Time-Varying dynamics of the Norwegian economy*

Q. Farooq Akram† Haroon Mumtaz‡
Norges Bank Research Queen Mary College

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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 petroleum revenue spending. 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

The Norwegian economy has experienced substantial structural and policy changes since the 1980s. From 1990 to 2014, the share of imports of goods and services from emerging economies increased steadily from below 5% to 24%. 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. Over the same period 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)

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†Email: farooq.akram@norges–bank.no
‡Email: h.mumtaz@qmul.ac.uk

GDP. 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 annual petroleum revenue to around 4% of the fund's market value. 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 of 2.5% in the medium run while attenuating fluctuations of aggregate output around its trend level; see Svensson (2005).[1] These developments in combination with shifts in government policies over the period may have altered the dynamics of Norwegian macroeconomic variables.

In this paper, we examine the dynamic properties of key Norwegian macroeconomic variables and their co-movements over the last three decades. Our aim is to investigate if trends, persistence, volatility and cross-correlations of these variables have changed over time and whether the timing of any changes coincides with structural shifts in the economy. To estimate these time-varying statistics, we employ a time-varying parameters VAR model with stochastic volatility to describe the behaviour of macroeconomic variables over the period 1983Q4–2014Q4. The variables modelled are: real Norwegian GDP relative to its trend, consumer price inflation, nominal effective exchange rate (NEER) changes, short term money market rates and real crude oil prices.

The analysis in this paper is thus closely related to Cogley and Sargent (2005), Primiceri (2005) and Benati (2007) (amongst others) who use similar models to explore the time-varying dynamic properties of US and UK data. Our investigation adds to this literature by providing results for an economy that has several unique characteristics – First, Norway is a major petroleum producing country with well regulated spending 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). Our analysis complements the work in Peersman and Van Robays (2012) and Alstadheim *et al.* (2013) who focus on changes in the structural impact of oil market shocks and the monetary policy rule, respectively. In contrast to these papers, our work investigates the possibility of time-variation in trends, persistence, volatility and cross correlations of Norwegian data. To our knowledge, our paper is the first to provide these results for Norway.

Our main results are as follows: Evidence for a 'Great Moderation' in Norway is mixed at best: The volatility of the GDP gap does not display a large decline, while the variance of CPI inflation and the NEER changes have increased in the post-2001 period. However, the inflation targeting period coincided with a fall in trend inflation and inflation persistence. The long run correlation between oil prices and the other variables display an increase over this period with a similar result observed for the correlation between the GDP gap and the money market rate. In contrast, the correlation between the money market rate and the NEER changes has declined over this period. Counterfactual simulations from the model suggest that monetary policy shocks were important in driving the changes in inflation persistence and the dynamic correlations.

The paper is organized as follows. The next Section 2 lays out the modelling framework

[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).

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 contribution of monetary policy and aggregate shocks by way of counterfactual analysis. Section 5 concludes. Further details about the estimation method and several robustness tests are presented in the technical 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 HP-filtered real oil price. Z_t is a data matrix that includes HP-filtered real GDP, quarterly inflation calculated as quarterly growth rate of prices p_t, the 3 month money market rate and the quarterly growth of the NEER respectively: $Z_t = (y_t, \Delta p_t, R_t, \Delta q_t)'$ where Δ represents the growth rate. c_t is a vector of intercepts while $B_{i,t}(L)$ denotes a lag polynomial with L denoting the lag length. We fix $L = 2$ in the interest of parsimony.

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 CPI as a measure of p_t and Model B which uses aggregate CPI.

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,

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

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 $[v_t', \, \eta_t', \, \tau_t', \, \tilde{\nu}_t']'$ to be distributed as:

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

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 technical appendix to the paper.

The data set runs from 1971Q1 to 2014Q4. Over the period, 1980Q1 to 2014Q4 the data is obtained from Norges Bank's data base. For the earlier sample period, the data is extracted from Global Financial Database (GFD). The estimation algorithm is initialised (and priors set) by using a pre-sample of 50 observations. This pre-sample and the two lags used in estimation imply that the effective sample starts in 1983Q4 and the GFD data is only employed as a training sample.

Table 1 presents a detailed definition of the data series. Note that GDP and the two versions of CPI are seasonally adjusted.

Variable	Definition	Norges Bank Code
q	NEER. Increase implies depreciation	QUA_SI44
p	CPI	QSA_PCPI
p	Core CPI: CPI adjusted for fuel, electricity prices, indirect taxes	QSA_PCPIJAE
R	3 month money market rate (NIBOR)	QUA_RN3M
y	Norwegian real GDP	QSA_Y
O	Brent Blend crude spot oil prices in USD deflated by US CPI	QUA_POILUSD/US_CPI

Table 1: Definitions of data series

3 Empirical Results

In this section we use the posterior estimates of the TVP-VAR parameters to estimate statistics that can shed light on the possibility of a Great Moderation in Norway. We first investigate if the VAR implied trends in key variables such as inflation have declined and if measures of macroeconomic volatility have fallen. We then examine the possibility of temporal changes in measures of inflation persistence and variable cross-correlations.

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:

$$E(Y_t) = e_N (I - F_t)^{-1} \mu_t, \tag{7}$$

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 and policy 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 NEER growth 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.

