WORKING PAPER

The role of oil prices and monetary policy in the Norwegian economy since the 1980s

NORGES BANK
RESEARCH

1 | 2016

AUTHORS:

Q. FAROOQ AKRAM
AND
HAROON MUMTAZ

NORGES BANK

Working papers fra Norges Bank, fra 1992/1 til 2009/2 kan bestilles over e-post:
FacilityServices@norges-bank.no

Fra 1999 og senere er publikasjonene tilgjengelige på www.norges-bank.no

Working papers inneholder forskningsarbeider og utredninger som vanligvis ikke har fått sin endelige form. Hensikten er blant annet at forfatteren kan motta kommentarer fra kolleger og andre interesserte. Synspunkter og konklusjoner i arbeidene står for forfatternes regning.

Working papers from Norges Bank, from 1992/1 to 2009/2 can be ordered by e-mail
FacilityServices@norges-bank.no

Working papers from 1999 onwards are available on www.norges-bank.no

Norges Bank's working papers present research projects and reports (not usually in their final form) and are intended inter alia to enable the author to benefit from the comments of colleagues and other interested parties. Views and conclusions expressed in working papers are the responsibility of the authors alone.

ISSN 1502-819-0 (online)
ISBN 978-82-7553-890-9 (online)

The role of oil prices and monetary policy in the Norwegian economy since the 1980s*

Q. Farooq Akram[†] Norges Bank Research

Haroon Mumtaz[‡] Queen Mary College

December 30, 2015

Abstract

We use a TVP-VAR model to investigate possible changes in the time series properties of key Norwegian macroeconomic variables since the 1980s. The sample period is characterised by deregulation, globalization, sizable petroleum revenues, a switch from exchange rate to inflation targeting and adoption of a policy rule for the use of petroleum revenues. We find that the long-run means of CPI and core inflation rates declined significantly until the mid-1990s and have since then remained close to the inflation target of 2.5% from 2001 onwards. The persistence in especially CPI inflation has fallen during the inflation targeting period while the volatility of both inflation rates and the nominal effective exchange rate has increased. We document an increase in the correlations between money market rates and the inflation rates as well as the output gap during the inflation targeting period and a steady decline towards zero in the correlations between money market rates and nominal exchange rate changes. There is evidence of an increase in the correlations between oil prices and the other macroeconomic variables over time. Our counterfactual analysis suggests oil shocks to have been important for output gap and inflation volatility while monetary policy shocks have been important for driving inflation persistence and the correlation of money market rates with macroeconomic variables.

Key words: Time-varying coefficients, stochastic volatility, persistence, great moderation, inflation targeting.
JEL codes: C51, E31, E32, E52, E58.

1 Introduction

We examine the dynamic properties of key Norwegian macroeconomic variables and their comovements over the last three decades. We shed light on especially the following issues: (a) how has the nominal exchange rate, interest rates, output gap and inflation behaved under the exchange rate targeting and inflation targeting regimes? (b) did Norway experience moderation in macroeconomic volatility prior to the recent financial crisis as has been documented for e.g. the US and the UK?; see Cogley and Sargent (2005) and Benati (2007); (c) to what extent

*This Working Paper should not be reported as representing the views of Norges Bank. The views expressed are those of the authors and do not necessarily reflect those of Norges Bank. The authors would like to thank the seminar participants at Norges Bank for useful comments.

[†]Email: farooq.akram@norges–bank.no

[‡]Email: h.mumtaz@qmul.ac.uk

have oil prices affected the properties of the nominal exchange rate, output gap and inflation over time, particularly since the adoption of the Norwegian fiscal policy rule regarding the consumption of oil revenues? (d) how has monetary policy responded to these variables over time, especially under the inflation targeting regime? And finally, (e), are there changes in the correlations between variables that coincide with shifts in the openness of the economy?

The relatively small and open Norwegian economy with a large petroleum sector has undergone substantial structural and policy changes since the 1980s, in addition to deregulation of house and credit markets and international capital flows during the 1980s; see Bårdsen and Klovland (2000) and Norges Bank (1995). For example, from 1990 to 2014, the share of imports of goods and services from emerging economies increased steadily from below 5% to 24%; the China's share of imports increased from close to zero to about 10%. The economy also became more open to inflow of foreign labour; the total number of immigrants more than doubling over the last ten year mostly due to the process of European labour market integration. From 1990 onwards, the share of crude petroleum exports of total exports increased from around 25% to more than 50% while the share of the Norwegian petroleum sector increased from around 10% to around 30% of (mainland) GDP. These developments in combination with shifts in government policies over the period may have altered the dynamics of Norwegian GDP, exchange rates and inflation and their co-movements.

Regarding government policies, public petroleum revenues have been accumulated in an oil fund since 1996 whose size is currently more than double Norwegian mainland GDP. To partly manage the flow of oil revenues into the mainland economy, the government has mostly followed a fiscal policy rule since March 2001 which limits oil revenues spending to around 4% of the fund's market value. One of the objectives of the fiscal rule has been to shield the economy from excessive fluctuations in petroleum revenues due to e.g. changes in oil prices; (see Olsen and Skjæveland (2002) and Gjedrem (2005)).

Norwegian monetary policy switched formally from exchange rate to inflation targeting in 2001, simultaneously with the adoption of the fiscal policy rule. This has been practiced as flexible inflation targeting where the central bank's interest rate setting has aimed to achieve the inflation target at 2.5% in the medium run while avoiding fluctuations of aggregate output around its trend level; see Svensson (2005).[1]In addition to the formal shifts in monetary policy regimes over time, actual policies within prevailing regimes could have changed over time due to e.g. possible shifts in decision makers preferences or the severity of shocks. There could have been changes in the policy response before and after the move away from exchange rate targeting to inflation targeting and in the aftermath of the financial crisis of 2008; see e.g. Gjedrem (1999), Norges Bank (2012), Evjen and Kloster (2012) and Olsen (2013, 2014).

We employ a time-varying parameters VAR model with stochastic volatilities to describe the behaviour of the macroeconomic variables over the period 1983Q4–2014Q4; see Primiceri (2005) and Cogley and Sargent (2005). The variables modelled are the real Norwegian GDP relative to its HP-filtered trend, consumer price inflation, nominal effective exchange rate changes and short term money market rates. Real crude oil prices are treated as exogenous in the model. The model allows for time-variation in all parameters including variances-covariances of shocks. It is therefore suitable for characterizing possible shifts in the behaviour of variables and stochastic shocks in response to gradual and swift structural and policy changes. Allowance for time variation in the variances of shocks enables us to assess the contribution of shocks to variation

[1]The inflation target in Norway was set a half percentage point higher than in most of its main trading partners including many European union countries in anticipation of a real exchange rate appreciation of a half percentage point because of Norway's substantial petroleum revenues; see Olsen and Skjæveland (2002). A gap of half percentage point between the inflation targets in Norway's and its main trading partners was expected to maintain a stable nominal exchange rate. An inflation target equal to that in the trading partners on the other hand was expected to lead to a systematic nominal exchange appreciation to bring about the real exchange rate appreciation implied by the petroleum revenues; see Olsen and Skjæveland (2002).

in macroeconomic volatility over time.

Our paper is related to the empirical literature on the Great Moderation, performance of inflation targeting regimes, changes in policy transmission mechanims and the macroeconomic effects of commodity prices. It is however the first such study based on Norwegian data.[2] Evidence on the effects of oil prices, the performance of inflation targeting and the monetary policy response in Norway may be of general interest for at least two reasons. First, Norway is a major petroleum producing country with well regulated use of petroleum revenues through the fiscal policy rule. Second, the implementation of the flexible inflation targeting regime in Norway has been close to if not the best practice according to leading monetary policy researchers; see Svensson (2010), Walsh (2014) and Woodford (2007, 2013).

The paper is organized as follows. The next Section (2) lays out the modelling framework together with data and estimation details. Section 3 presents the time varying properties of the variables and corresponding stochastic shocks in addition to a discussion of changes in the persistence of inflation across different monetary policy regimes over the sample period. Section 4 investigates more closely the response of the Norwegian economy to oil shocks and monetary policy shocks by way of counterfactual analysis. Section 5 concludes. Further details about the estimation method and several robustness tests are presented in the appendix.

2 Empirical model

We estimate the following time-varying parameter VAR model:

$$\begin{pmatrix} O_t \\ Z_t \end{pmatrix} = c_t + \begin{pmatrix} B_{1,t}(L) & 0 \\ B_{2,t}(L) & B_{3,t}(L) \end{pmatrix} \begin{pmatrix} O_t \\ Z_t \end{pmatrix} + v_t, \tag{1}$$

where O_t denotes the de-trended real oil price. Z_t is a data matrix that includes HP filtered real GDP, quarterly inflation, the 3 month money maket rate and the quarterly growth of the nominal effective exchange rate (NEER) respectively: $Z_t = \{y_t, \Delta p_t, R_t, \Delta q_t\}$. c_t is a vector of intercepts while $B_{i,t}(L)$ denotes a lag polynomial with L denoting the lag length. The model assumes that the oil price is pre-determined with respect to Norwegian variables and follows an autoregressive process. We estimate two versions of the model: (1) Model A which uses core inflation as a measure of Δp_t and Model B which uses CPI inflation. Both inflation series are in terms of annualised quarterly growths of the corresponding price indices. Precise defintions of the data series used are presented in Appendix A.

We postulate the following law of motion for the coefficients:

$$\tilde{\phi}_{l,t} = \tilde{\phi}_{l,t-1} + \eta_t, \tag{2}$$

where $\tilde{\phi}_{l,t} = \{vec(c_t), vec(B_{i,t})\}$ represents the time-varying coefficients stacked in one vector and η_t is a conformable vector of innovations.

The covariance matrix of the innovations v_t is factored as in Primiceri (2005):

$$VAR(v_t) \equiv \Omega_t = A_t^{-1} H_t (A_t^{-1})'. \tag{3}$$

The (time-varying) matrix A_t is lower triangular with ones on the main diagonal while matrix H_t is defined as $diag(h_{1,t}, h_{2,t}, .., h_{N,t})$; $h_{i,t}$ evolves as geometric random walks,

$$\ln h_{i,t} = \ln h_{i,t-1} + \tilde{\nu}_t.$$

[2] Our paper is close to Alstadheim *et al.* (2013) in its focus on the monetary policy response function before and after the introduction of inflation targeting. Based on Markov Switching models, they concluded that monetary policy continued to respond to exchange rate fluctuations after the switch to the inflation targeting regime in 2001.

Following Primiceri (2005), we postulate the non-zero and non-one elements of the matrix A_t to evolve as driftless random walks,

$$\alpha_t = \alpha_{t-1} + \tau_t, \tag{4}$$

and we assume the vector $[\upsilon_t', \eta_t', \tau_t', \tilde{\nu}_t']'$ to be distributed as:

$$\begin{bmatrix} \upsilon_t \\ \eta_t \\ \tau_t \\ \tilde{\nu}_t \end{bmatrix} \sim N(0, V), \text{ with } V = \begin{bmatrix} \Omega_t & 0 & 0 & 0 \\ 0 & Q & 0 & 0 \\ 0 & 0 & S & 0 \\ 0 & 0 & 0 & G \end{bmatrix} \text{ and } G = \begin{bmatrix} \sigma_1^2 & 0 & 0 & 0 & 0 \\ 0 & \sigma_2^2 & 0 & 0 & 0 \\ 0 & 0 & \sigma_3^2 & 0 & 0 \\ 0 & 0 & 0 & \sigma_4^2 & 0 \\ 0 & 0 & 0 & 0 & \sigma_5^2 \end{bmatrix}. \tag{5}$$

2.1 Estimation and data

The model described by equations (1)–(5) constitutes a Seemingly Unrelated Regression (SUR) model with time-varying parameters. The model is estimated using the Bayesian methods described in Chib and Greenberg (1995). In particular, we employ a Gibbs sampling algorithm that approximates the posterior distribution. A detailed description of the prior distributions and the sampling method is given in the Appendix B. Here we summarize the basic algorithm which involves the following steps:

1. The coefficients $\tilde{\phi}_{l,t}$ and the off-diagonal elements of the covariance matrix A_t are simulated by using the methods described in Carter and Kohn (1994). As is common practice in this literature (see e.g. Cogley and Sargent (2005)) we impose the constraint that the VAR coefficient matrix should be stable at each point in time.

2. The volatilities of the reduced form shocks H_t are drawn using the date by date blocking scheme introduced in Jacquier *et al.* (1994).

3. The hyperparameters Q and S are drawn from an inverse Wishart distribution while the elements of G are simulated from an inverse gamma distribution.

Appendix C shows that the recursive means of the retained draws appear stable providing evidence of convergence.

The lag length is fixed at two. Given the relatively large size of the model, this choice of lag length helps to ensure that the stability constraint in step 1 of the algorithm can be imposed.

The main data set runs from 1980Q1 to 2014Q4. As described in Appendix A, the estimation algorithm is initialised (and priors set) by using a pre-sample of 50 observations. This pre-sample is chosen to be 1971Q3 to 1983Q4. The actual estimation is carried out using data starting in 1983Q4.

