

STAFF MEMO

Oil price shocks and the Norwegian effective exchange rate – an SVAR approach

NO. 16 | 2016

SASKIA TER ELLEN,
KJETIL MARTINSEN



NORGES BANK

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ISSN 1504-2596 (online)

ISBN 978-82-7553-932-6 (online)

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Saskia ter Ellen, researcher, Norges Bank Research and Kjetil Martinsen, advisor, Market Operations and Analysis¹

Abstract

We employ a structural VAR model to investigate direct and indirect effects of oil price changes on the Norwegian effective exchange rate (I44). The model is estimated on different subsamples and with different model specifications. Our main finding is that the direct effect of oil price shocks on the I44 has increased over time, independent of the model specification we choose. Furthermore, an increasing impact of oil shocks on interest rates and an increased impact of interest rates on the I44 account for the rise in the indirect impact of oil on the I44 over time. We further find that long (short) term interest differentials become relatively more (less) important for explaining movements in the I44 during recent samples. A possible interpretation could be the (zero) lower bound and unconventional monetary policy conducted by Norway's trading partners.

1. Introduction

The economic literature on the relation between oil price shocks and macroeconomic and financial variables is extensive, see for example Killian (2008), or Hamilton (2009) for an overview. However, much of this literature has focused on large oil importing economies, such as the United States. Baumeister et al. (2009) show that there are pronounced differences of the impact of oil shock on various countries. Being a small open oil producing economy, the Norwegian economy might be affected by oil price shocks in a different way (see, for example, Bjørnland, 2009). Norway's small open economy characteristic makes it vulnerable to foreign shocks (Bergholt 2015, Aastveit et al. 2016), whereas its status as an oil producer also implies that oil price changes have an impact on the Norwegian economy through for example Dutch disease effects (Bjørnland and Thorsrud, 2015).

Although a large part of the current literature on Norway focuses on the effect of oil price shocks on real macroeconomic variables, it is just as relevant to investigate how the Norwegian nominal² effective exchange rate (I44) is affected by changes in the oil price. After all, an important question for a central bank in an oil producing economy, where fluctuations in the exchange rate affect inflation and export developments, is how its exchange rate is affected by shocks to the oil price. The answer to this is not straightforward, as an oil price shock can affect the I44 through different channels, such as through changes in interest rate differentials. Because oil importing trading partners will typically be affected by oil price shocks in a different way than Norway, oil price shocks may also have an indirect effect on the Norwegian exchange rate through foreign interest rates.

¹ The views expressed are those of the authors and do not necessarily reflect those of Norges Bank. We would like to thank Farooq Akram, Tom Bernhardsen, Alexander Flatner, Arne Kloster, Leif Anders Thorsrud, Hong Xu and seminar participants at Norges Bank for valuable input and comments.

² As we will work with weekly data and financial variables, we focus on the nominal rather than the real exchange rate.

In this memo we examine the effects of oil price shocks on the I44, and whether these have changed over time. Among the models Norges Bank uses for analyzing the I44 is a so-called single equation BEER-model (Behavioral Equilibrium Exchange Rate model), in which the Norwegian krone (I44) is affected by the interest rate differential against its main trading partners, the oil price, and Norwegian specific FX market volatility³. Although such a model is useful for evaluating the main drivers of the I44, it does not explicitly capture the effects that explanatory variables have on each other and the impact of these relations on the I44, nor does it capture possible reverse effects (e.g. the feedback effect from exchange rates on interest rates). What we are after is how an oil price shock propagates through the system of specified variables and finally affects the I44. A useful tool for this is a structural Vector Autoregressive (VAR) model.

We start our analysis by specifying a (reduced-form) VAR model for the Norwegian economy, with a focus on variables that are relevant for the Norwegian nominal exchange rate. Based on the existing models in use and the desired frequency (weekly), these are the I44 itself, Norwegian 12 month swap interest rates, Norwegian trading partners' 12 month swap interest rates, and the Brent Blend oil price. Although the reduced form VAR is useful to get an idea of the cross effects of different variables, it does not tell us anything about the structure of the economy. Hence, we cannot interpret the error terms as structural shocks. In order to do this, we need to use our knowledge about the structure of the economy to obtain a structural representation of the VAR. Our results are therefore based on the estimation of several specifications of a structural VAR, identified by applying Cholesky and exogenous block restrictions.