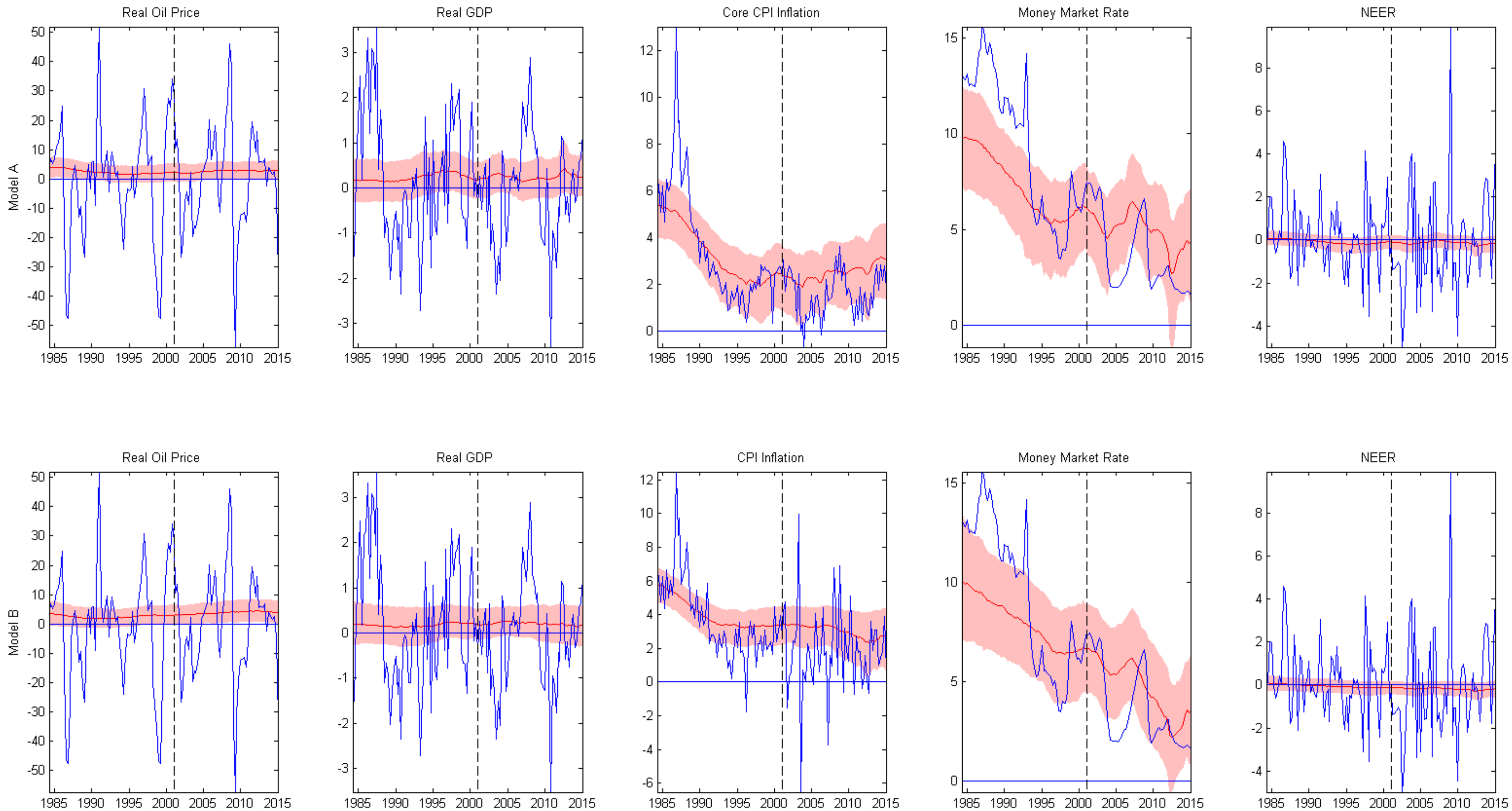

Figure 1: Time-varying unconditional means of endogenous variables and actual data. The red line is the median estimate while the shaded area represents the 68% error band. The blue lines represent the actual data.

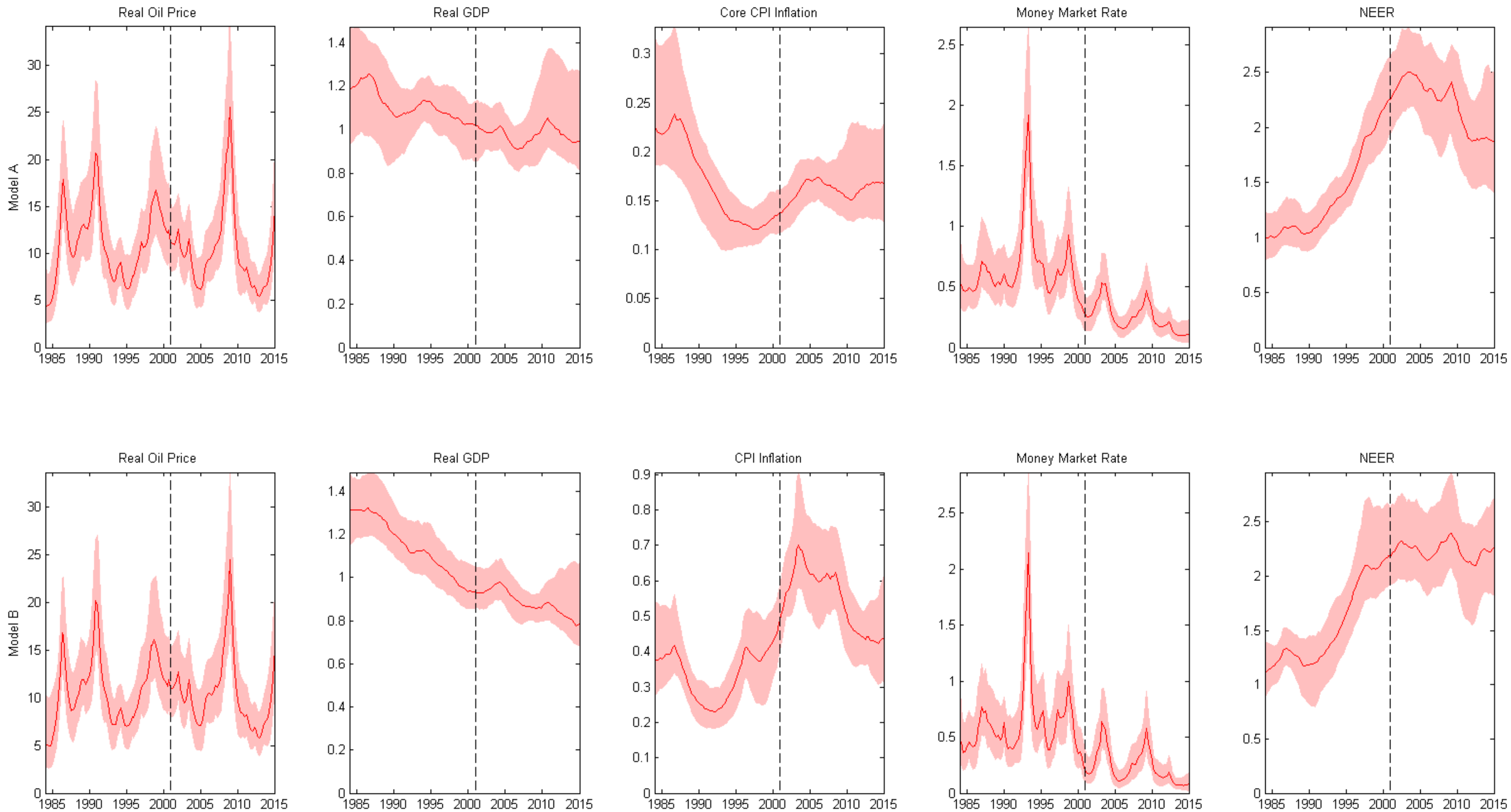

Figure 2: Stochastic Volatility. The red line is the median estimate while the shaded area represents the 68% error band.