3 Empirical Results

3.1 Time-varying trends

Consider the TVP-VAR model in equation (1) written in companion form at time t:

$$Y_t = \mu_t + F_t Y_{t-1} + V_t, VAR(V_t) = \Omega_t^*, \tag{6}$$

where $Y_t = \{O_t, Z_t, O_{t-1}, Z_{t-1}, ..., O_{t-L-1}, Z_{t-L-1}\}$ and μ_t, F_t and Ω_t^* are the VAR intercepts, coefficients and the error covariance written in a form conformable with Y_t. We estimate the time-varying unconditional mean of each variable as the local linear approximation:

$$E(Y_t) = e_N (I - F_t)^{-1} \mu_t,$$

where e_N is a selection matrix that picks out the first N elements of $E(Y_t)$. The estimated unconditional means are shown in Figure 1 along with the actual data used in the two benchmark models. These estimates allow us to investigate if they have experienced notable changes in the face of several and substantial structural and policy changes.

It is seen that the estimated long run mean of HP-filtered real GDP has not changed over time despite structural changes in the Norwegian economy. It is roughly equal to the level in the 1980s. It is also interesting to observe that the mean of the nominal exchange rate depreciation has been close to zero throughout the estimation period. Notably, we do not observe any systematic appreciation or depreciation of the exchange rate despite the growing importance of the petroleum sector and shifts from fixed exchange rate to floating exchange rate policies over the sample period. The estimated means of the money market rates generally decline over the whole estimation period.

The long run means of the inflation rates decline over time but stabilize at annual rates of around 2.5%, the inflation target since 2001Q1. The long run mean of the quarterly core inflation declined smoothly until around 1995, and then stabilized at the level achieved afterwards. We do not observe any notable further change in it in the late 1990s and when inflation targeting was introduced in 2001. While the convergence to lower inflation rates and money market rates roughly coincided until the mid-1990s, the further decline in interest rates since then has not been accompanied by changes in the mean of the inflation rate. The fall in the long run means of inflation is in line with the observations of Great Moderation in e.g. the US and the UK. Such falls have been partly contributed to the success of inflation targeting regimes/approaches.

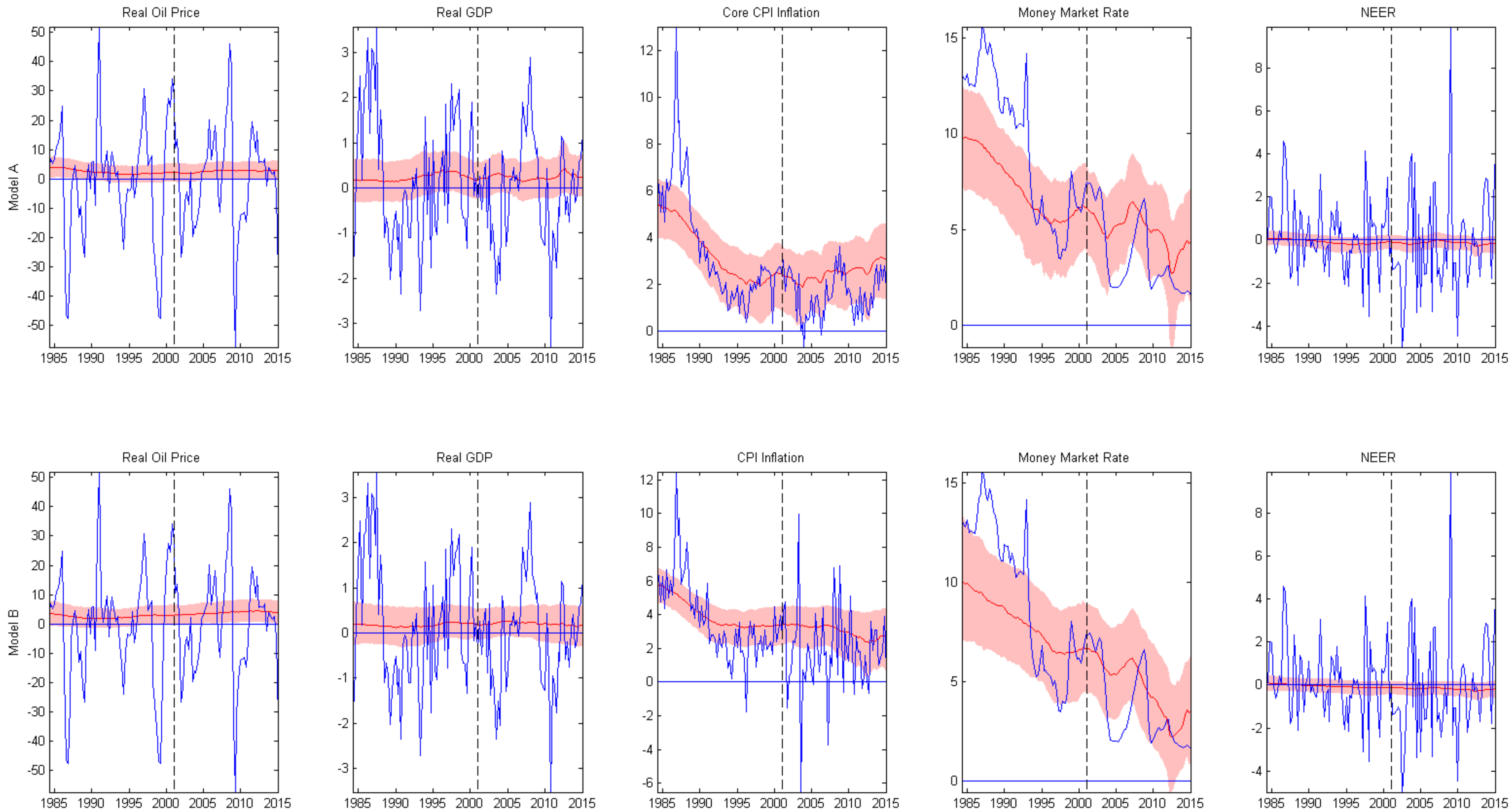

Figure 1: Time-varying unconditional means of endogenous variables and actual data. The red line is the median estimate while the shaded area represents the 68% error band. The blue lines represent the actual data.

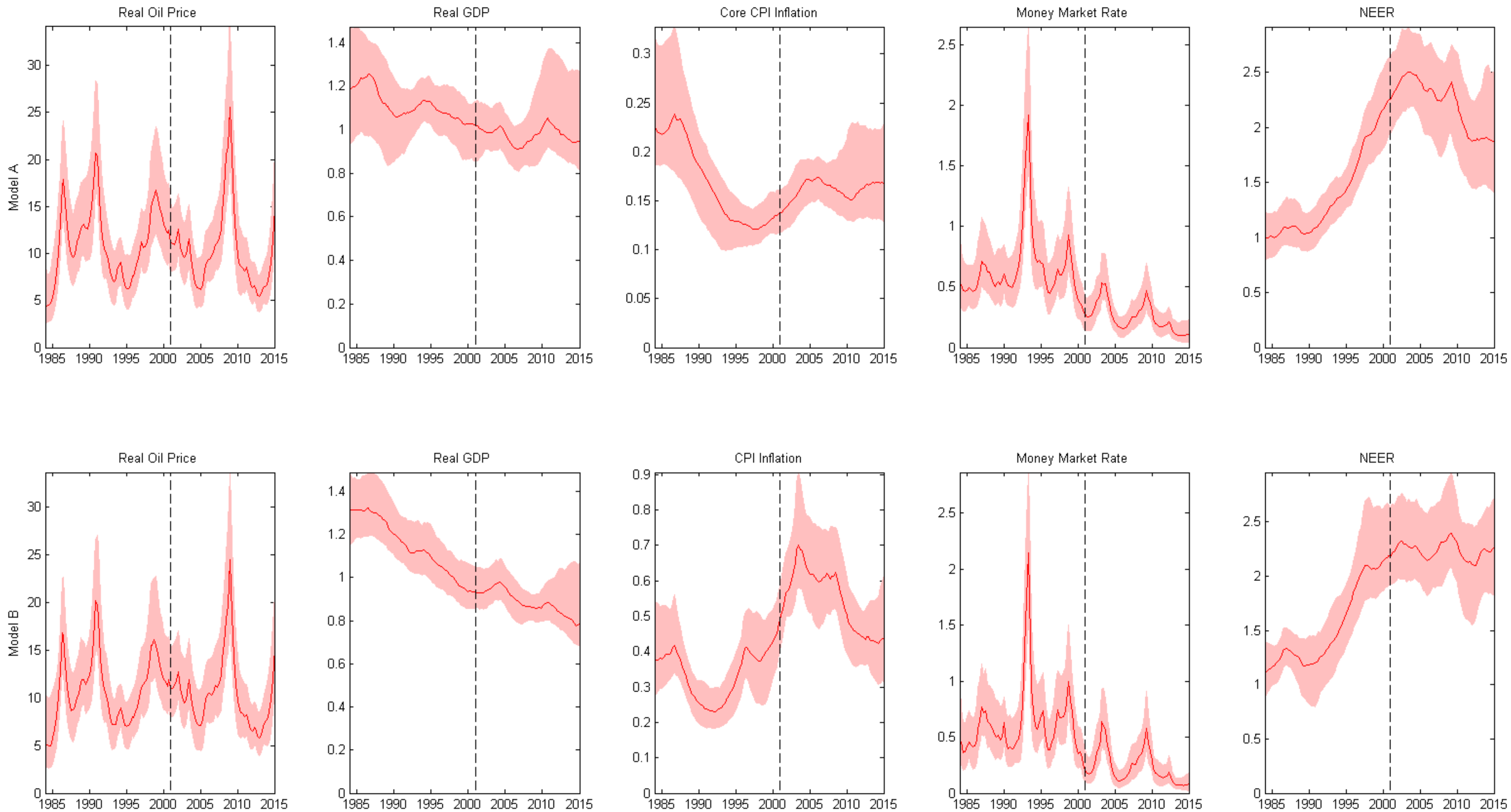

Figure 2: Stochastic Volatility. The red line is the median estimate while the shaded area represents the 68% error band.

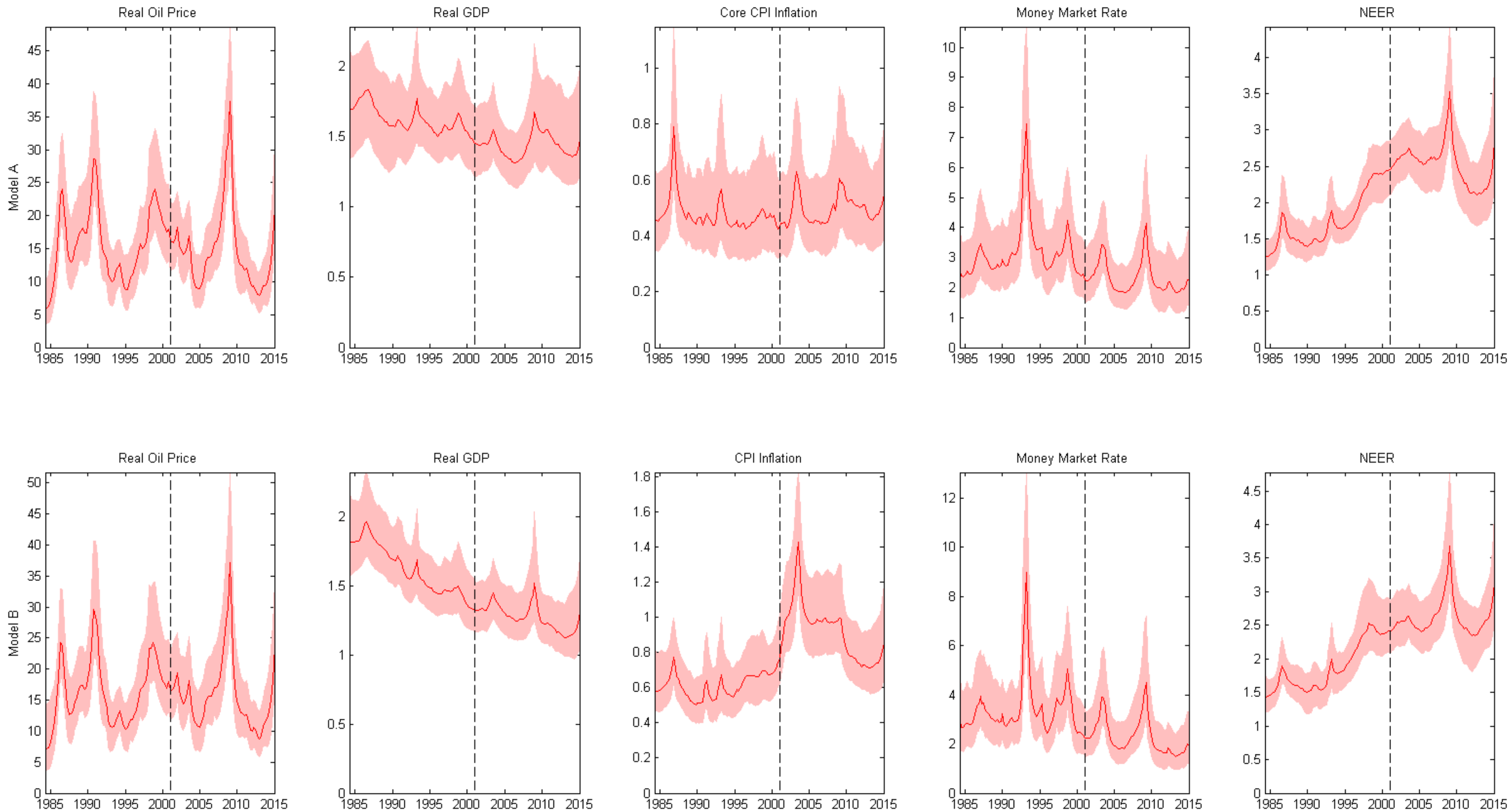

Figure 3: Time-varying unconditional standard deviation of endogenous variables and actual data. The red line is the median estimate while the shaded area represents the 68% error band.

