the case of the aggregate demand

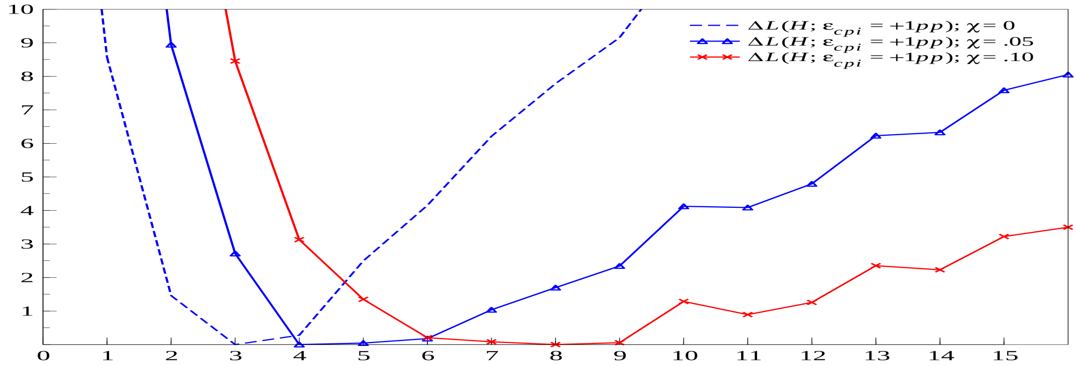

Figure 16: *Plots of the relative loss function defined by different χ values against different policy horizons in the case of the the supply shock. The policy horizon is optimal when $\Delta L(.) = 0$ and the relative loss is measured in %.*

and the house price shocks, while a relatively short horizon is suggested in the case of the exchange rate shock. Output is affected before inflation in the case of a direct shock to aggregate demand and house prices. Therefore, concern for output stabilisation $\lambda > 0$, would lead one to choose a short horizon, while no concern for output stabilisation would lead one to choose a relatively longer horizon. In the latter case, one is only concerned about price stability, and hence there is no need to reign in the inflationary effects of the shocks before they appear.

The opposite is the case when there is a shock to the exchange rate and to the *cpi* directly. In these cases, inflation is affected before output. Hence, a concern for output stabilisation would lead one to choose a relatively longer horizon, while concern for price stability alone would lead one to offset the inflationary effects of the shocks as soon as possible.

6.2 Concern for interest rate volatility

Figure 16 shows that an increase in concern for interest rate volatility, represented by χ, raises the optimal policy horizon. However, there seems to be a concave relationship between χ and the optimal policy horizon. The figure shows that if χ is 0.05, instead of zero in the benchmark case, the optimal policy horizon becomes 4 quarters, and if it is 0.1, the optimal policy horizon becomes 8 quarters. The value of χ equal to 0.1 is commonly assumed in the literature, see e.g. Smets (2003) and Taylor (1999). A closer examination suggests that there is not a linear relationship between χ and optimal policy horizon, conditional on a given value of λ. For example, a further doubling of χ from 0.1 to 0.2 would not increase the optimal policy horizon from 8 to 16 quarters. Figure 16 shows that if χ is 0.5, the optimal policy horizon becomes 15 quarters.

7 Model properties and policy horizons

We demonstrate the strong model-dependence of optimal policy horizons by replacing the wage and price systems of the macroeconometric model with alternative equations and exposing the model to a supply shock as defined above.[15] The following investigation particularly underscores the importance of equilibrium-correcting properties of models for the implied optimal policy horizons. It also suggests possible costs of deriving optimal policy horizons using models that turn out to be invalid.

The incumbent wage and price system (in the macroeconometric model) is a VECM of wages and consumer prices which is derived in the light of open economy models of imperfect competition in product markets and a wage-bargaining framework. This is sequentially replaced by two systems of Phillips curves for prices and wages. In the first system, the Phillips curves are data consistent, but downward sloping even in the long run. In the second system, the Phillips curves for wage and price inflation are restricted to be vertical in the long run through homogeneity restrictions. The apparently small differences between the two systems of Phillips curves in their parameter estimates are especially useful in demonstrating the model-dependency of optimal policy horizons (and of monetary policy). The three systems of wages and prices are presented in Appendix C, while their economic and statistical properties are discussed in detail in Akram and Nymoen (2006).