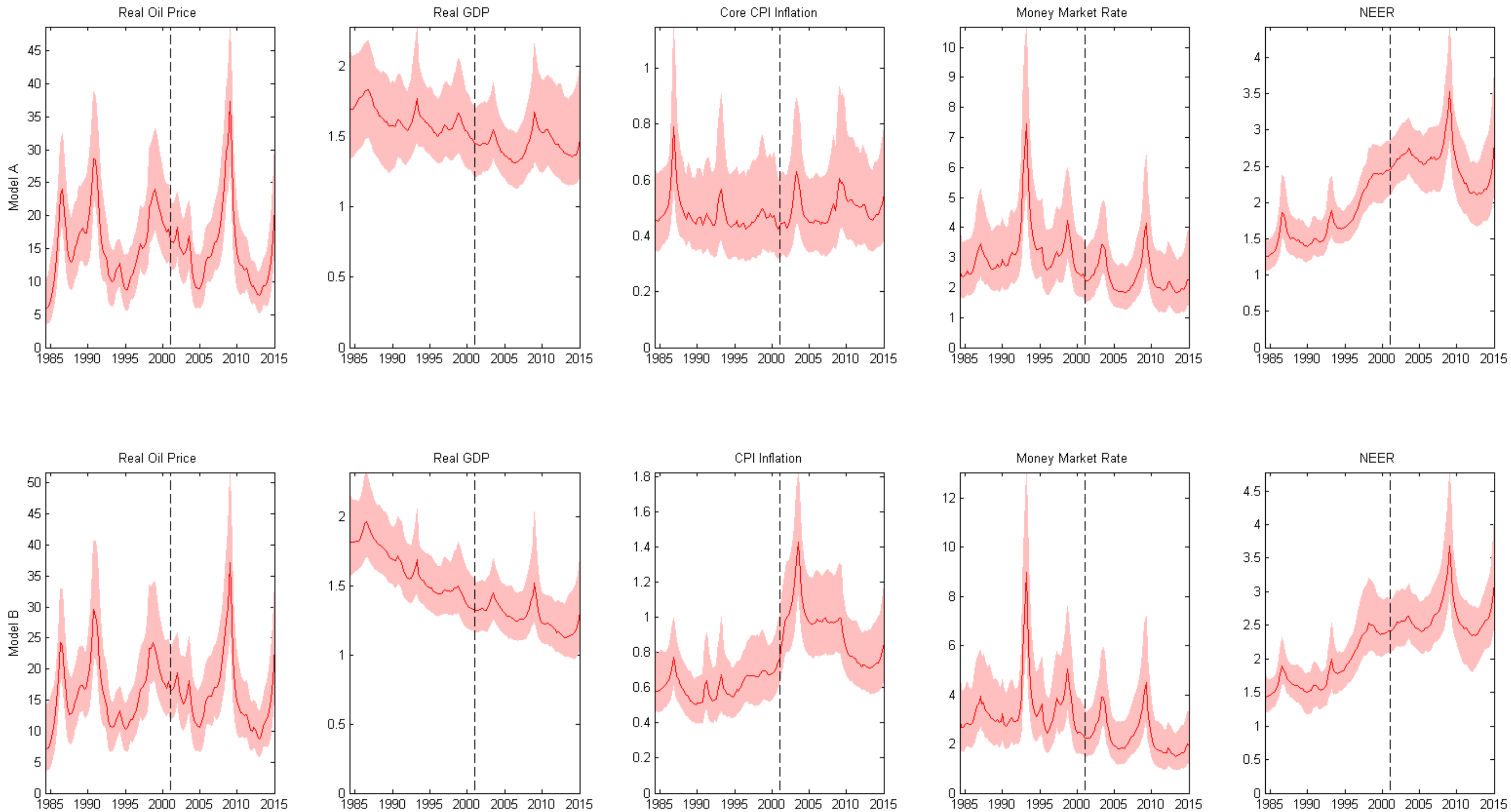

Figure 3: Time-varying unconditional standard deviation of endogenous variables and actual data. The red line is the median estimate while the shaded area represents the 68% error band.

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:

$$sd\left(Y_t\right) = \sqrt{e_N \left(I - F_t \otimes F_t\right)^{-1} vec\left(\Omega_t^*\right)} \tag{8}$$

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 NEER changes have 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 CPI 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 latter 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 more 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; see Figure 3. 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