3.2 Macroeconomic volatility

Figures 2 and 3 show the evolution of volatility as measured by our empirical model. In Figure 2 we plot the stochastic volatility of shocks from the two models. Figure 3 plots the estimated unconditional standard deviation of each endogenous variable in the models. This is approximated at each time period from the companion form of the model in equation (6) as:

$$sd\left(Y_t\right) = \sqrt{e_N \left(I - F_t \otimes F_t\right)^{-1} vec\left(\Omega_t^*\right)}$$

Consider Figure 2. While the volatility of shocks to GDP gap, core inflation and the money market rate has declined over time, there is strong evidence that the variance of shocks to oil prices, CPI inflation and the change in the NEER has increased over the last two decades. Therefore, evidence of the Great Moderation in Norway appears to be mixed.

This observation is underscored by the estimates of unconditional standard deviations in Figure 3. There is no evidence of moderation in the volatility of key macroeconomic series except for GDP over time.

Substantial increases in the volatility of real oil prices in different periods are consistent with the relatively large falls of oil prices in 1986, 1998, 2008-2009, 2014 and the sharp rise during the Gulf War in 1990. These falls and rises in the volatility of oil prices coincide with comparable swings in the volatility of oil price shocks; see Figure 2.

GDP gap volatility shows a downward trend over time; see Figure 3. Except for a brief period due to the recent financial crisis, the GDP gap fluctuations decreased steadily over almost the whole sample period from 1985 onwards. There does not seem to be any notable change in the trend after 2001 when inflation targeting and the fiscal policy rule were adopted. The steady decline in the volatility of the GDP gap except for occasional changes coincides with a comparable but smoother decline in the volatility of shocks to GDP gap.

In contrast, the volatility of inflation was relatively lower and more stable in the sample period before 2001. Since then, the volatility of CPI inflation initially increased, but has subsequently stabilised at relatively lower level, yet at a somewhat higher level than during the 1990s. Figures 2 and 3 suggest that the substantial increase in the volatility of CPI inflation coincided with a substantial rise in the volatility of shocks to inflation. The former follows largely the same pattern as the volatility of CPI inflation. The volatility of core inflation has also stabilized at a higher level over time relative to its remarkably low level during the second half of the 1990s.

Exchange rate volatility increases notably after 1992–1993 onwards and stabilizes at a relatively high level after the year 2000. If one overlooks the exceptional rise during 2008–2009 and the recent increase, it has stabilized at a level around two times higher than before the autumn of 1998. Thus there seems to be a clear distinction between the period before and after the autumn of 1998, when the policy of exchange rate stabilisation was given up in the face of a particularly large depreciation of the exchange rate in response to the relatively large fall in oil prices.

Figure 2 shows that the volatility of exchange rate shocks increased over the same period as the volatility of the exchange rate. Spikes in the volatility of the exchange rate in 2008 and 2014 do not seem to be due to comparable increases in the volatility of shocks to the exchange rate; volatility of the shocks to the exchange rate rises in a relatively smoother way than the unconditional volatility of the exchange rate. Variation in the volatility of the shocks to the exchange rate can be roughly described as a smooth transition from a low to high volatility regime with a clear distinction between the period before and after 1997/1998.

The relatively high degree of comparability between time variation in the volatility of the exchange rate changes and that of volatility in the shocks to the exchange rate is consistent

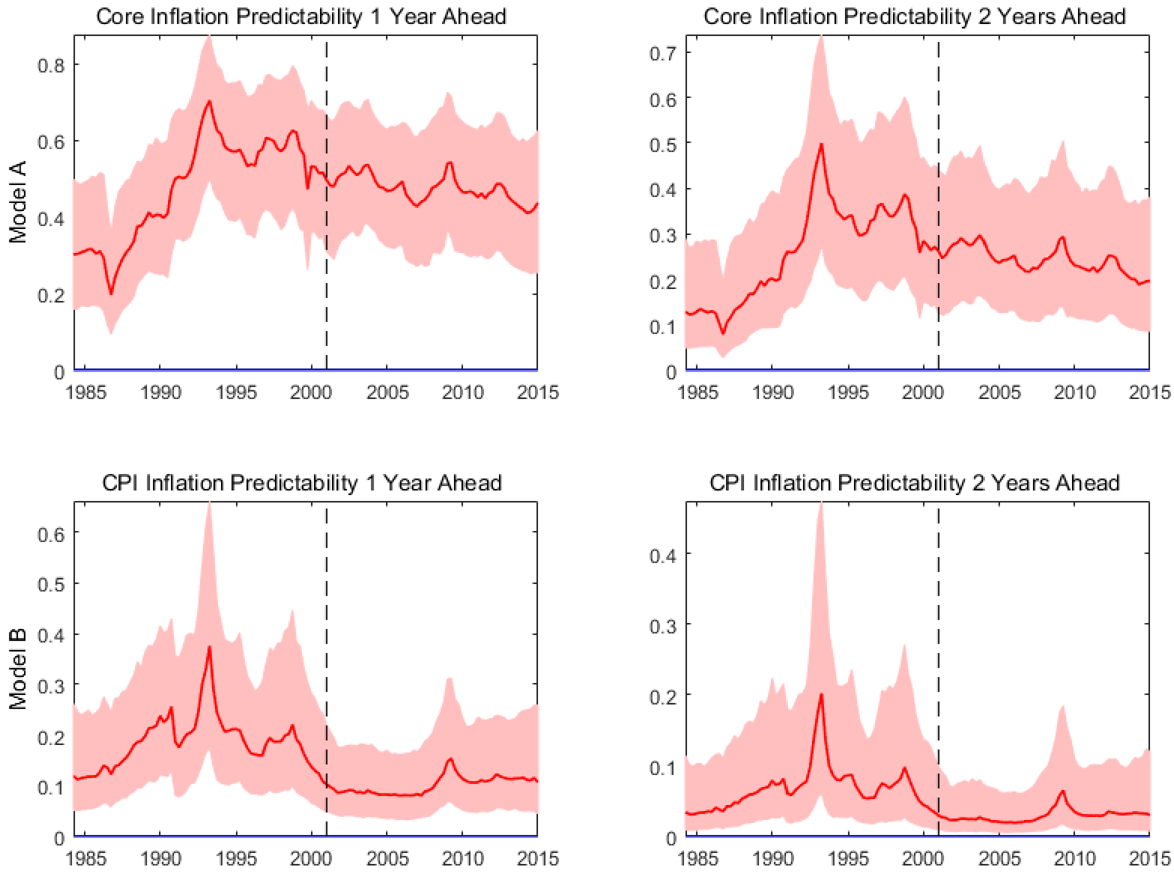

Figure 4: Inflation predictability one year ahead and two years ahead. The solid red line is the median estimate while the red band is the 68% error band.

with the disconnect puzzle; accordingly, nearly all of the variation in the exchange rate changes can be ascribed to variation in the shocks to the exchange rate changes.

In sum, we do not observe clear evidence of the Great Moderation. While there is a trend-wise decline in the variance of the GDP gap since the mid 1980s, we do not find evidence of a decline in the variance of both inflation measures. It is difficult to associate the decline in the variance of the GDP gap to any policy change and it seems to be owing at least predominantly if not exclusively to a decline in the variances of shocks to the GDP gap. The volatility of the exchange rate has increased as expected with the shift to a regime of floating exchange rates. On the other hand, one may have expected a decline in the volatility of the inflation rate under the flexible inflation targeting regime which has not taken place. This seems to be mainly due to the volatility of shocks.

3.3 Inflation persistence

In order to explore inflation persistence we calculate the predictability of inflation rates as proposed in Cogley *et al.* (2008). That is, we measure the variability of inflation in excess of its unconditional mean due to past shocks relative to the variability due to future shocks. This predictability measure can be calculated as:

$$R_J^2 = 1 - \frac{e_\pi \sum_{j=1}^{J} F^j V_{t+j} F^{j\prime}}{e_\pi \sum_{j=1}^{\infty} F^j V_{t+j} F^{j\prime}}$$

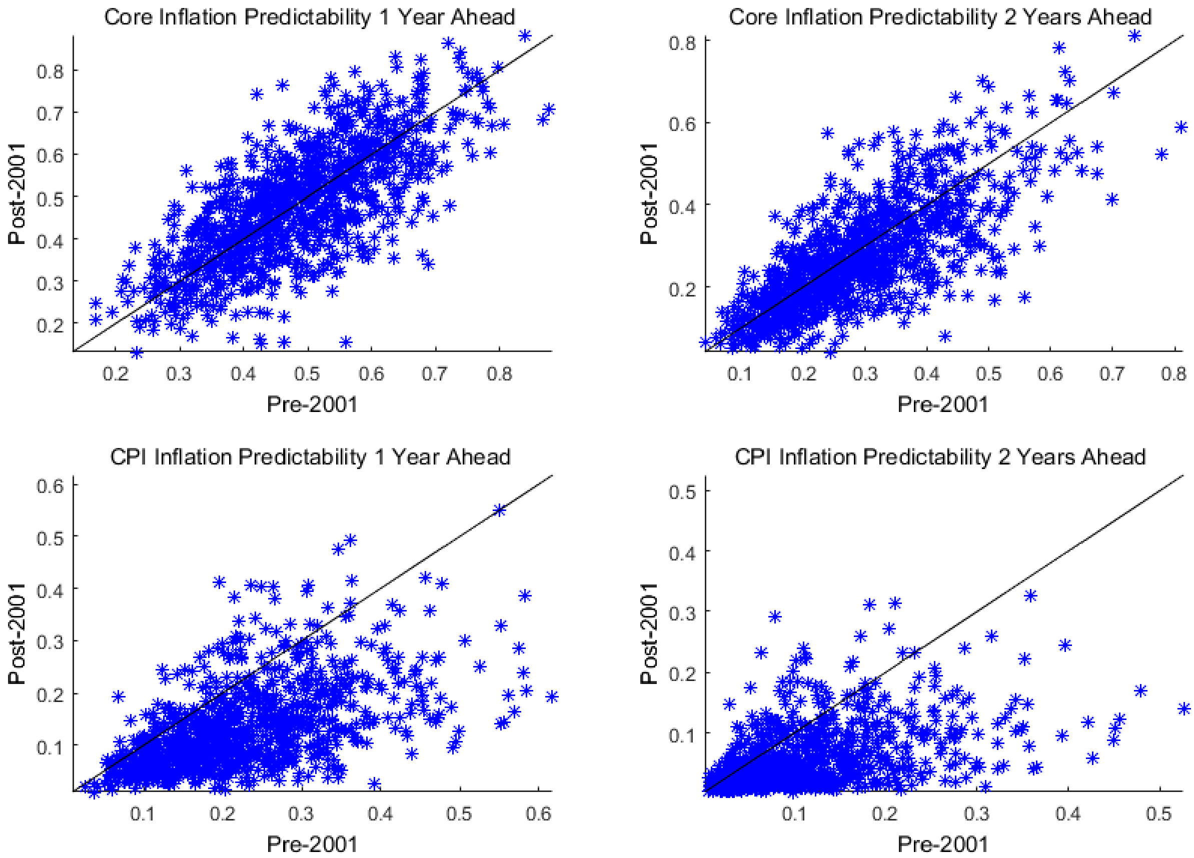

Figure 5: Inflation predictability one year ahead and two years ahead. Joint distribution pre and post-2001.

where e_π is a selection vector that picks out inflation relative to its unconditional mean. This formula calculates the predictability of inflation at horizon J as 1 minus the contribution of future shocks to the unconditional variance of inflation. R_J^2 indicates the contribution of past shocks to the predictability of inflation at horizon J. Figure 4 shows estimates of R_J^2 for $J = 4$ and 8 quarters for core inflation (top panels) and CPI inflation (bottom panels).

The figure suggests that, overall, core inflation is more persistent than CPI inflation. This possibly reflects the fact that CPI inflation containing more volatile prices such as fuel and electricity prices is generally more volatile than core inflation.

The temporal evolution of the persistence measure is similar for core and CPI inflation. Predictability is low during the 1980s, but then rises during the early 1990s. The post-inflation targeting period is generally associated with a decline in predictability with the largest reduction seen in the persistence of CPI inflation.