The difference between the three versions of the macroeconometric model essentially consists of differences in restrictions on the overall equilibrium-correction behaviour. The version with the wage-price VECM 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 denote the version of the macroeconometric model with the VECM as ECM, that with the unrestricted Phillips curves as PCM, and the restricted Phillips curve implying vertical Phillips curve as PCMr.

Figure 17 suggests that three model versions imply substantially different monetary policy responses to the supply shock. The figure depicts the interest rate paths defined by selected policy horizons in the face of a supply shock.

Figure 18, left panel, sets out the economic performance of the policies in the face of the supply shock suggested by the three models. The economic performance associated with every policy horizon is measured by the standard deviations of the output gap and inflation. The right panel presents values of the loss function under different policy horizons relative to their value under the optimal policy horizon (H^*) for a given model version ($\mathcal{M}$), where $\mathcal{M} =$ ECM, PCM, PCMr.

Figure 18, right panel, presents the economic performance of (optimal and suboptimal) policies employed in response to the supply shock. The left panel of the figure shows that there is a trade-off

[15] It can be demonstrated that the optimal policy horizon in the case of a demand shock remains invariant to the alterations of the wage and price systems discussed here. This is because the interaction of the wage and price system with the demand side remains largely unaltered.

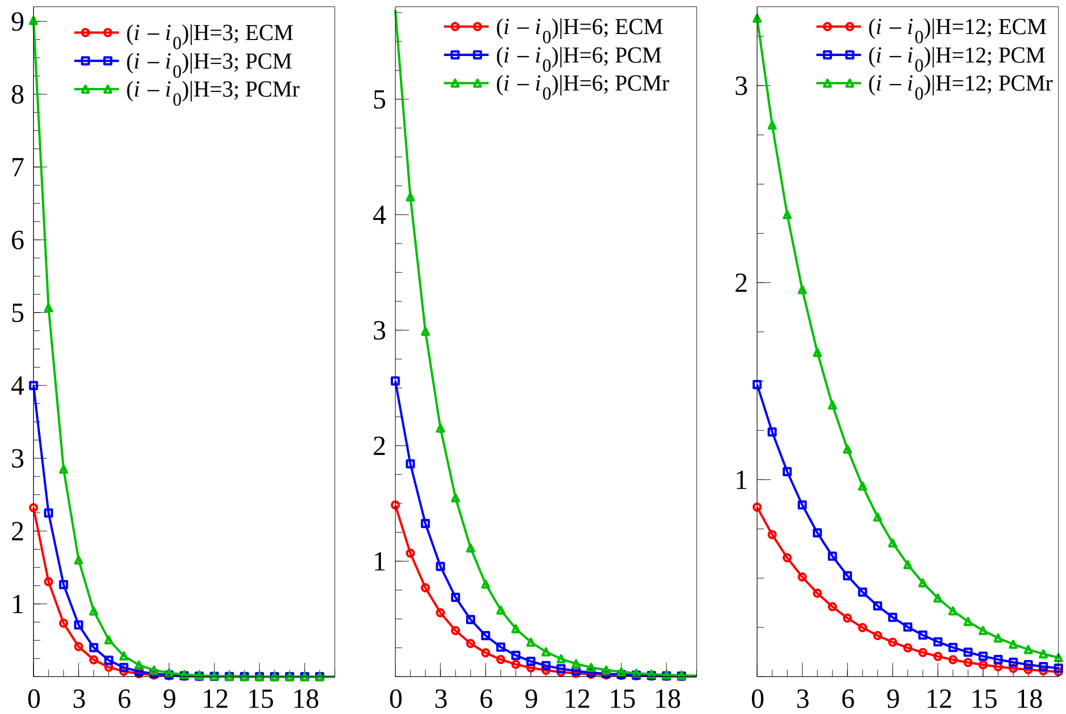

Figure 17: *Interest rate paths over time suggested by three versions of the model in the face of the supply shock. The three frames shows interest rate paths associated with the policy horizons of 3, 6 and 12 quarters, respectively. The interest rates are measured as deviation from the reference interest rate in percentage points, while the horizontal axes depict periods in quarters.*

between price and output stabilisation for different ranges of policy horizons. We note that in the case of ECM and PCM there is a trade-off in the range of 0 to 6 and 8 quarters. Policy horizons that are longer than 8 quarters appear inefficient as both price and output stabilisation 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 18, right panel, shows 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 λ from 0.5 would have increased the optimal policy horizons in all three models.)