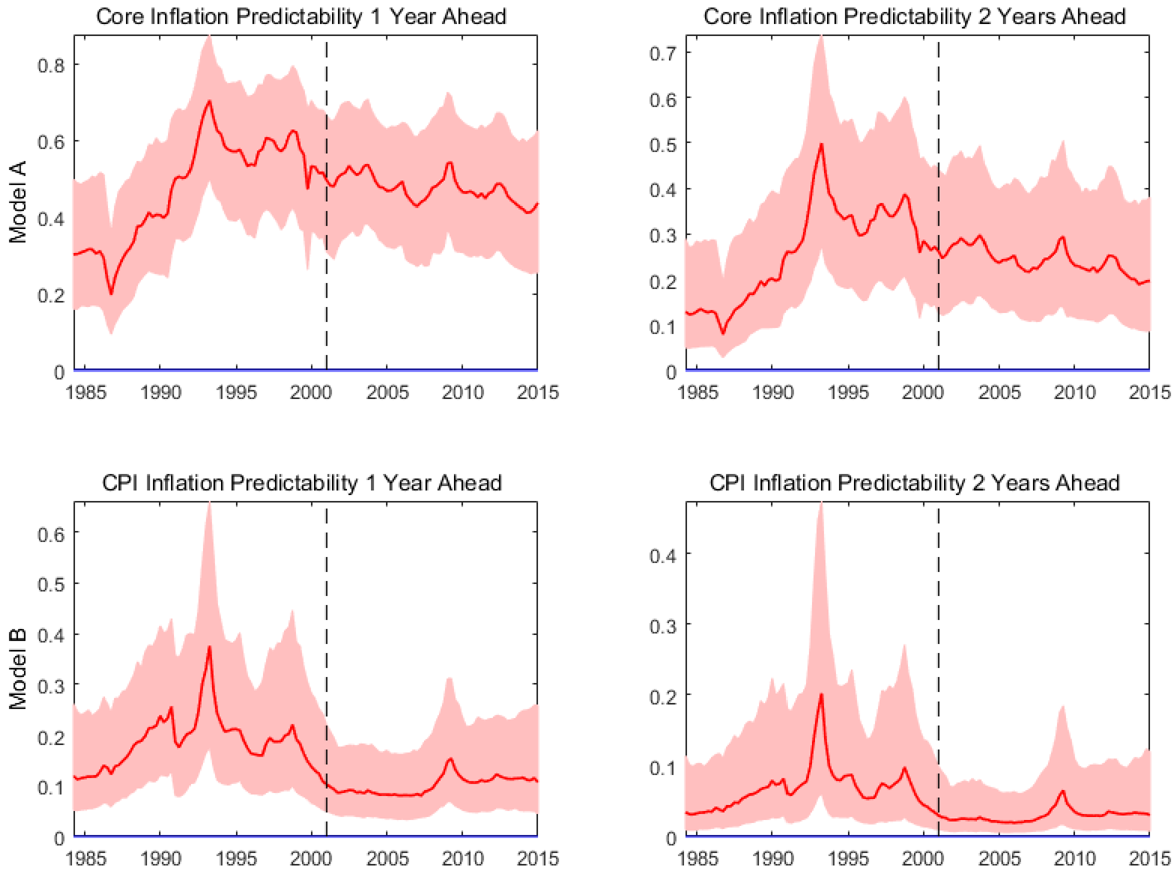

Figure 4: Inflation predictability one year ahead and two years ahead. The solid red line is the median estimate while the red band is the 68% error band.

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 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 increase in 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:

$$R_J^2 = 1 - \frac{e_\pi \sum_{j=1}^{J} F^j V_{t+j} F^{j\prime}}{e_\pi \sum_{j=1}^{\infty} F^j V_{t+j} F^{j\prime}} \tag{9}$$

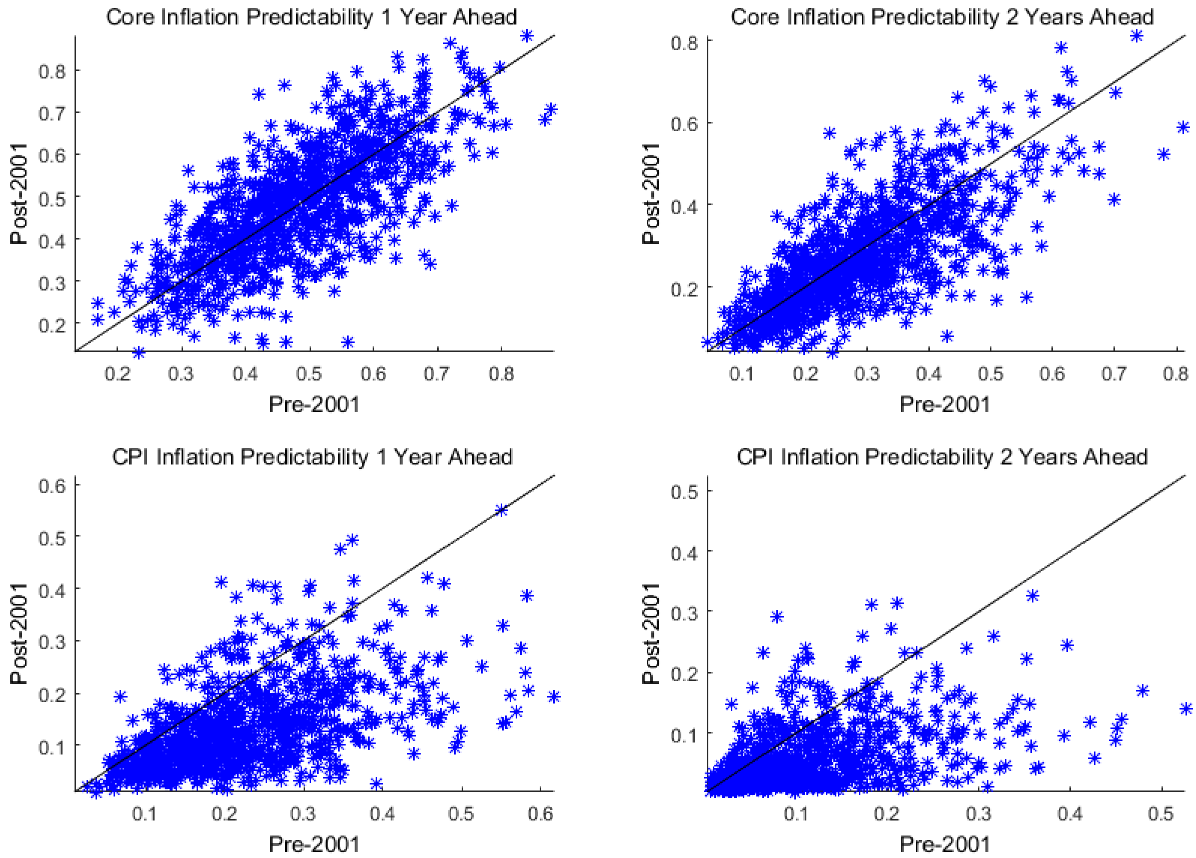

Figure 5: Inflation predictability one year ahead and two years ahead. Joint distribution pre and post-2001.

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. Therefore, 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 panel) and CPI inflation (bottom panel).

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.