In Figure 5 we consider if the temporal changes in predictability are systematic. Following Cogley *et al.* (2008), we plot the joint distribution of the average estimate of R_J^2 before and after 2001 and compare this with the 45-degree line. A deviation of the distribution from the 45-degree line would provide evidence of a systematic change after inflation targeting was adopted. The figure suggests that evidence for changes in core inflation predictability is limited with the distribution clustered around the 45-degree line. In contrast, the distribution for CPI inflation predictability is mostly located below the line before 2001. The results, therefore, indicate that the introduction of inflation targeting was accompanied by a reduction in the persistence of CPI inflation.

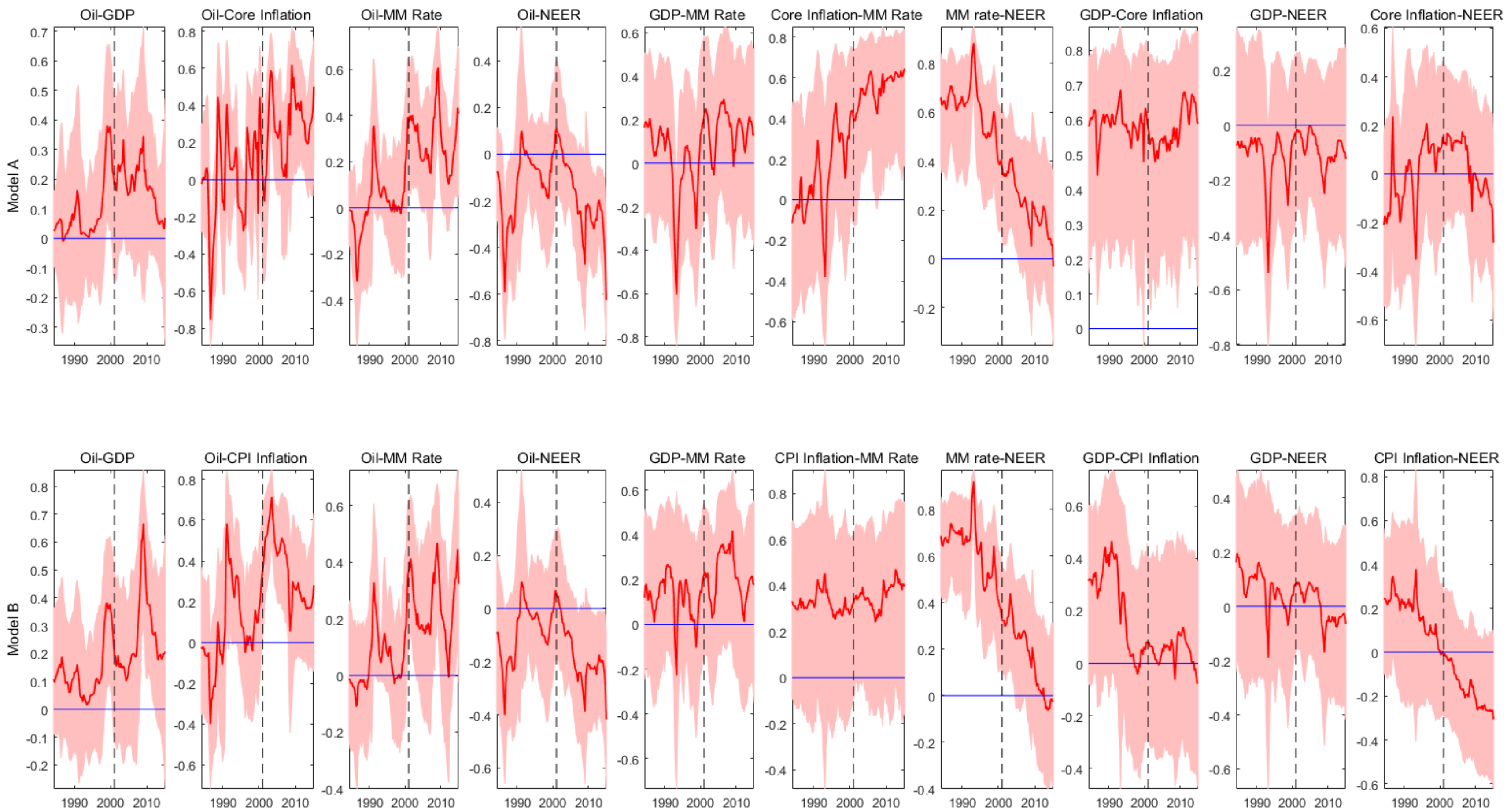

Figure 6: Dynamic Correlations at frequency zero. The solid line is the median estimate while the shaded area represents the 68% error band.

3.4 Dynamic correlations

The TVP-VAR model can also be used to examine the time-varying co-movement between the endogenous variables. In particular, the VAR implied spectral density matrix contains information about the synchronisation of the variables at different frequencies. The spectral density matrix of endogenous variables can be calculated at each point in time as:

$$\hat{f}_t(\omega) = (I - F_t e^{-i\omega})^{-1} \frac{\Omega_t^*}{2\pi} \left[(I - F_t e^{-i\omega})^{-1}\right]',$$

where ω denotes the frequency. The off-diagonal elements of the spectral density matrix summarises the relationship between the endogenous variables at different frequencies. We focus on a particular measure of association called dynamic correlations proposed in Croux *et al.* (2001). This measure is defined as:

$$\frac{\hat{c}_{ij}(\omega)}{\sqrt{\hat{f}_t^{ii}(\omega)\hat{f}_t^{jj}(\omega)}},$$

where $\hat{c}_{ij}(\omega)$ denotes the cospectrum between variable i and j at frequency ω. The dynamic correlation lies between -1 and 1. It equals one if series i and j are exactly synchronised at a given frequency.

Figure 6 plots the estimated dynamic correlation at the long run frequency (i.e corresponding to cycles of 60 years). We focus on long run comovements in order to shed light on potential structural shifts and to abstract from high frequency volatile movements in the data. Still, the time variation in the long run correlation is quite high while the associated confidence bands are relatively wide. We will therefore focus on the overall impression from the graphs and less on details. The following observations can be made.

First, the Norwegian macroeconomy does not seem to covary less with oil prices from the late 1990s onwards in comparison with the earlier periods. One could argue that the correlations between oil prices and the key macro variables has increased over time. It can be seen from Figure 6 that the correlation between the (detrended) oil price and the GDP gap increased in the late 1990s and has mostly been at a higher level since than compared with the period before the late 1990s. The posterior medians of the correlations between oil prices and the GDP gap has been positive throughout the estimation period. The posterior medians of the correlation between inflation and oil prices also increase in the late 1990s and has been positive since then. Overall, the correlation between oil prices and the money market rate has also been positive and higher from the late 1990s relative to earlier peiods. The variation in the correlation between oil prices and money market rates could be reflecting the policy interest rates response to the GDP gap and inflation after the switch to the inflation targeting regime in 2001Q1.

Regarding the nominal effective exchange rate changes, Figure 6 suggests that while their correlation with oil prices was almost absent during the 1990s and the early years of 2000, its strength has increased to a higher level in the last decade. The correlation between oil prices and the nominal effective exchange rate changes is negative in general and varies over time. The relatively high degrees of correlation are seen in 1986, 2008–2009 and in 2014, periods that are characterized by oil price falls. The observed time-varying correlation between oil prices and exchange rate changes is in line with previous studies; see Akram (2004).

Second, the correlation between money market rates and core inflation has increased over time since the early 2000s and been statistically significant after the adoption of the inflation targeting regime. The correlation between the money market rates and CPI inflation has however remained positive and relatively stable throughout the estimation period; see the bottom panel of Figure 6.

Third, the correlation between nominal effective exchange rate changes and interest rates has been positive throughout the sample period but it has declined steadily since 1993 and become close to zero by the end of the estimation period. The start of the decline coincides with the abandonment of a fixed exchange rate regime in December 1992. Until then, the median correlation was relatively high and stable, with a brief spike in late 1992, just before it started its decline. A positive correlation indicates that interest rate increases go together with exchange rate depreciations. Although Norway abandoned fixed exchange rate targeting in December 1992, it maintained its aim of stabilizing the exchange rate at the level it depreciated to.

Fourth, the correlation between money market rates and the GDP gap has not exhibited any systematic decline after the introduction of the inflation targeting regime. It has often been higher than in the pre-inflation targeting period. For example, the median correlation even takes on relatively large negative values in the pre-inflation targeting period while it almost never declines to negative values in the latter period.

Fifth, correlations between money market rates, inflation rates, nominal exchange rate changes and the GDP gap largely vary as expected with the move from the exchange rate targeting regime to a flexible inflation targeting regime which cares about output stabilization. As shown, the gradual rise in the correlation between core inflation and interest rates coincides with the fall in the correlation between the nominal effective exchange rate and interest rates. This contrasting development is consistent with a gradual rather than an abrupt move away from exchange rate stabilization to flexible inflation targeting over time. Accordingly, the transition to an inflation targeting regime without incorporation of notable concern for exchange rate volatility in interest rate setting has recently been completed.

Sixth, Figure 6 shows that the correlation between the GDP gap and CPI inflation has fallen towards zero from the mid-1990s. In contrast, the correlation between the GDP gap and core inflation has remained statistically significant and relatively stable over the whole sample period. There is no evidence of a sizable change in the correlation between the GDP gap and core inflation which is remarkable given substantial changes in the openness of the economy noted earlier.

Finally, it is worth remarking that the correlation between CPI inflation and the nominal effective exchange rate changes has declined since the mid-1990s. The remaining correlations involving the nominal effective exchange rate changes, core inflation and the GDP gap have mostly fluctuated around or close to zero over the estimation period. Further analysis is therefore required to say whether or not the correlations are consistent with a possible change in the exchange rate pass through to inflation or the activity level represented by the GDP gap.

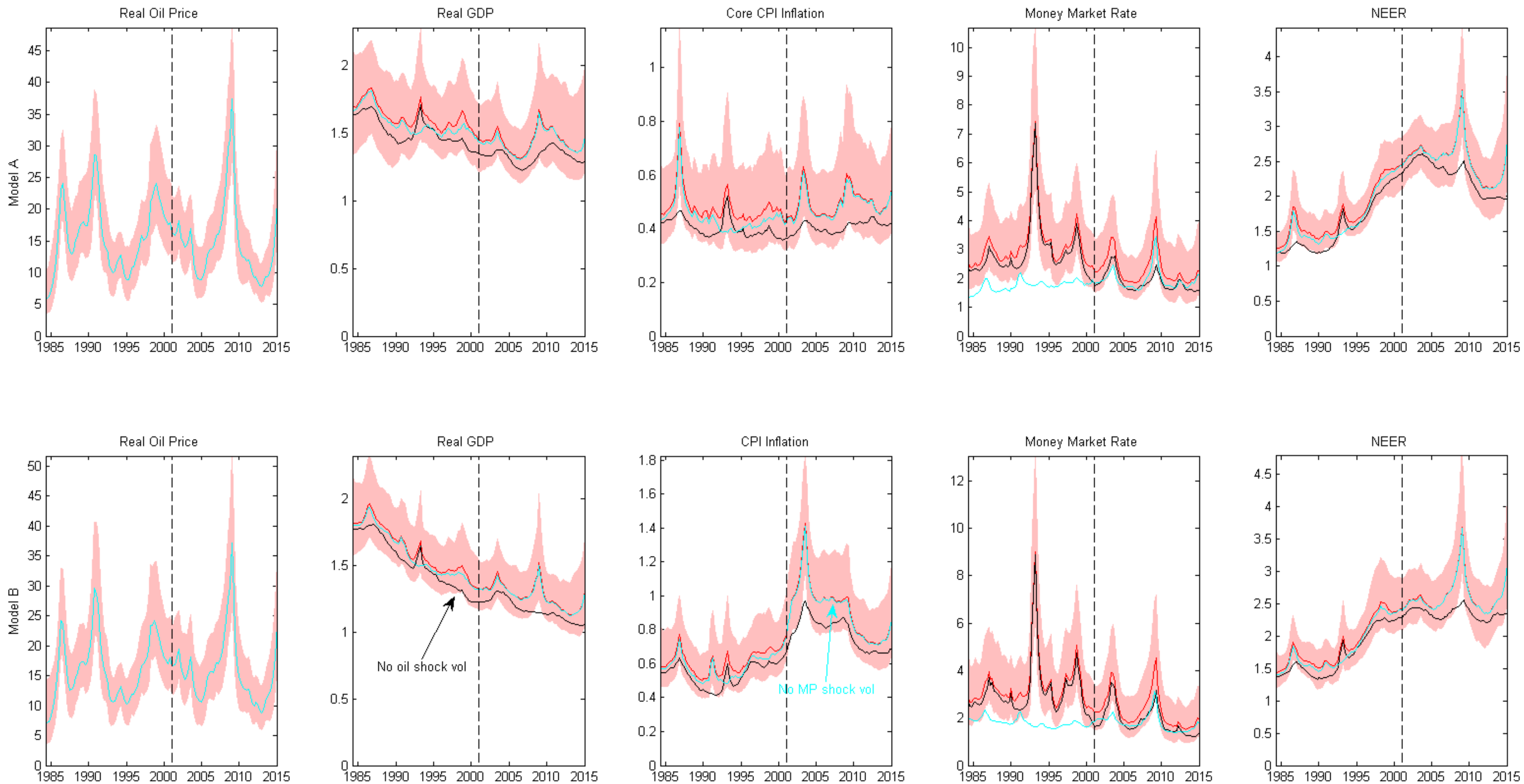

Figure 7: Actual and counterfactual estimates of unconditional volatility. The black line assumes that the variance of oil shocks is zero. The blue line assumes that the variance of monetary policy shocks is zero.