The large differences in the monetary policy response represented by the optimal policy horizons across the three model versions can be mainly 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 systems of Phillips curves, (27) and (28), which have relatively stronger autoregressive effects than the wage-price VECM, (26), effectively make the transitory supply shock a more persistent one than the VECM. The larger the persistence, the more lasting

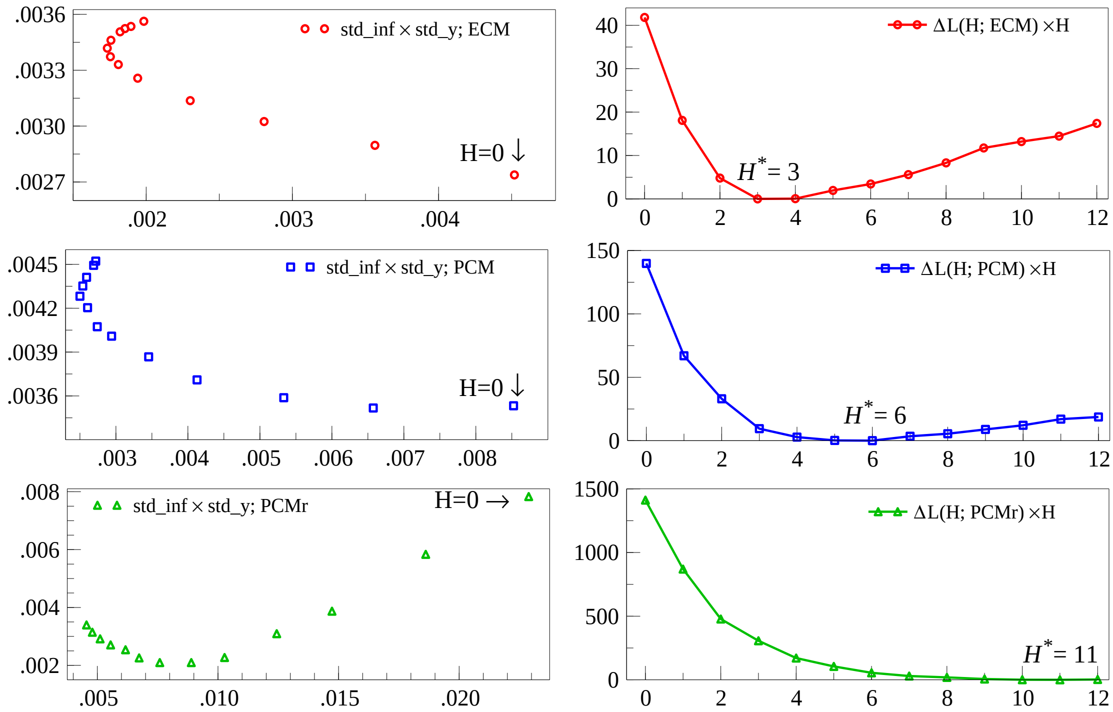

Figure 18: *Economic performance and optimal policy suggested by three versions of the model in the face of the supply shock. Left column: Standard deviations of inflation gap and output gap (horizontal axis) associated with different (policy) horizon-specific rules in response to the supply shock. The standard deviations are plotted for rules associated with policy horizons (H) in the range of 0–12 quarters, where that for $H = 0$ is indicated. Right column: Values of the relative loss function (in %), defined by equation (5), at the different policy horizons (horizontal axis).*

the inflationary effects. From above, we know that the optimal policy horizon increases with the degree of persistence.