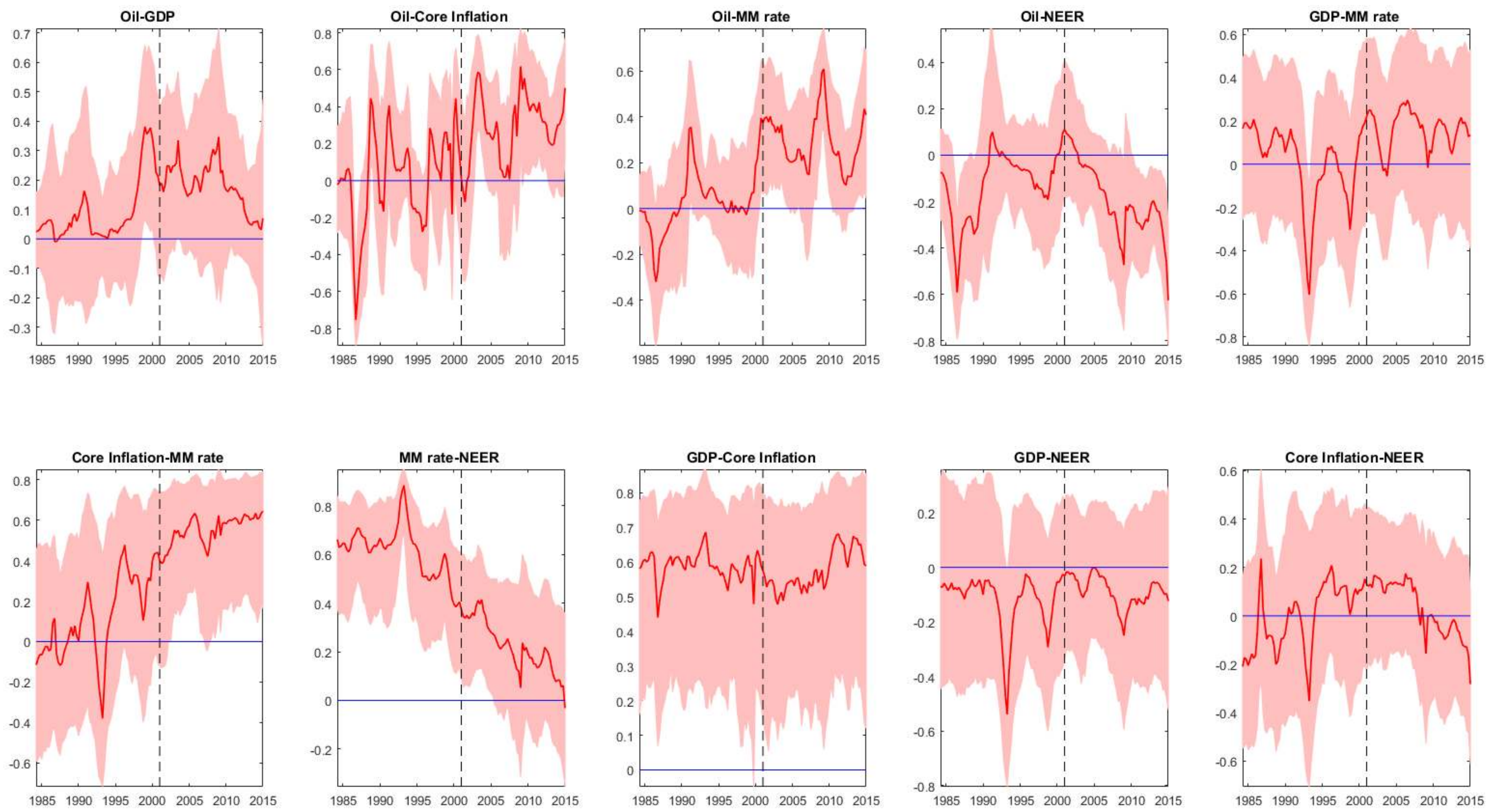

Figure 6: Dynamic Correlations at frequency zero using model A. The solid line is the median estimate while the shaded area represents the 68% error band.

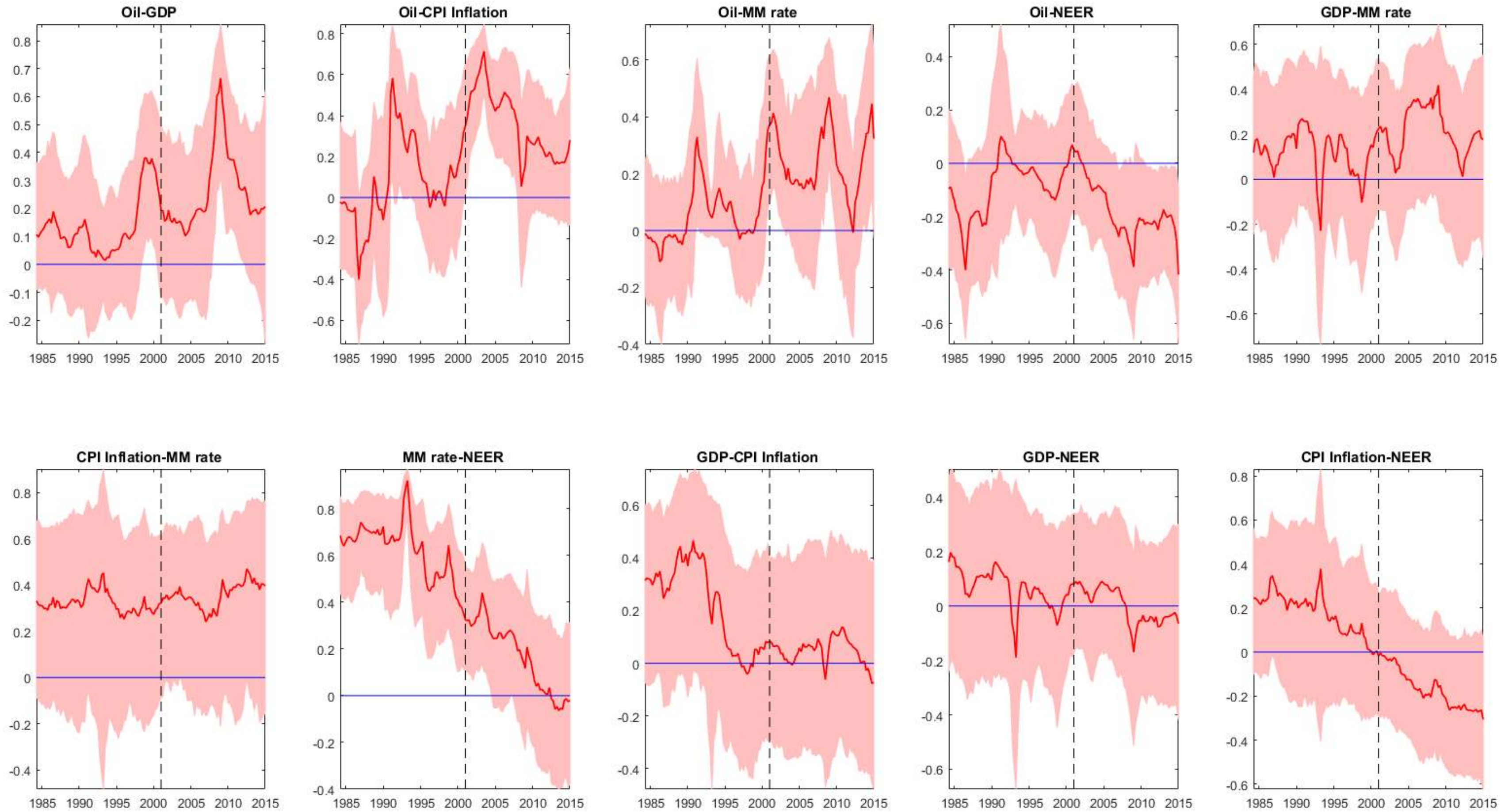

Figure 7: Dynamic Correlations at frequency zero using model B. The solid line is the median estimate while the shaded area represents the 68% error band.