The structure of this memo is as follows. Section 2 gives an overview over the variables we use, and sets forth our arguments for including these variables. Section 3 describes our subsamples. Section 4 explains the model setup, and our choice of Cholesky ordering. Results are discussed in Section 5, and Section 6 concludes.

2. Data

In order to answer our main research question, we will set up a (structural) VAR model with the oil price, the Norwegian nominal effective exchange rate, and channels through which the oil price might have an indirect effect on the effective exchange rate. For the latter we use Norwegian swap interest rates and a weighted foreign swap interest rate, of 12 month and 10 year. For one of the specifications we also introduce a variable that proxies the economic outlook in Norway. The variables are all collected on a weekly frequency and the sample period ranges from the first week of 1999 to the end of 2015.

The nominal effective exchange rate, I44, is a weighted index of the Norwegian krone as measured against the currencies of Norway's most important trading partners⁴. The I44 is calculated as a weighted average of the exchange rates of 44 countries (with 31 unique currencies since the introduction of the euro), of which the euro, Swedish krone, Chinese yuan, UK pound and US dollar make up about 70 percent of the basket. 15 currencies have a weight larger than 1 percent, and these currencies make up 93 percent of the basket all together. To test whether the log level of the I44 is non-stationary, we perform an Adjusted Dickey Fuller (ADF) test, of which the results can be found in Table 1. The null-hypothesis of a unit root cannot be rejected (p-value of 0.3663), and we use the first difference of the log of I44 in our analysis.

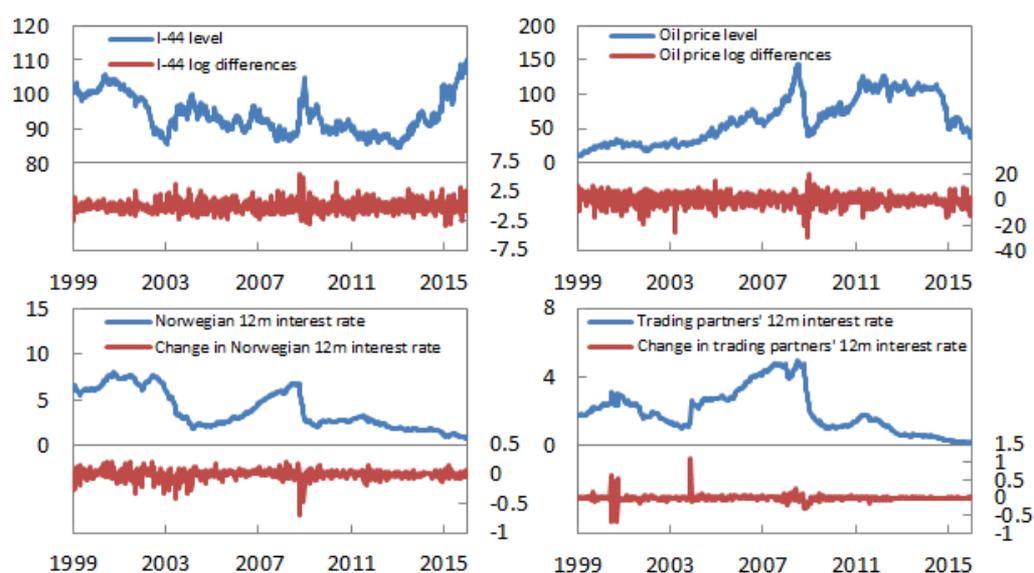
³ See for instance Flatner et al. (2010).

⁴ See http://www.norges-bank.no/en/Statistics/exchange_rates/Calculated-rates---explanation/ for more information on the I44.

For oil prices, we use weekly observations of the Brent Blend, measured as US dollars per barrel. Brent Blend is the type of oil that is extracted in the North Sea, and hence the price of this type of oil is assumed to be representative for the oil that Norway exports. Again, as the series of Brent Blend in log levels has a unit root with a p-value of 0.1353; it is made stationary by log differencing the series, see Table 1 and upper right panel of Figure 1.

Our short term interest rates are measured as the 12 month swap interest rates for Norway (lower left panel of Figure 1) and a computed average of the trading partners' 12 month swap interest rates⁵ (lower right panel of Figure 1).⁶ We use 12 month rather than 3 month swaps to capture expectations of monetary policy for the coming year. Ideally, the computed average of trading partners' swap interest rates should contain the same countries and weights as in the I44 index. In practice this has been impossible to conduct due to limited availability of swap interest rates among several trading partners. However, a weighted average of Norway's seven biggest trading partners make up the interest rate aggregate with the Euro area (including Denmark), Sweden, UK and US being the biggest countries in the swap index. These seven countries make up roughly 75% of the weights in I44.