Specifically, the degree of persistence implied by the lagged and contemporaneous terms of wages and prices in the vertical Phillips curves system (28) is higher than that implied by the Phillips curve system (27), which in itself implies higher persistence than equilibrium correction system (26). 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 optimal policy horizon is longer in the case of PCMr than in the case of PCM and relatively low in the case of ECM.

This analysis also sheds light on the costs of choosing a suboptimal policy horizon when the 'true' model is unknown. It appears that such costs depend on the model selected. For example, if we wrongly assume that $H^* = 3$, the loss would be much higher if PCMr turns out to be the true model rather than PCM.

8 Conclusions

We find that optimal policy horizons, and consequently optimal target horizons, hereafter 'the horizon(s)' are highly shock-specific and vary substantially with properties of shocks and a central banks's preferences for output stabilisation and smooth interest rate paths. When an inflation-targeting central bank cares about output stabilisation, the horizon depends on the shock type and its persistence, while its size and sign do not matter. The horizon is extremely short in response to an aggregate demand shock and implies an aggressive interest rate response to immediately eliminate deviations from the inflation target. In this case, there is no trade-off between inflation and output stabilisation. However, in the case of an aggregate supply shock, i.e. a direct shock to inflation, the horizon is relatively longer as there is a trade-off between inflation and output stabilisation in the short and medium run. In this case, the horizon increases with preferences for output stabilisation in a strongly concave fashion, up to some shock-specific level, though. Policy horizons beyond some shock-specific level amplify both inflation and output fluctuations and are therefore not chosen, irrespective of the strength of preferences for output stabilisation.

However, the result of a short optimal horizon in response to an aggregate demand shock and a relatively long one in response to an aggregate supply shock does not generalise to other kinds of demand and supply shocks. For example, we find that the horizon in the case of a shock to house prices, which can also be interpreted as a demand shock, is substantially longer than that for the aggregate supply shock. This is because the horizon generally depends on lags from effects of shocks and interest rates on inflation, additionally on output and/or interest rates under flexible inflation targeting. The horizon contributes to synchronising the effects of interest rate changes on inflation with those of shocks to maximise their offsetting effects. Thus, if the effects of a particular shock on inflation (and other target variables) emerge gradually and/or are distributed over many periods, relatively long (optimal) horizons will be preferred since they would, by extending the duration of a non-neutral monetary policy stance, make policy more effective in offsetting the effects of the shock than relatively short horizons. A relatively short horizon would be preferred in the opposite case. Accordingly, the horizon generally increases with the persistence of a shock, since the effects of a persistent shock are distributed over more periods than those of a less persistent or transitory shock. Furthermore, even a strict inflation-targeting central bank may prefer a long horizon when the inflationary effects of a shock emerge gradually.

The horizon increases with the size of a shock when the central bank also cares about interest rate fluctuations. A longer horizon moderates required interest rate movements. The increase in the horizon with the size of the shock depends on the degree of concern for interest rate fluctuations. An extension of the horizon beyond some shock-specific level can, however, prove counterproductive and hence not undertaken, as in the case of strong concern for output fluctuations. The horizon does not depend on the sign of a given shock as the model is linear.

However, our results for the case when the central bank faces a combination of several shocks differ somewhat from the above-noted results for individual shocks. In contrast to the latter case, the sizes and signs of different shocks also influence the horizon, even in the absence of preferences for smooth interest rates and despite using a linear model. This is because shocks may outweigh or amplify the effects of each other. Therefore, the horizon associated with a combination of shocks may not be just a convex combination of the horizons suggested by the different shocks individually. Moreover, combined shocks may contribute to a complex dynamic behaviour of inflation and output, warranting a quite complex monetary policy response to achieve stabilising effects. In a substantial number of such cases, monetary policy as modelled has even turned out to be destabilising, calling for complex interest rate paths to achieve desirable effects in the face of combined shocks.

Our investigation of the model-dependence of the horizons suggests that they fall with the strength of equilibrium-correcting mechanisms in a model, ceteris paribus. When such mechanisms are weak, effects of shocks tend to be distributed over more periods than when the mechanisms are strong. Thus, relatively long horizons are preferred when the mechanisms are weak, and vice versa. This analysis sheds light on relatively long optimal horizons found previously.