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:

$$\hat{f}_t(\omega) = (I - F_t e^{-i\omega})^{-1} \frac{\Omega_t^*}{2\pi} \left[(I - F_t e^{-i\omega})^{-1}\right]', \tag{10}$$

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:

$$\frac{\hat{c}_{ij}(\omega)}{\sqrt{\hat{f}_t^{ii}(\omega)\hat{f}_t^{jj}(\omega)}}, \tag{11}$$

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.

Figures 6 and 7 plot estimated dynamic correlations 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 have increased over time. It can be seen from the first panel in the figures 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 have been positive throughout the estimation period. The posterior medians of the correlation between inflation and oil prices also increase in the late 1990s and have 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 onwards relative to earlier periods. 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 NEER changes, Figure 6 and 7 suggest 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 NEER 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 7 .

Third, the correlation between NEER 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 rates increases go together with exchange rate depreciations. After abandoning fixed exchange rate targeting in December 1992, Norway formally pursued exchange rate stabilisation until the introduction of the inflation targeting regime.

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, NEER 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 NEER changes 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.

Sixth, Figure 7 shows that the correlation between the GDP gap and CPI inflation has fallen towards zero from the mid-1990s. However, the estimated error bands are large suggesting that this correlation is poorly estimated. 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 NEER changes has declined since the mid-1990s. The remaining correlations involving the NEER 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.

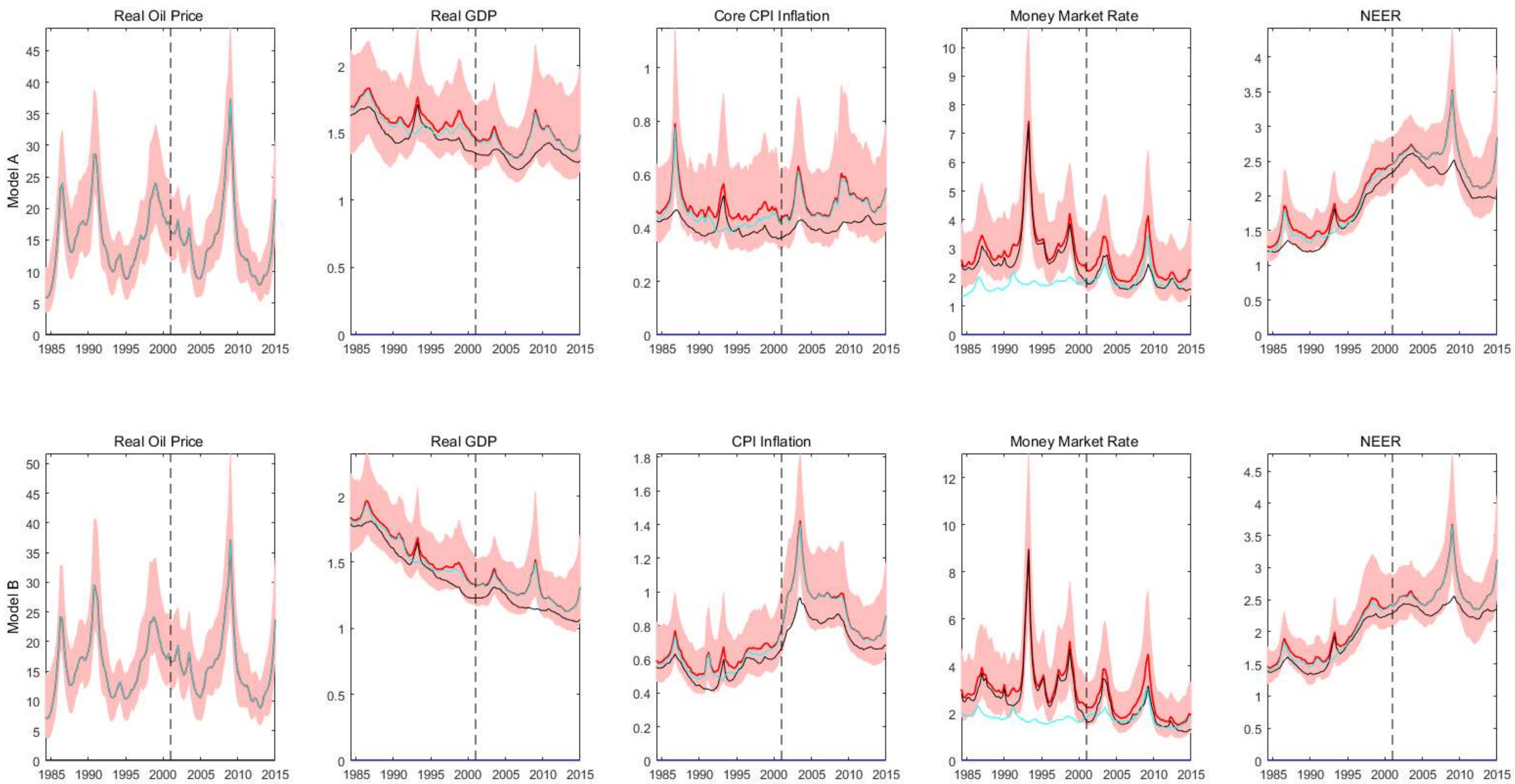

Figure 8: Actual and counterfactual estimates of unconditional volatility. The black line assumes that the variance of oil shocks is zero. The blue line assumes that the variance of monetary policy shocks is zero.