Figure 1. Main variables of interest



Notes: Upper left: The nominal effective exchange rate (I44) measured in levels (blue line, index points) and log differences (red line, percent). Upper right: Oil price (Brent blend) measured in levels (blue line, USD per barrel) and log differences (red line, percent). Lower left: Norwegian 12 month swap interest rate in levels (blue line, percent) and differenced (red line, percentage points). Lower right: Calculated trading partners' 12 month swap interest rate in level (blue line, percent) and differenced (red line, percentage points).

Both the Norwegian and the trading partners' 12 month swap interest rates have a unit root in levels. To make the series stationary, we difference them, see Table 1. Note that we want to include the interest rates in our analysis, as opposed to interest

⁵ Documentation here: http://static.norges-bank.no/pages/103520/Norges-Bank-Memo_2_2015.pdf?v=18062015130020&ft=.pdf

⁶ An interest rate swap is an agreement between two counterparties to exchange cashflows, i.e. fixed and floating, in the same currency.

differentials (between domestic and foreign rates) as is common in the exchange rate literature. The reason for this is that we want to be able to distinguish the effect on domestic and foreign rates separately, as opposed to combined through the interest differential.

For the second part of our analysis, we introduce the 10 year swap rates for Norway and trading partners. We follow the same procedure and make the series stationary by first differencing, see Table 1 and Figure 2.

In line with some of the internal models of Norges Bank⁷, we also include a measure of Norwegian specific volatility in one of our specifications, to proxy for the foreign exchange risk premium. The idea is that Norway's risk premium in the FX market is related to increased uncertainty regarding the Norwegian economy and Norges Bank's monetary policy, especially following the drop in oil prices from the autumn of 2014. We have created an indicator that computes the difference between implied volatility in the Norwegian and the international foreign exchange market⁸. More precisely, we construct the indicator by using a recursive regression of EURNOK implied volatility on a constant and a measure of global implied volatility. The residuals from this recursive regression represent the component of the EURNOK implied volatility that is not accounted for by global implied volatility, and hence we name the residual Norwegian specific volatility (NOKVOL). In the lower panel of Figure 2, we see that NOKVOL increased a lot during both the financial crisis of 2008 and during the European debt crisis. The level of the NOKVOL has remained elevated and spiked even higher after the latest fall in oil prices. In the SVAR we difference the NOKVOL measure in order to make it stationary, see Table 1.

3. Subsamples

Both the Norwegian and the global economy have changed dramatically since the end of the 1990s. The world has seen a dot-com bubble burst, the outbreak of the global financial crisis and the European debt crisis. Whereas several central banks adopted an inflation targeting regime in the late 1990s to early 2000s to fight high inflation, some central banks have implemented unconventional monetary policy tools in the recent years to combat low inflation.

One of our key research questions is whether direct and indirect effects of oil price shocks on the Norwegian nominal effective exchange rate (I44) have been stable over time. Hence, we divide our sample period into different sub periods, and compare the results from each period. Since our dataset is on a weekly frequency and a large VAR-model has a large number of parameters to estimate, we have to make sure that our sub periods are sufficiently long enough to produce reliable estimates for our model parameters.

⁷ See for instance Flatner et al. (2010).