Our estimates of the horizons and the associated optimal target horizons in the case of transitory shocks are close to those typically announced by inflation-targeting central banks. Such horizons may be rather short in the face of relatively persistent shocks, however. It also appears that there may be substantial costs associated with adhering to a fixed policy horizon, irrespective of shock type and its properties. Such losses imply substantial gains from a precise derivation of the horizons in response to different shocks as well as from timely identification of shocks and their properties. Moreover, the non-negligible number of cases with combined shocks where monetary policy has turned out to be destabilising is a useful reminder of Friedman's argument that active monetary policy is demanding.

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A Impulse responses

Figures 19–23 display the response of the key variables inflation (Inf) and output (y) to transitory partial increases in the nominal interest rate (i), aggregate demand (y), consumer prices (cpi), the nominal exchange rate (e) and house prices (hp). The results are invariant to the choice of simulation horizon because the model is (log) linear.

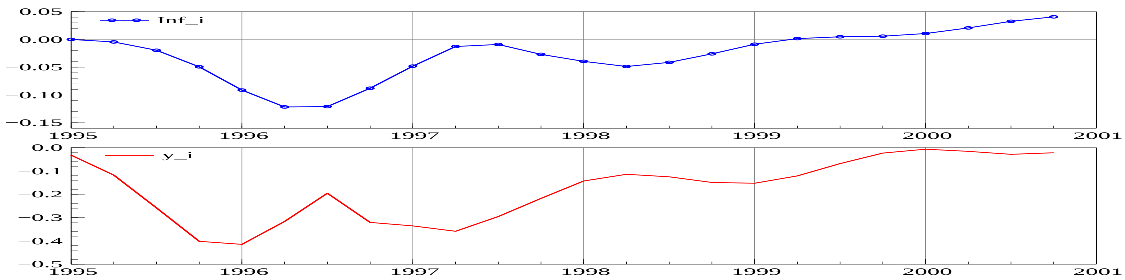

Figure 19: *Responses to a one percentage point (pp) higher short-term interest rate over the period 1995q1–1995q4. Here and elsewhere, solid lines depict deviations from the baseline simulations. "Inf_i" and "y_i" represent the impulse responses of inflation and output gaps, respectively, to the change in interest rate.*

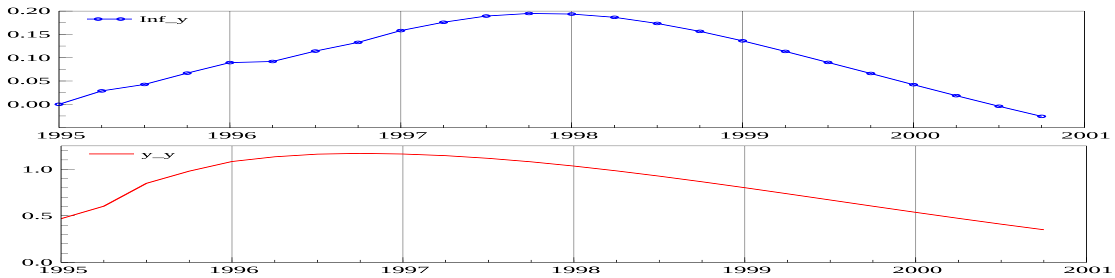

Figure 20: *Responses to a transitory shock that induces a 1 pp increase in output growth in 1995.*

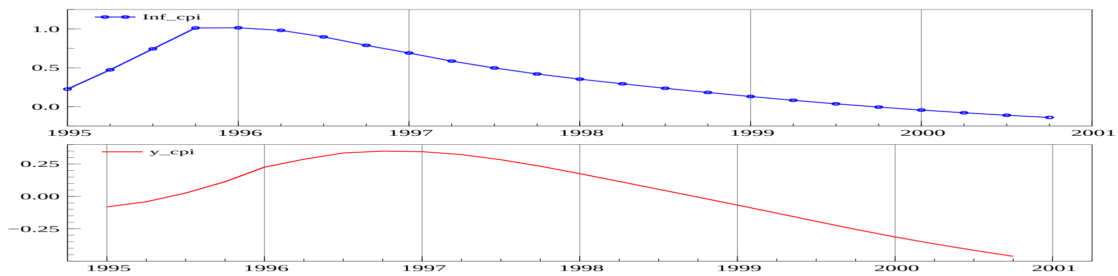

Figure 21: *Responses to a transitory shock that increases CPI-inflation by 1 pp in 1995.*