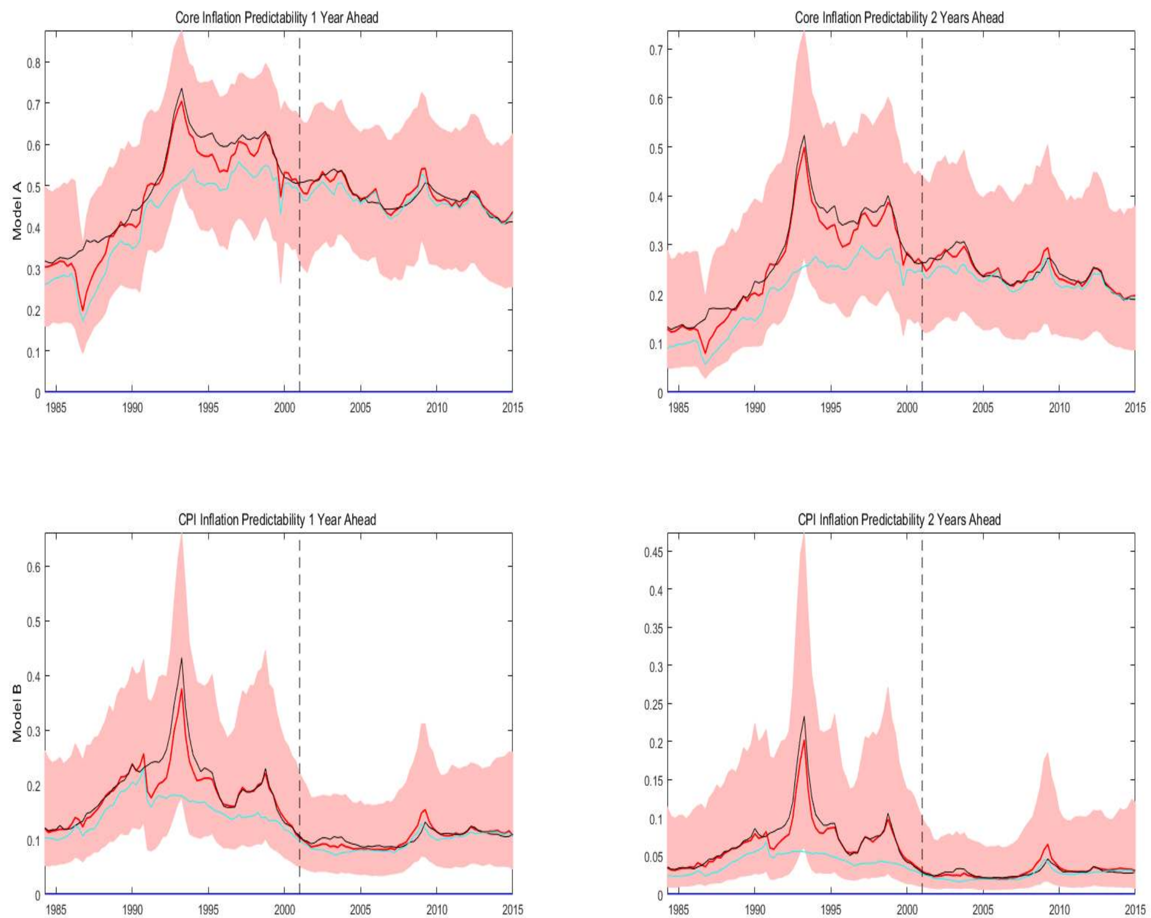

Figure 9: Actual and counterfactual estimates of predictability. The black line assumes that the variance of oil shocks is zero. The blue line assumes that the variance of monetary policy shocks is zero.

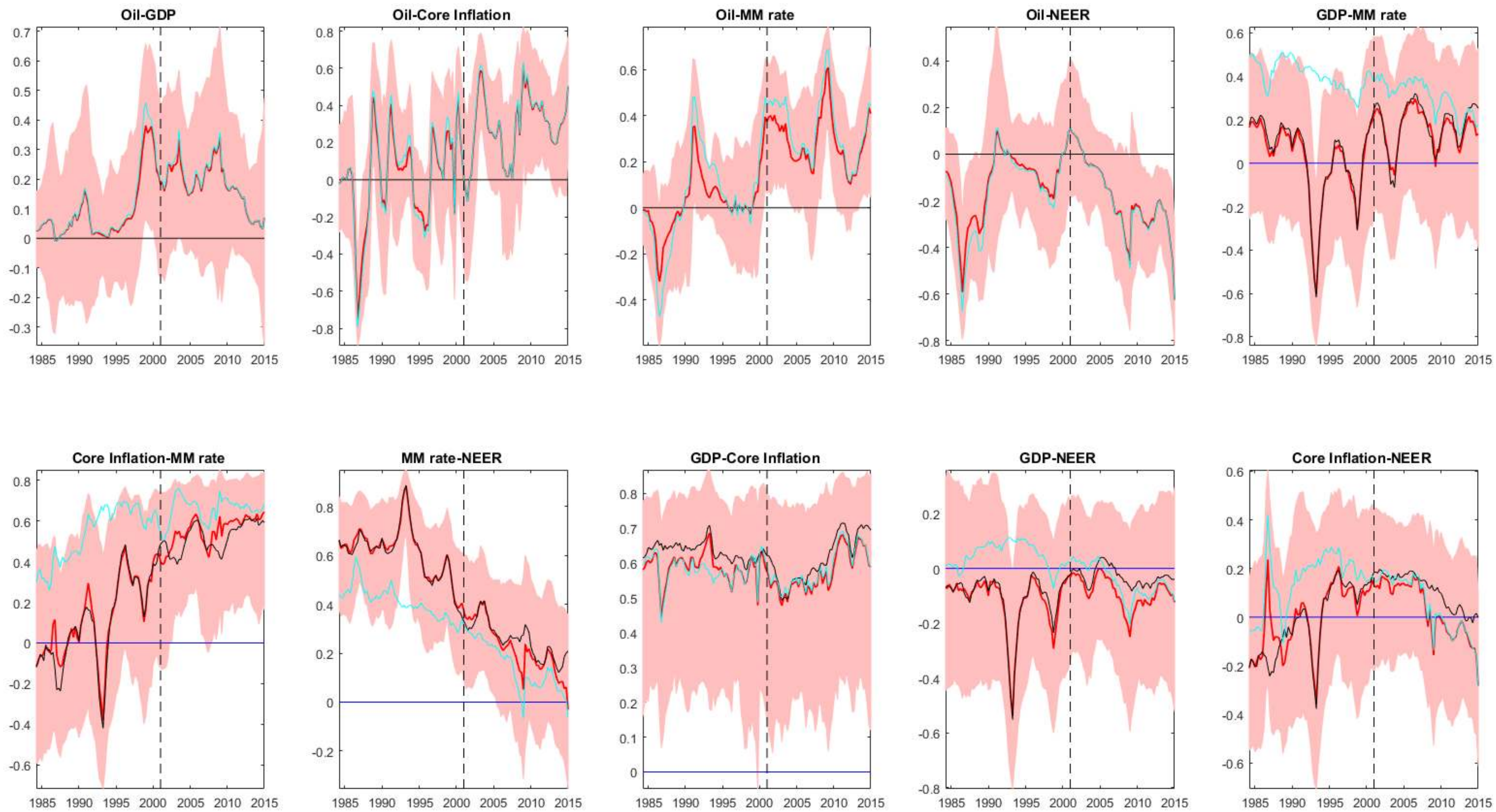

Figure 10: Actual and counterfactual estimates of dynamic correlation at frequency zero using model A. The black line assumes that the variance of oil shocks is zero. The blue line assumes that the variance of monetary policy shocks is zero.