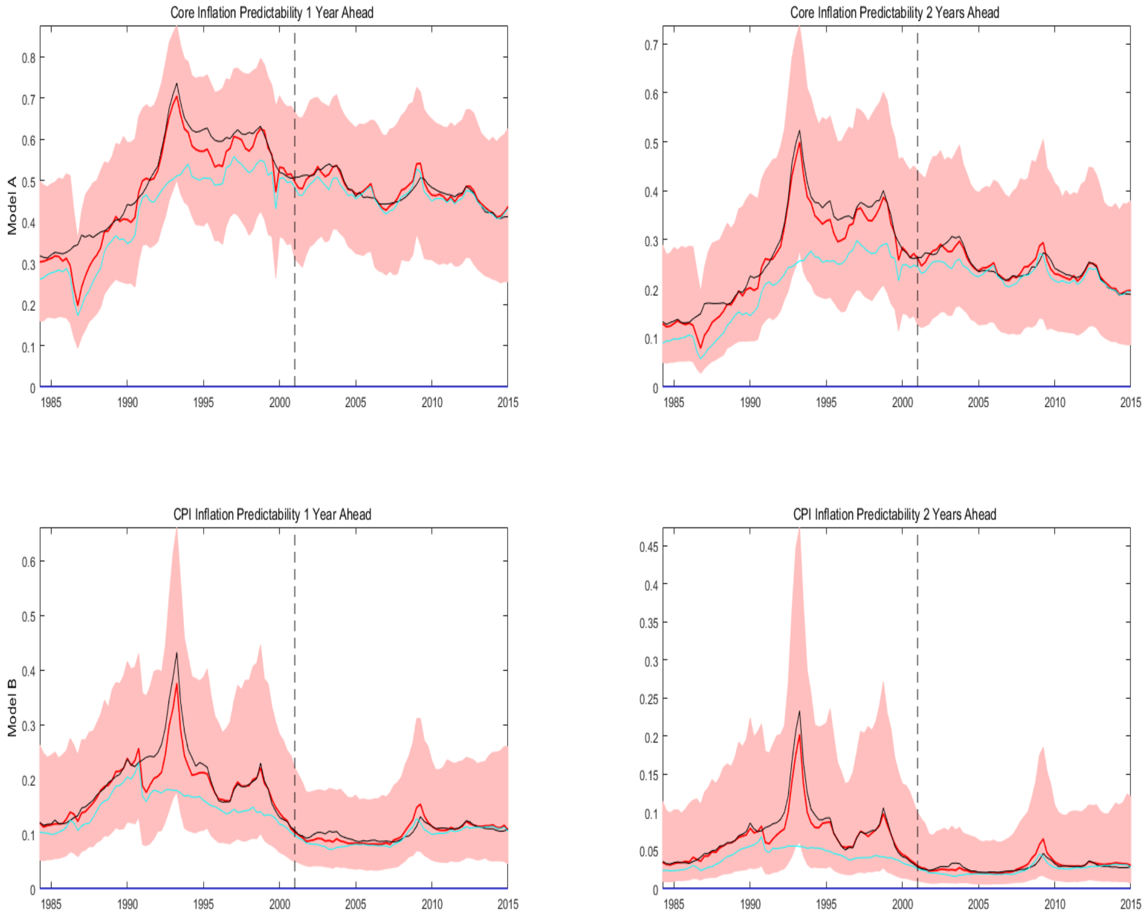

Figure 8: Actual and counterfactual estimates of predictability. The black line assumes that the variance of oil shocks is zero. The blue line assumes that the variance of monetary policy shocks is zero.

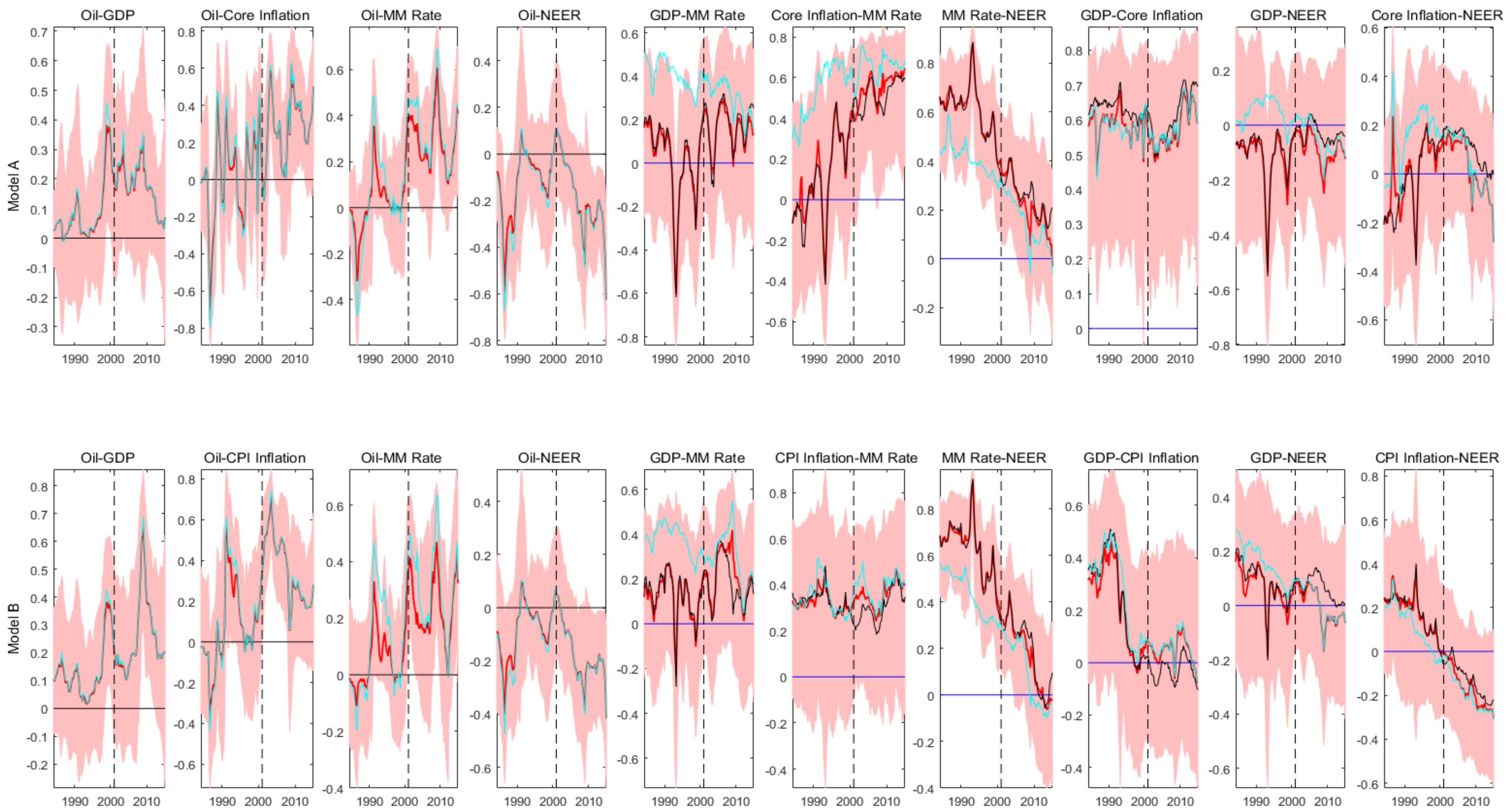

Figure 9: Actual and counterfactual estimates of dynamic correlation at frequency zero. The black line assumes that the variance of oil shocks is zero. The blue line assumes that the variance of monetary policy shocks is zero.

4 The role of oil and monetary policy shocks

In this section we provide some preliminary evidence of the role played by oil and monetary policy shocks in driving the time-varying moments described above. The recursive structure inherent in the A_t matrix allows us to place an economic intepretation on the shocks to the oil and money market rate equations and their time-varying volatility. In particular, the recursive structure implies that the shock to the money market rate equation has no contemporaneous impact on all variables except the nominal effective exchange rate and can be interpreted as a monetary policy shock on the basis of policy lags. The oil shock affects the Norwegian economy but the other shocks are unable to have any impact on the real oil price. While admittedly simple, these assumptions are plausible in the context of a small open economy and allow us to provide a tentative assessment of the role of these key shocks.

In order to asses the contribution of these shocks we consider a series of counterfactual calculations. In particular, we re-estimate the unconditional variances, predictability of the inflation rates and the dynamic correlations under the assumption that the volatility of oil and monetary policy shocks, respectively, is zero. If these shocks are important, the counterfactual estimates would be different from the estimates based on the posterior from the benchmark model. This analsyis is in the spirit of e.g. Gali and Gambetti (2009).

Figure 7 shows that the volatility of the GDP gap, inflation and exchange rate change is relatively lower when the volatility of oil shocks is switched off (black line). The difference in volatility relative to that in the benchmark models, presented by the solid black and red lines, respectively, is present throughout the estimation period indicating that the volatility of oil shocks is an important concern both before and after 2001; see Bjørnland and Thorsrud (2015).

In contrast, the monetary policy shock appears to be only important for the volatility of the money market rate in the pre-inflation targeting period (blue line). In particular, absent the volatility of this shock, the standard deviation of the money market rate is much lower over this period, suggesting that policy shock variance was a major driving force of interest rate volatility. Post-2001, the volatility of policy shocks has little impact on the variance of the money market rates, possibly suggesting that monetary policy is to a larger extent determined by key macroeconomic variables such as inflation and the GDP gap than in the pre-2001 period.

Figure 8 suggests that the monetary policy shock played a crucial role in driving the predictability of inflation pre-2001, especially at the two-year horizon. The estimated predictability in the absence of policy shock variance (blue line) is much lower than the benchmark estimates over this period. Monetary policy shocks therefore seems to be an important source of the relatively high persistence in both core inflation and CPI inflation during the 1990s. As shown, oil shocks do not contribute to inflation persistence over the whole estimation period; deviations between the black and red lines in Figure 8 are mostly negligible.

Figure 9 shows the counterfactual estimates of the dynamic long-run correlation between the variables. When the volatility of oil shocks is zero, its correlation with other variables is undefined by construction as the oil equation is an autoregressive process in the model. The figure shows that this shock has little impact on the other correlations. The monetary policy shock, however, plays an important role in driving the correlation between the money market rate and the other variables, especially in the model with core inflation. If it is assumed that this shock has zero variance, the dynamic correlation between the GDP gap and the money market rate is estimated to be large and positive both pre- and post-2001. A similar pattern can be seen for core inflation suggesting that monetary policy shocks during the pre-2001 period contributed to substantially weaken the positive correlation between core inflation and money market rates. In contrast, the correlation between the nominal effective exchange rate and the money market rate is lower in the absence of these shocks pre-2001. One way to intepret these result is to note that in each case, the counterfactual scenario in the pre-2001 period implies a correlation closer to that observe post-2001, i.e. during the inflation targeting period. This implies that monetary policy shocks have become less important after 2001 and the resulting long run comovements between the interest rate and GDP gap and core inflation represents the outcome of systematic response by Norges Bank to movement in these variables. Such response appears to have been absent in the pre-inflation targeting period.

5 Sensitivity analysis

We test the robustness of the results through a number of sensitivity checks on the main model. First, we test if the results depend on the key prior distributions used for estimation. One of the crucial priors in the model relates to the variance of the shock of the transition equation of the VAR coefficients; see eq (2). As described in Appendix B, the prior for the variance Q is inverse Wishart with scale matrix $var(\hat{\phi}^{OLS}) \times 10^{-4} \times 3.5$ where $var(\hat{\phi}^{OLS})$ denotes OLS estimates of the VAR coefficient covariances obtained over a training sample. In the sensitivity analysis, we reduce the scaling factor from $10^{-4} \times 3.5$ to $10^{-4} \times 1$ to check if this dampens the time-variation in the coefficient estimates. The results from the model with CPI inflation are presented in Figure 13 in Appendix C. The estimated volatility and inflation predictability is very similar to benchmark case in Figures 3–4. The estimated dynamic correlations are also very alike the main results – there is an increase in the absolute correlation between oil prices and the remaining variables, the median correlation between the GDP gap and the money market rate is on average higher over time and the correlation between the exchange rate and the money market rate mostly falls from mid-1990s onwards; cf. Figure 6.