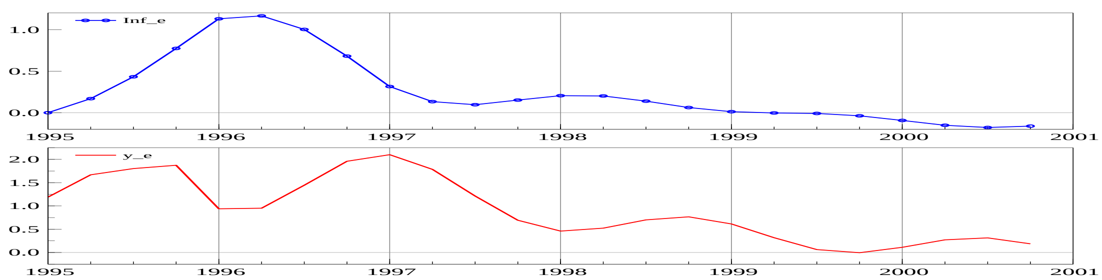

Figure 22: *Responses to a transitory shock that induces a 10% depreciation of the nominal exchange rate in 1995.*

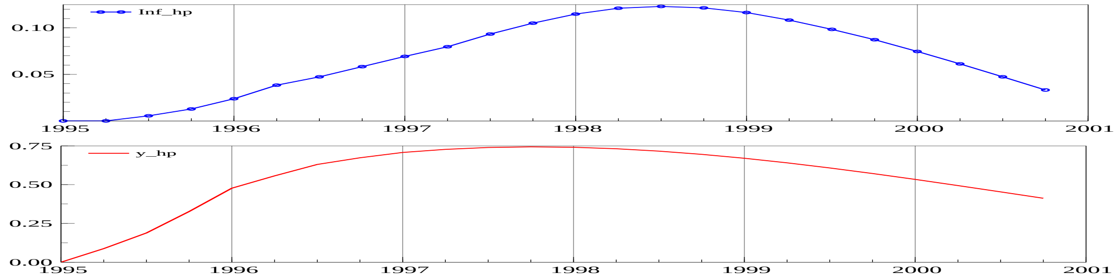

Figure 23: *Responses to a transitory shock that induces a 10% increase in house prices in 1995.*

B Data definitions

The econometric model is based on seasonally unadjusted quarterly data. Unless another source is given, the time series have been extracted from databases maintained by Norges Bank (the central bank of Norway). The variables are precisely defined in Rikmodnotat 140, Norges Bank. The variables as named in the RIMINI database are noted in square brackets [.] below. Where relevant, the base year is 1991 and the unit of measurement is mill. NOK.

Mainland economy is defined as the total Norwegian economy excluding oil and gas production and international shipping.

Impulse dummies are denoted as *iyyq***x**. For example, *i80q2* is 1 in the second quarter of 1980 and 0 in all other quarters.

E Effective import-weighted value of NOK; 1991 = 1. [CPIVAL].

H Standard working hours per week. [NH]

L Nominal credit volume. Mill. NOK. [K1M]. ℓ is log of nominal credit volume. L is a domestic credit indicator, including loans to the non-financial private sector and municipalities from all domestic financial institutions as well as bonds and short-term papers issued by some sectors.

$OILP$ Brent Blend crude oil prices per barrel in USD. [SPOILUSD].

P Norwegian Consumer Price Index. [CPI].

P^* Index for consumer prices in Norway's trading partners in foreign currency. [PCKONK].

PH Index for house prices in Norway. [PH].

PI Deflator of total imports; [PB].

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

PU Underlying consumer price index: CPI adjusted for indirect taxes, electricity and fuel prices. [CPI-ATE].

r Euro-krone nominal interest rate with 3-month maturity. [RS].