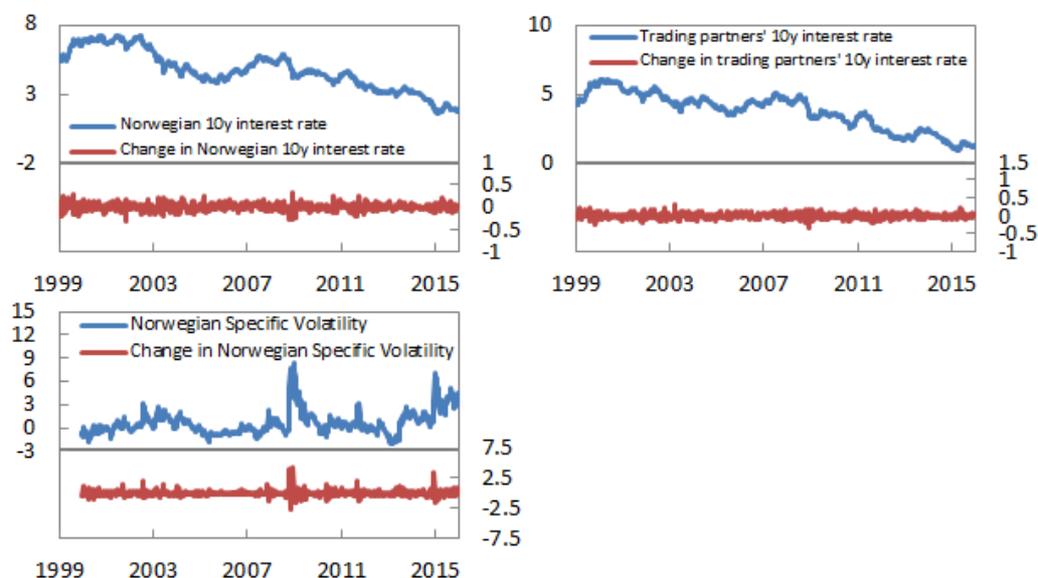
⁸ To be precise, global implied volatility is an equally weighted measure of EURUSD, USDJPY, and EURJPY implied volatilities.

Table 1. ADF non-stationarity test

Variable	ADF non-stationarity test			
	Log levels	Log differences	Levels	Differences
Nominal effective exchange rate	0.3663	0.0000	-	-
Oil price	0.1353	0.0000	-	-
Norwegian 12 month swap interest rates	-	-	0.7441	0.0000
Trading partners' 12 month swap interest rates	-	-	0.7117	0.0000
Norwegian 10 year swap interest rates	-	-	0.953	0.0000
Trading partners' 10 year swap interest rates	-	-	0.8246	0.0000
Norwegian specific volatility	-	-	0.0005	0.0000

Notes: Results from an Augmented Dickey-Fuller unit root test on the model variables with lag selection based on the Bayesian Information Criteria. Reported ADF values are p-values under the null hypothesis that the variables have a unit root in levels, differences, log levels and log differences. Reported results are based on weekly observations from 1. January 1999 to 31. December 2015. For the measure of Norwegian specific volatility (NOKVOL), the sample range is from 1. January 2000 to 31. December 2015.

Figure 2. Extended model variables



Notes: Upper left: Norwegian 10 year swap interest rate in levels (blue line, percent) and differenced (red line, percentage points). Upper right: Calculated trading partners' 10 year swap interest rate in level (blue line, percent) and differenced (red line, percentage points). Lower left: Measure of Norwegian specific volatility ("NOKVOL") in levels (blue line, index points) and differences (red line, index points).

Against this background, we have decided to split our full sample into four subsamples, see Figure 3. The first subsample is from 1. January 1999 – 31. December 2002, a period in which Norges Bank and several other central banks adopted their inflation targeting regime. Norges Bank adopted its inflation targeting regime in March 2001. Since the beginning of the 1970s Norway has experienced different monetary policy regimes. In the 1980s and 1990s the interest rate was mostly used to stabilize the exchange rate. In a regime with inflation targeting higher inflationary pressure and capacity utilization are typically met by higher interest rate and an appreciation of the krone. Thus, the first subsample period is aimed to capture the effects of oil price changes on the I44 in the period around adoption of the inflation targeting regime. The second subsample period stretches from 1. January 2003 – 31. December 2006 and comprises a period of recovery in the US economy following the dot-com bubble and steadily increasing oil prices from around 25 USD per barrel to roughly 75 USD per barrel in the middle of 2006. The third subsample covers the years up to and after the global financial crisis, when financial markets were highly volatile, and western central banks responded to a large extent by cutting rates after the outbreak of the crisis. Lastly, the fourth subsample period over the latest four years, 1. January 2011 – 31. December 2015, comprises the European debt crisis and also a period in which central banks of some of Norway's most important trading partners have adopted unconventional monetary policy measures such as quantitative easing and negative interest rates.