Figure 14 in Appendix C presents results from a version of the benchmark model where detrended mainland real GDP is used. This measure excludes petroleum production and shipping. The top panel of the figure shows that the pattern of dynamic correlations is very similar to the benchmark model; cf. Figure 6. It is interesting to note that the correlation between mainland GDP and oil price/money market rate also increased over the recent past while the mainland GDP gap's correlation with CPI declined. The temporal pattern of volatility is also similar to the benchmark case; cf. Figure 3. Note, however, that the spike in mainland GDP volatility over the recent financial crisis is somewhat larger than the estimated increase in the volatility of total GDP shown in Figure 3 above.

Finally, Figure 15 presents results from a version of the benchmark model where the nominal effective exchange rate (NEER) is replaced by changes in the real effective exchange rate (REER). The middle panel of the figure shows that the temporal pattern of the volatility of REER is very alike to that estimated for the nominal effective exchange rate in Figure 3. The results for volatility of the other variables and inflation persistence are very similar to the benchmark case; cf. Figures 3–4. The median estimates of the dynamic correlations between oil prices and GDP gap, CPI inflation and interest rates are negative after the late 1990s mimicking the results from the benchmark model. Similarly the correlation between REER and the money market rate declines over time while the correlation with GDP is stable as in the benchmark case. However, in contrast to the benchmark model with NEER, the estimated correlation between the real exchange rate changes and CPI inflation does not show a noticeable decline. Note also that this model does not suggest a decline in the correlation between GDP gap and CPI inflation perhaps indicating that the interaction of these variables with the nominal exchange rate is important for this result. The remaining results for volatility and persistence are very similar to the benchmark case.

In summary, the results from the additional models are broadly supportive of the main conclusions on time-variation in volatility, persistence and dynamic correlations reported above.

6 Conclusions

We have used time-varying parameter VAR models to investigate changes in the dynamic of key Norwegian macroeconomic variables over the last three decades. As is often the case when estimating numerous parameters that can vary at each point in time, the estimates are subject to relatively high uncertainty. Yet, one can summarise the main results as follows.

There seems to be mixed evidence of the Great Moderation in Norwegian data. Over the last 30 years, the long-run mean of the GDP gap has remained stable while inflation rates have declined and since the mid-1990s stabilized at around 2.5%, the inflation target from 2001 onwards. While there are indications of a reduction in the volatility of the GDP gap, the volatility of inflation has increased. The results are also mixed or rather uncertain regarding the correlation of inflation with the GDP gap and the nominal exchange rate. Hence, it is difficult to associate changes in these correlations, which may have bearings on potential changes in the slope of the Phillips curve and exchange rate pass-through, to increases in the openness of the economy.

Long run correlations between oil prices and the other variables (GDP gap, Inflation, nominal exchange rate change) have increased. This is not unexpected, given the increased importance of the petroleum sector over time. Our counterfactual analysis suggests that oil price shocks have contributed to sizable volatility in the macroeconomic variables over the whole sample period starting from the early 1980s.

The behaviour of nominal exchange rate changes and nominal interest rates are consistent with the prevailing monetary policy regimes in different time periods. Specifically, nominal exchange rate changes have been more volatile after the move from the exchange rate stabilization regime to the inflation targeting regime. There does not seem to be any appreciation or depreciation trend over the sample period.

The inflation targeting period is characterized by a positive and increasingly higher correlation between nominal interest rates and inflation. The correlation of the nominal interest rates with the GDP gap has also been higher during the inflation targeting period than in the earlier period. In contrast, correlations between nominal interest rates and nominal exchange rate changes have weakened steadily since the abandonment of the strict exchange rate targeting regime in the end of 1992. The correlations do not indicate more influence of output and exchange rate considerations on interest rate decisions at the expense of inflation targeting over time, not even after the financial crisis of 2008–2009.

Moreover, we find evidence of a reduction in the persistence of inflation accompanying the change from exchange rate stabilization regime to inflation targeting regime. Accordingly, the inflation has become less predictable around its target rate over time, which can be possibly credited to the inflation targeting regime. Our counterfactual analysis suggests that monetary policy shocks were important contributors to the relatively high inflation persistence in the pre-inflation targeting period and contributed to relatively low correlations of money markets rates with the GDP gap and core inflation.

The empirical analysis in this paper has been largely limited to document multivariate time series properties of the Norwegian economy. A structural analysis of our findings remain on our research agenda.

References

Akram, Q. F., 2004, Oil prices and exchange rates: Norwegian evidence, *Econometrics Journal* **7**, 476–504.

Alstadheim, R., H. Bjørnland and J. Maih, 2013, Do central banks respond to exchange rate movements? - A Markov Switching investigation, *Norges Bank Working Paper (24)*.

Bårdsen, G. and J. T. Klovland, 2000, Shaken, or stirred? Effects of financial deregulations on money, credit, and output in Norway, *Scandinavian Journal of Economics* **102, 4**.

Benati, L., 2007, The Great Moderation in the United Kingdom, *Working Paper Series* 769, European Central Bank.

Bjørnland, H. C. and L. A. Thorsrud, 2015, Commodity prices and fiscal policy design: Procyclical despite a rule, *Working Papers 0033*, Centre for Applied Macro- and Petroleum economics (CAMP), BI Norwegian Business School.

Carter, C. and P. Kohn, 1994, On Gibbs sampling for state space models, *Biometrika* **81**, 541–53.

Chib, S. and E. Greenberg, 1995, Hierarchical analysis of SUR models with extensions to correlated serial errors and time-varying parameter models, *Journal of Econometrics* **68**(2), 339–360.

Cogley, T., G. E. Primiceri and T. J. Sargent, 2008, Inflation-Gap Persistence in the U.S, *NBER Working Papers 13749*, National Bureau of Economic Research, Inc.

Cogley, T. and T. J. Sargent, 2005, Drift and Volatilities: Monetary Policies and Outcomes in the Post WWII U.S, *Review of Economic Dynamics* **8**(2), 262–302.

Croux, C., M. Forni and L. Reichlin, 2001, A Measure of Comovement for Economic Variables: Theory and Empirics, *The Review of Economics and Statistics* **83**(2), pp. 232–241.

Evjen, S. and T. B. Kloster, 2012, Norges Bank's new monetary policy loss function - further discussion, *Staff Memo 11*, Norges Bank.

Gali, J. and L. Gambetti, 2009, On the Sources of the Great Moderation, *American Economic Journal: Macroeconomics* **1**(1), 26–57.

Gamble, J. A. and J. P. LeSage, 1993, A Monte Carlo Comparison of Time Varying Parameter and Multiprocess Mixture Models in the Presence of Structural Shifts and Outliers, *The Review of Economics and Statistics* **75**(3), pp. 515–519.

Gjedrem, S., 1999, Utfordringer i pengepolitikken, *Aftenposten* ***Newspaper article***, May 4.

Gjedrem, S., 2005, Petroleum and the Norwegian economy, Speech at Alfred Berg ABN AMRO's Nordic Energy Conference 30 August, Norges Bank.

Jacquier, E., N. Polson and P. Rossi, 1994, Bayesian analysis of stochastic volatility models, *Journal of Business and Economic Statistics* **12**, 371–418.

Norges Bank, 1995, Norwegian monetary policy and financial markets, *Norges Banks Skriftserie/Occasional Papers* 24.

Norges Bank, 2012, *Monetary Policy Report, 2012/2*, Norges Bank, Oslo.

Olsen, Ø., 2013, Macroprudential regulation and monetary policy, Speech 7 October, Norges Bank.

Olsen, Ø., 2014, Financial imbalances - how can they be counteracted?, Speech 30 September, Norges Bank.

Olsen, Ø. and A. Skjæveland, 2002, Hva gjør oljeinntektene med oss?, *in* A. J. Isachsen (editor), *Handlingsregelen for bruk av oljeinntekter*, Cappelen Akademisk Forlag, Oslo.

Primiceri, G., 2005, Time varying structural vector autoregressions and monetary policy, *Review of Economic Studies* **72**, 821–852.

Svensson, L. E. O., 2005, Optimal Inflation Targeting: Further Developments of Inflation Targeting, unpublished manuscript, available at `http://www.princeton.edu/svensson/`.

Svensson, L. E. O., 2010, Where do the central banks go from here?, *Norges Bank Symposium* 18 November, BIS.

Walsh, C. E., 2014, Multiple objectives and central bank trade-offs under flexible inflation targeting, *Working Paper* 5097, CESifo.

Woodford, M., 2007, The case for forecast targeting as a monetary policy strategy, *Journal of Economic Perspectives* **21, 4**, 3–24.

Woodford, M., 2013, Forward-guidance by inflation targeting central banks, Paper presented at the conference: Two decades of inflation targeting, Sveriges Riksbank.

A Appendix A: Data

We use quarterly data. The main data set runs from 1980Q1 to 2014Q4 and has been extracted from Norges Bank's data base. The main data set has been supplemented with data from the Global Financal Database for the period 1971Q3 to 1983Q4.

The levels of the data series used are defined as follows, where the variable names in the Norges Bank data base are noted in parentheses. Except for the nominal money market interest rate (R), we de-trend (H-P) or take first differences of the natural logs of the variables as noted in the main text, where variable names in small letters represent natural logs of the variables while Δ denotes the first difference of the variables.

- Q: Nominal effective exchange rate; an increase indicates depreciation; (QUA_SI44)
- P: Norwegian CPI - Seasonally adjusted; (QSA_PCPI)
- P: Norwegian Core CPI - Seasonally adjusted. Core CPI is CPI adjusted for fuel and electricity prices in addition to indirect taxes; (QSA_PCPI)
- R: Norwegian 3 month money market rate (NIBOR); (QUA_RN3M)
- Y: Norwegian real GDP - Seasonally adjusted; (QSA_Y)
- Y: Norwegian real mainland GDP (on-shore) - seasonally adjusted; (QSA_YMN)
- O: Brent Blend crude spot oil prices in USD deflated by US CPI; (QUA_POILUSD/US_CPI)

B Appendix B: Estimation

B.1 Prior distributions and starting values

The initial conditions for the VAR coefficients ϕ_0 are obtained via an OLS estimate of a fixed coefficient VAR using the first 40 observations of the sample period.

Let $\hat{v}^{ols}$ denote the OLS estimate of the VAR covariance matrix estimated on the pre-sample data described above. The prior for the diagonal elements of the VAR covariance matrix is defined as $\ln h_0 \sim N(\ln \mu_0, I_3)$ where μ_0 are the diagonal elements of the Cholesky decomposition of $\hat{v}^{ols}$.

The prior for the off-diagonal elements A_t is $A_0 \sim N\left(\hat{a}^{ols}, V\left(\hat{a}^{ols}\right)\right)$ where $\hat{a}^{ols}$ are the off-diagonal elements of $\hat{v}^{ols}$, with each row scaled by the corresponding element on the diagonal. $V\left(\hat{a}^{ols}\right)$ is assumed to be diagonal with the elements set equal to 10 times the absolute value of the corresponding element of $\hat{a}^{ols}$. The prior on Q is assumed to be inverse Wishart $Q_0 \sim IW\left(\bar{Q}_0, T_0\right)$ where $\bar{Q}_0$ is assumed to be $var(\hat{\phi}^{OLS}) \times 10^{-4} \times 3.5$ and T_0 is the length of the sample used to for calibration. The results are not sensitive to this prior. We obtain similar results for smaller values of the scaling parameter. The prior distribution for the blocks of S is inverse Wishart: $S_{i,0} \sim IW(\bar{S}_i, K_i)$ where i indexes the blocks of S. $\bar{S}_i$ is calibrated using $\hat{a}^{ols}$. Specifically, $\bar{S}_i$ is a diagonal matrix with the relevant elements of $\hat{a}^{ols}$ multiplied by 10^{-3}. Following Cogley and Sargent (2005) we postulate an inverse-gamma distribution for the elements of G, $\sigma_i^2 \sim IG\left(\frac{10^{-4}}{2}, \frac{1}{2}\right)$

B.2 Simulating the posterior distribution

We use a Gibbs sampling algorithm to sample from the posterior distribution. The details of each conditional distribution is provided below.

B.2.1 Time-varying VAR coefficients

Conditional on the time-varying volatilities and contemporaneous coefficients, the model is a SUR system with time-varying parameters. Following Chib and Greenberg (1995), the Carter and Kohn (1994) algorithm is used to sample from the conditional posterior of ϕ_t. The distribution of the time-varying VAR coefficients ϕ_t conditional on all other parameters and hyper-parameters is linear and Gaussian: $\phi_t \backslash O_t, Z_t, \Xi \sim N\left(\phi_{T\backslash T}, P_{T\backslash T}\right)$ and $\phi_t \backslash \phi_{t+1,} O_t, Z_t, \Xi \sim N\left(\phi_{t\backslash t+1,\phi_{t+1}}, P_{t\backslash t+1,\phi_{t+1}}\right)$ where $t = T-1, ..1$, Ξ denotes a vector that holds all the other VAR parameters and $\phi_{T\backslash T} = E\left(\phi_T \backslash O_t, Z_t, \Xi\right), P_{T\backslash T} = Cov\left(\phi_T \backslash O_t, Z_t, \Xi\right), \phi_{t\backslash t+1,\phi_{t+1}} = E\left(\phi_t \backslash O_t, Z_t, \Xi, \phi_{t+1}\right)$ and $P_{t\backslash t+1,F_{t+1}} = Cov\left(\phi_t \backslash O_t, Z_t, \Xi, \phi_{t+1}\right)$. As shown by Carter and Kohn (1994) the simulation proceeds as follows. First we use the Kalman filter to draw $\phi_{T\backslash T}$ and $P_{T\backslash T}$ and then proceed backwards in time using $\phi_{t|t+1} = \phi_{t|t} + P_{t|t}P_{t+1|t}^{-1}\left(\phi_{t+1} - \phi_t\right)$ and $\phi_{t|t+1} = \phi_{t|t} - P_{t|t}P_{t+1|t}^{-1}P_{t|t}$.