S Stock Price Index for Oslo Stock Exchange. [OSE].

S^* Morgan Stanley World Index (MSCI).

$\tau 1$ Employers' tax rate; [$T1$]

$\tau 3$ Indirect tax rate; [T3].

U Unemployment rate. [UR2].

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

W Hourly wages in mainland Norway.

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

$Pdum$ Composite dummy for introduction and removal of direct price regulations. 1 in 1971q1, 1971q2, 1976q4, 1979q1; -1 in 1975q1, 1980q1, 1981q1, 1982q1; and zero otherwise.

C Alternative wage and price models

A VECM of wages and prices:

$$\begin{aligned}\Delta w_t &= -\underset{(0.01)}{0.11}[w_{t-3} - p_{t-1} - pr_{t-1} + 0.15u_{t-2}] + \underset{(0.07)}{0.16}\Delta w_{t-1} \\ &\quad + \underset{(0.02)}{0.06}\Delta pr_t - \underset{(0.12)}{0.54}\Delta h_t - \underset{(0.002)}{0.02} W_{d,t} \\ \Delta p_t &= \underset{(0.01)}{-0.06}[p_{t-3} - 0.6(w_{t-3} - pr_{t-1} + \tau 1_{t-1}) - 0.4 pi_{t-1} + 0.5\tau 3_{t-1}] \\ &\quad + \underset{(0.05)}{0.16}\Delta p_{t-2} + \underset{(0.03)}{0.21}\Delta w_t + \underset{(0.03)}{0.13}\Delta w_{t-1} + \underset{(0.02)}{0.04}\Delta_2 y_{t-1} \\ &\quad - \underset{(0.01)}{0.01}\Delta pr_t + \underset{(0.01)}{0.03}\Delta pi_t + \underset{(0.01)}{0.06}\Delta pe_t - \underset{(0.001)}{0.01} P_{d,t}\end{aligned} \tag{15}$$

The system of Phillips curves favoured by data is reported in (27):

$$\begin{aligned}\Delta w_t &= -\underset{(0.07)}{0.20}\Delta w_{t-1} + \underset{(0.13)}{0.27}\Delta p_{t-1} + \underset{(0.13)}{0.28}\Delta p_{t-2} \\ &\quad - \underset{(0.004)}{0.01}\Delta u_t - \underset{(0.001)}{0.01} u_{t-1} - \underset{(0.002)}{0.016} W_{d,t} \\ \Delta p_t &= \underset{(0.07)}{0.10}\Delta p_{t-1} + \underset{(0.06)}{0.20}\Delta p_{t-2} + \underset{(0.05)}{0.31}\Delta w_t + \underset{(0.04)}{0.16}\Delta w_{t-1} + \underset{(0.01)}{0.05}\Delta_2 y_{t-1} \\ &\quad + \underset{(0.01)}{0.03}\Delta pi_t + \underset{(0.01)}{0.07}\Delta pe_t - \underset{(0.001)}{0.01} P_{d,t}\end{aligned} \tag{16}$$

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

$$\begin{aligned}\Delta w_t = &-\underset{(--)}{0.18}\Delta w_{t-1} + \underset{(0.12)}{0.58}\Delta p_{t-1} + \underset{(0.12)}{0.60}\Delta p_{t-2} \\ &- \underset{(0.006)}{0.01}\Delta u_t - \underset{(0.0013)}{0.003}u_{t-1} - \underset{(0.003)}{0.017}W_{d,t} \\ \Delta p_t = &\underset{(0.07)}{0.21}\Delta p_{t-1} + \underset{(0.06)}{0.26}\Delta p_{t-2} + \underset{(--)}{0.26}\Delta w_t + \underset{(0.03)}{0.16}\Delta w_{t-1} + \underset{(0.01)}{0.07}\Delta_2 y_{t-1} \\ &+ \underset{(0.01)}{0.04}\Delta pi_t + \underset{(0.01)}{0.07}\Delta pe_t - \underset{(0.001)}{0.01}P_{d,t}\end{aligned} \tag{17}$$

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