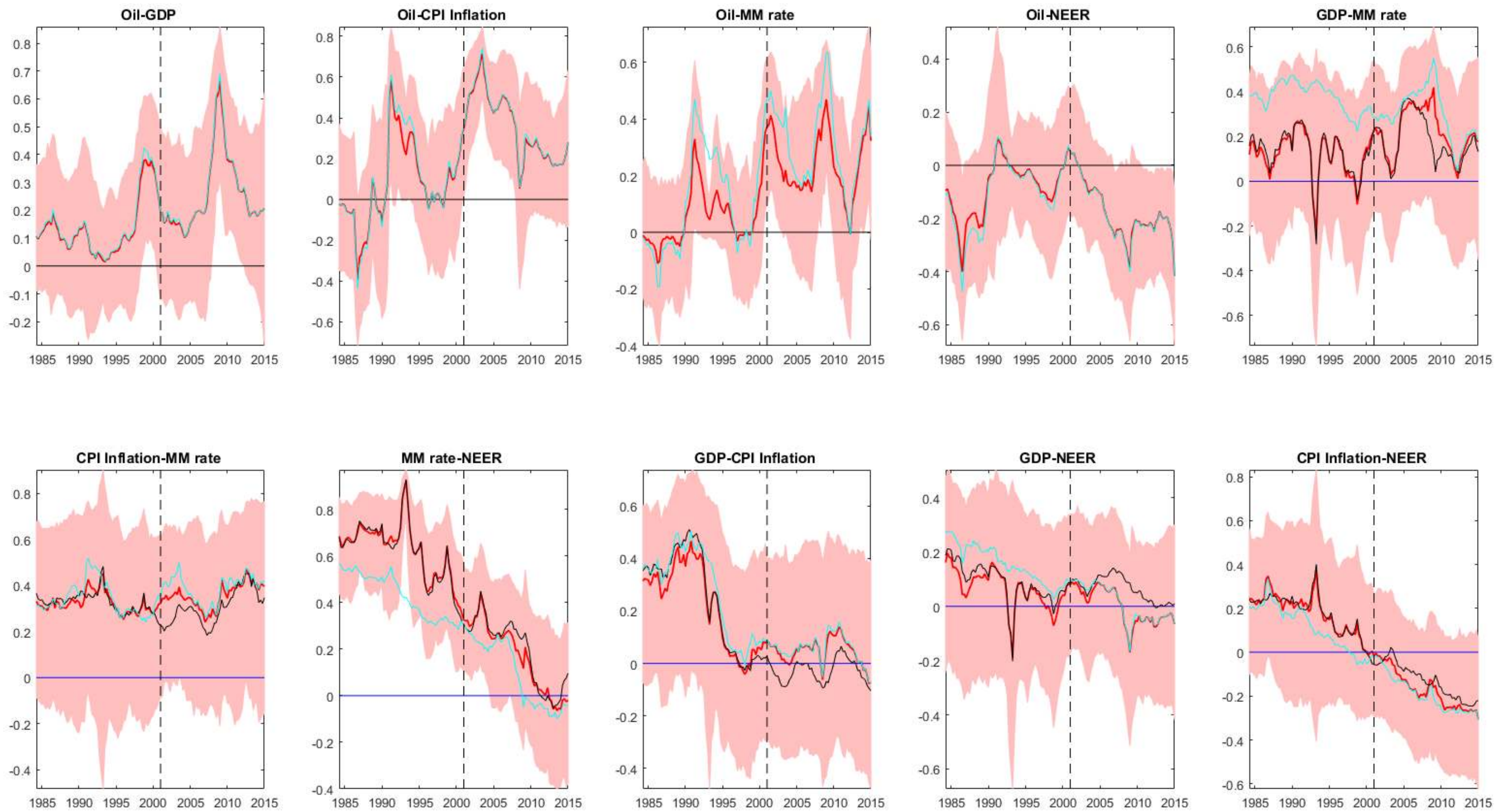

Figure 11: Actual and counterfactual estimates of dynamic correlation at frequency zero using model B. The black line assumes that the variance of oil shocks is zero. The blue line assumes that the variance of monetary policy shocks is zero.

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 (equation 3) allows us to place an economic interpretation 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, which we label the monetary policy shock, has no contemporaneous impact on all variables except NEER changes. In other words, following Eichenbaum and Evans (1995), we assume that the monetary policy shock affects macroeconomic variables with a lag but has a contemporaneous impact on 'fast moving' asset prices such as the NEER. 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. It should be noted, however, that this framework does not allow us to distinguish between oil demand and oil supply shocks which may have different effects (see for example Kilian (2009), Peersman and Van Robays (2009) and Peersman and Van Robays (2012)).

In order to assess 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 analysis is in the spirit of e.g. Gali and Gambetti (2009).

Figure 8 shows that the volatility of the GDP gap, inflation and exchange rate change is relatively lower when the volatility of aggregate 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 9 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 seem 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 9 are mostly negligible.

Figures 10 and 11 show 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 figures 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 NEER changes and the money market rate is lower in the absence of these shocks pre-2001. One way to interpret these result is to note that in each case, the counterfactual scenario in the pre-2001 period implies a correlation closer to that observed 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 represent 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. These results are presented in the on-line technical appendix to the paper. 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 the technical appendix, 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 4 in the appendix. 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 and 7.

Figure 5 in the appendix 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 7. 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 (in the main text). 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.

Figure 6 in the appendix presents results from a version of the benchmark model where changes in the NEER are 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 changes is very alike to that estimated for the NEER changes 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 NEER changes is important for this result. The remaining results for volatility and persistence are very similar to the benchmark case.

Finally, Figure 7 in the technical appendix shows results from a version of the model where HP-filtered GDP and oil prices are replaced by their growth rates. The temporal pattern of volatilities and measures of persistence are very close to the benchmark case. The estimate correlations are broadly similar to the benchmark case. However, as in the case of the previous robustness check, there is little evidence for a decline in the correlation between GDP and CPI inflation.

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 past 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 past 30 years, the long-run mean of the GDP gap has remained stable while inflation rates have declined and since the mid-1990s stabilised 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 NEER changes. Hence, it is it 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, NEER changes) 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 NEER changes and nominal interest rates are consistent with the prevailing monetary policy regimes in different time periods. Specifically, NEER 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 NEER 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.

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