B.2.2 Elements of H_t

Following Cogley and Sargent (2005), the diagonal elements of the VAR covariance matrix are sampled using the Metropolis Hastings algorithm in Jacquier *et al.* (1994). Given a draw for ϕ_t the VAR model can be written as $A_t'\left(\tilde{Z}_t\right) = u_t$. where $\tilde{Z}_t = Z_t - \sum_{l=1}^{L} \phi_{l,t} Z_{t-l} = v_t$ and $VAR(u_t) = H_t$. Jacquier *et al.* (1994) note that conditional on other VAR parameters, the distribution $h_{it}, i = 1..N$ is given by $f\left(h_{it} \backslash h_{it-1}, h_{it+1}, u_{it}\right) = f\left(u_{it} \backslash h_{it}\right) \times f\left(h_{it} \backslash h_{it-1}\right) \times f\left(h_{it+1} \backslash h_{it}\right) = h_{it}^{-0.5} \exp\left(\frac{-u_{it}^2}{2h_{it}}\right) \times h_{it}^{-1} \exp\left(\frac{-(\ln h_{it} - \mu)^2}{2\sigma_{h_i}}\right)$ where μ and σ_{h_i} denote the mean and

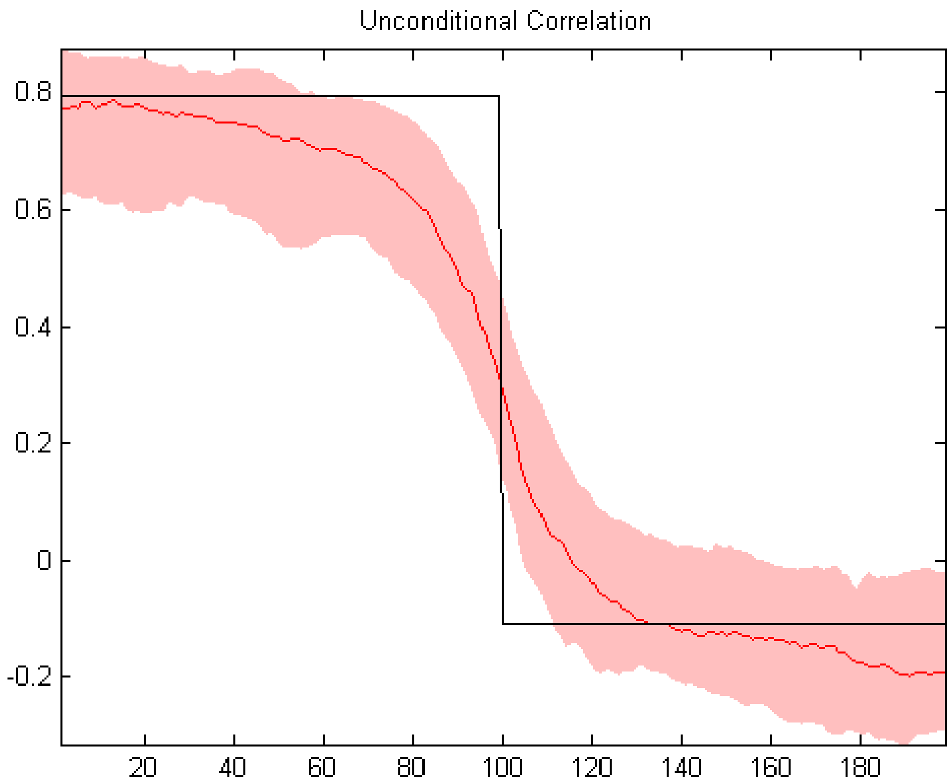

Figure 10: Monte Carlo experiment. The black line is the true unconditional correlation. The red line and shaded area represents the median estimate of the correlation and the 1 sd error band across 100 iterations.

the variance of the log-normal density $h_{it}^{-1}\exp\left(\frac{-(\ln h_{it}-\mu)^2}{2\sigma_{h_i}}\right)$. Jacquier *et al.* (1994) suggest using $h_{it}^{-1}\exp\left(\frac{-(\ln h_{it}-\mu)^2}{2\sigma_{h_i}}\right)$ as the candidate generating density with the acceptance probability defined as the ratio of the conditional likelihood $h_{it}^{-0.5}\exp\left(\frac{-u_{it}^2}{2h_{it}}\right)$ at the old and the new draw. This algorithm is applied at each period in the sample.

B.2.3 Element of A_t

Given a draw for ϕ_t the VAR model can be written as $A_t'\left(\tilde{Z}_t\right) = u_t$ where $\tilde{Z}_t = Z_t - \sum_{l=1}^{L}\phi_{l,t}Z_{t-l} = v_t$ and $VAR\left(u_t\right) = H_t$. This is a system of equations with time-varying coefficients and given a block diagonal form for $Var(\tau_t)$ the standard methods for state space models described in Carter and Kohn (1994) can be applied.

B.2.4 VAR hyperparameters

Conditional on Z_t, $\phi_{l,t}$, H_t, and A_t, the innovations to $\phi_{l,t}$, H_t, and A_t are observable, which allows us to draw the hyperparameters—, the elements of Q, S, and the σ_i^2—, from their respective distributions.

B.3 Evaluation of the estimation algorithm

To test the estimation algorithm and code we conduct a simple Monte Carlo experiment. 340 observations are generated from the following data generating process with the number of variables $N = 2$. The first 100 observations are discarded to remove the impact of initial conditions and 40 observations of the remaining series is used as a training sample. Estimation is carried out using 200 observations. The DGP is defined as:

$$Z_t = \beta_t Z_{t-1} + \Omega_t^{1/2} e_t, e_t \tilde{} N(0,1)$$

$$\begin{aligned} H_t &= \begin{pmatrix} \exp(h_{1t}) & 0 \\ 0 & \exp(h_{2t}) \end{pmatrix} \\ \beta_t &= \begin{pmatrix} \beta_{11,t} & \beta_{12,t} \\ \beta_{21,t} & \beta_{22,t} \end{pmatrix} \end{aligned}$$

Following Gamble and LeSage (1993) we assume that a one time shift defines the change in the VAR coefficients, variances and the non-zero element of A_t. During the first 100 observations these coefficients equal $\beta_t = \begin{pmatrix} 0.9 & 0.0 \\ 0.1 & 0.9 \end{pmatrix}$, $H_t = \begin{pmatrix} \exp(1) & 0 \\ 0 & \exp(1) \end{pmatrix}$ and $A = -1$. During the next 100 observations, the coefficients change to $\beta_t = \begin{pmatrix} 0.5 & 0.0 \\ -0.1 & 0.9 \end{pmatrix}$, $H_t = \begin{pmatrix} \exp(2) & 0 \\ 0 & \exp(2) \end{pmatrix}$ and $A = 0.1$. In Figure 10 we compare the true VAR implied correlation between the two variables (calculated using the assumed coefficients and covariance) with the estimate obtained using the TVP-VAR. This comparison suggests that the VAR model performs well and the estimated correlation tracks the true correlation closely.

B.4 Recursive means

Figure B.4 and B.4 shows that the recursive means of the retained draws of key parameters are fairly stable, providing evidence of convergence.

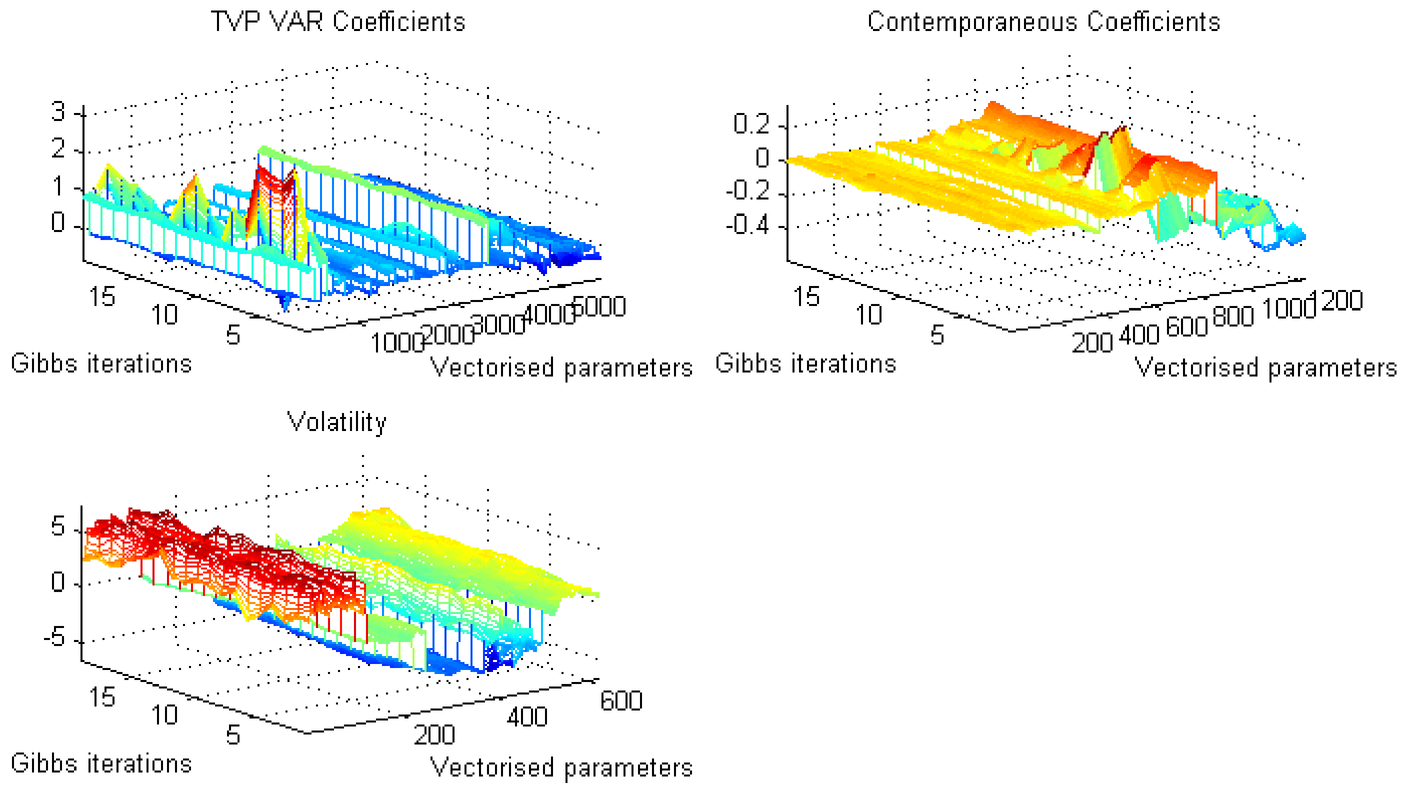

Figure 11: Recursive means of 1000 retained draws calculated every 50 iterations. Model A

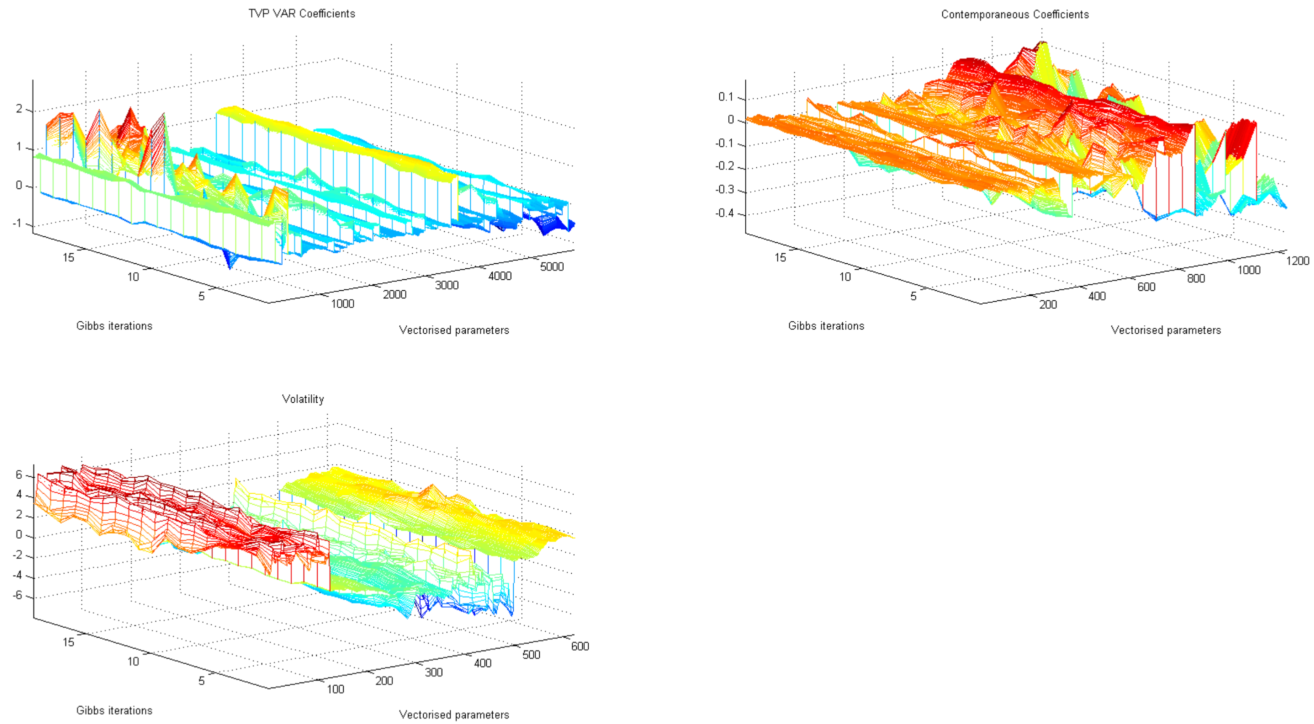

Figure 12: Recursive means of 1000 retained draws calculated every 50 iterations. Model B

C Appendix C: Sensitivity analysis

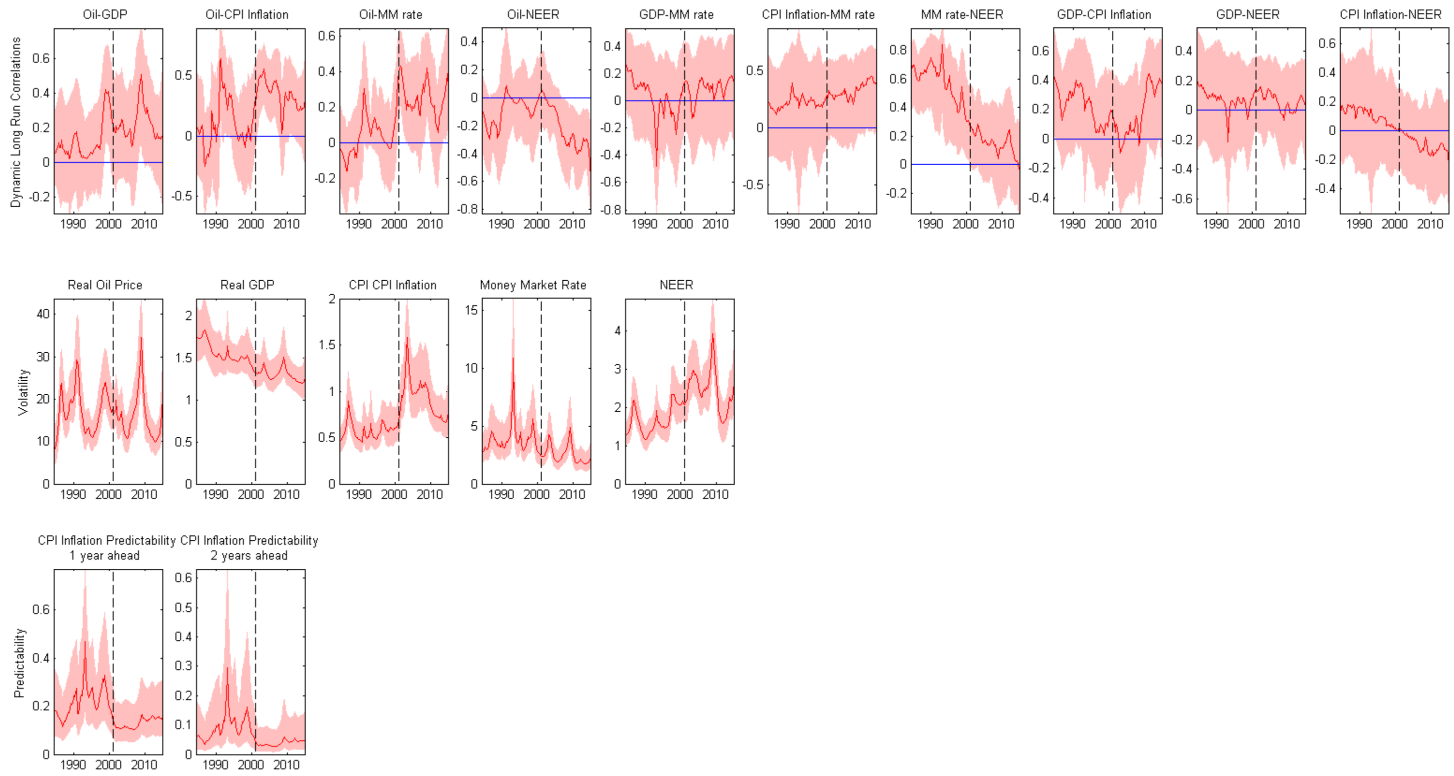

Figure 13: Using a tighter Prior. The top panel shows the dynamic log run correlations. The middle panel shows the unconditional volatility. The bottom panel shows the estimated predictability of CPI inflation.

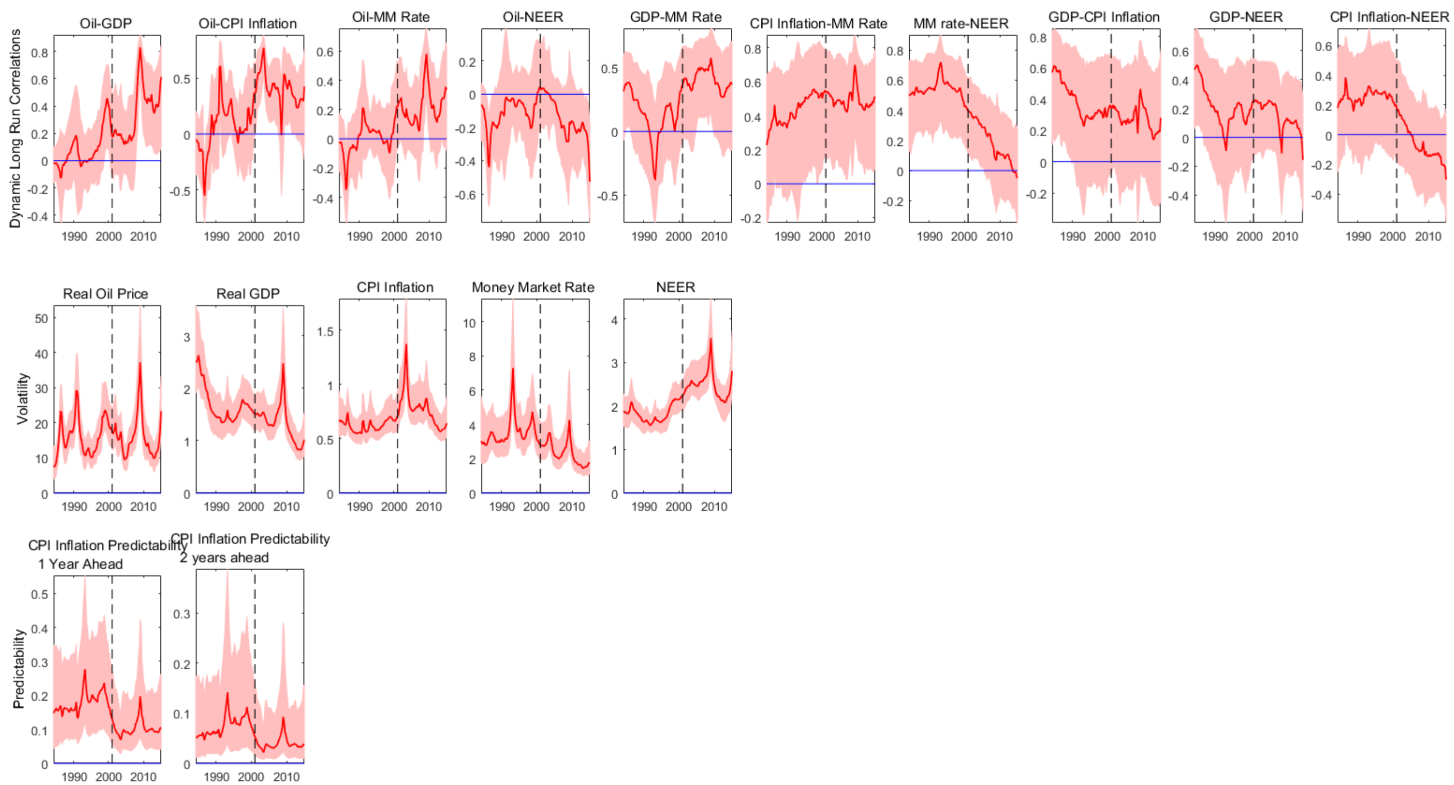

Figure 14: Using mainland real GDP. The top panel shows the dynamic log run correlations. The middle panel shows the unconditional volatility. The bottom panel shows the estimated predictability of CPI inflation.

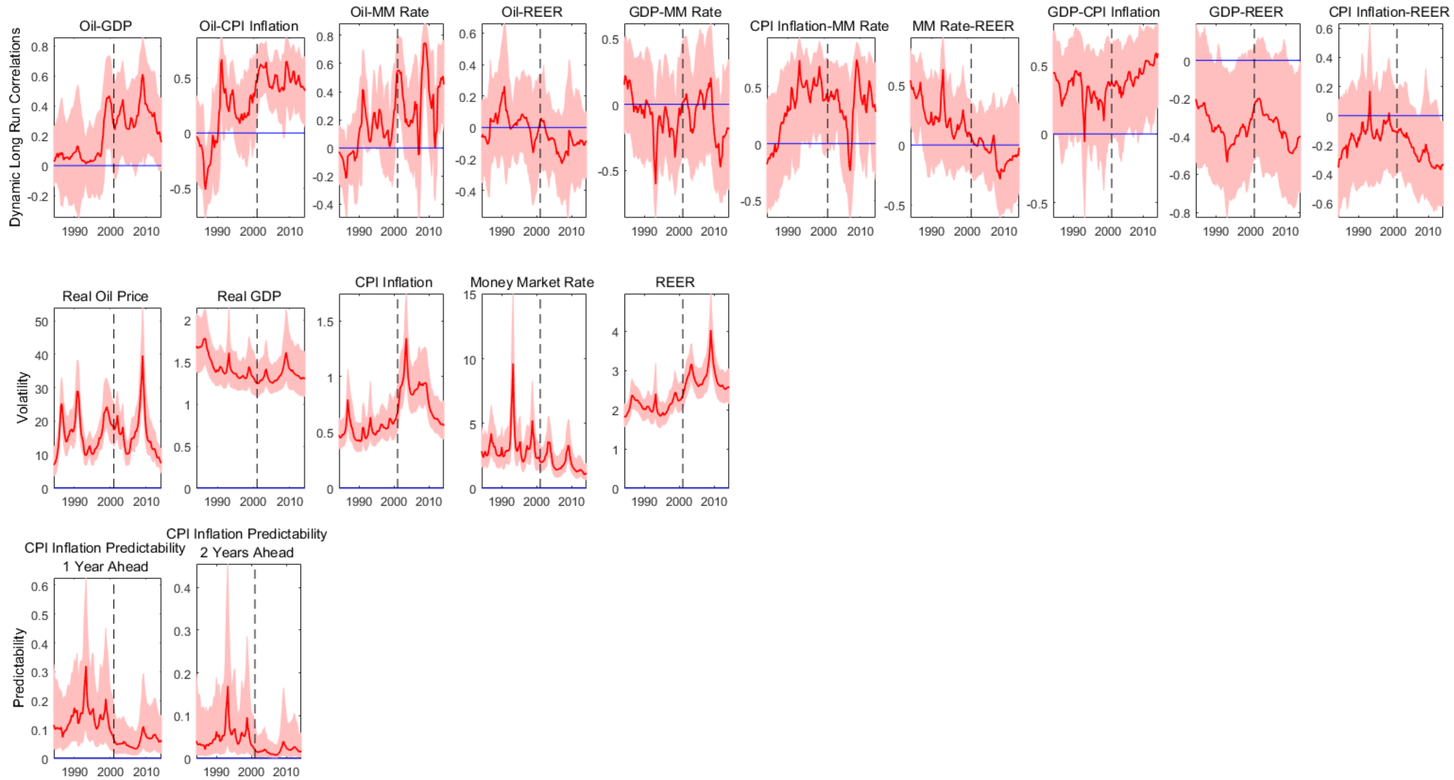

Figure 15: Using the real exchange rate. The top panel shows the dynamic log run correlations. The middle panel shows the unconditional volatility. The bottom panel shows the estimated predictability of CPI inflation.