The fourth subsample is of extra interest to us for at least two reasons. Following expansionary monetary policy among some of Norway's trading partners, the yield curves in these countries and also in Norway have flattened. When these central banks approached their lower bound in interest rate setting, unprecedented monetary policy was launched aiming at lowering longer term interest rates, and hence the correlation between long term rates and exchange rates may have increased over the past years⁹. Moreover, the latest fall in oil prices is especially interesting in a Norwegian perspective as it has fast-paced the discussion on restructuring the Norwegian economy from oil investments to more traditional export driven GDP growth. Hence, we perform an extra analysis for the fourth subsample, where we split this period into two overlapping 3 year periods, see Figure 4. The first period, 1. January 2011 – 31. December 2013, is a period with relative stable and high oil prices. The second period, 1. January 2013 – 31. December 2015, is a period characterized by falling oil prices to the lowest level since 2005.

⁹ Chinn and Meredith (2004) show that long term interest matter for exchange rates, and that the UIP coefficients are generally much closer to the theoretically implied coefficients than for short term rates.

Figure 3. Division of subsamples from 1999 to 2015 (shaded areas) and oil price in USD per barrel

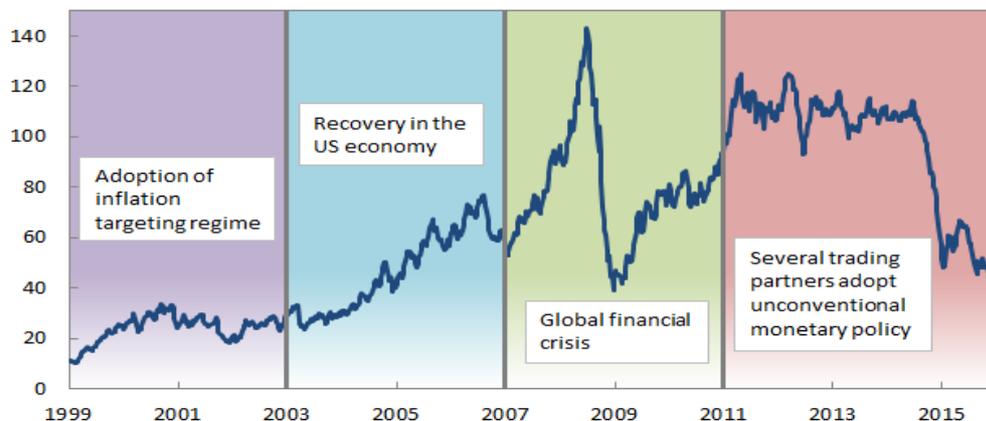
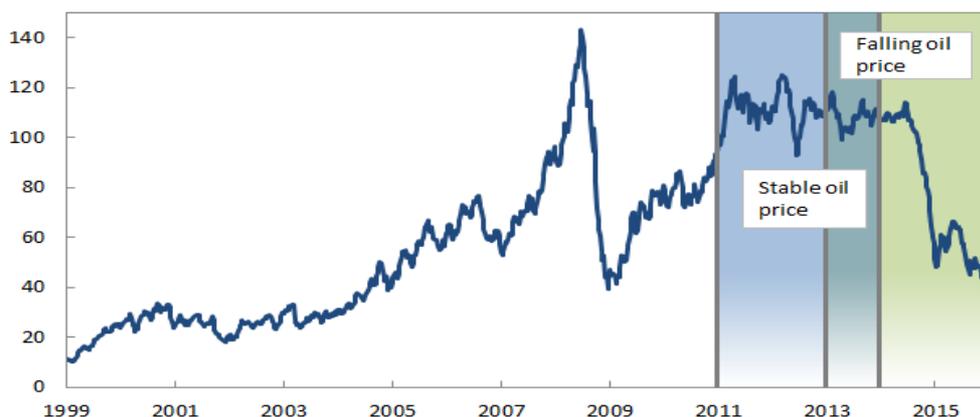


Figure 4. Additional subsamples from 2011 – 2015 (shaded areas) and oil price in USD per barrel



4. Econometric framework

4.1 The baseline model

To specify our VAR-model, we use the single equation BEER-model as base for the choice of variables as explained in Section 2. In the BEER-model, the exchange rate is estimated by using the interest rate differential¹⁰ and the oil price as explanatory variables. These two explanatory variables have had coefficients with expected signs in BEER-model estimations with a sample range dating back to early 2000s. The oil price may affect the I44 by means of terms of trade developments in the Norwegian economy, given that oil is Norway's main export product, accounting for more than half of the country's total export. Moreover, it may affect monetary policy in Norway and its trading partners. In our system, oil price shocks can therefore have a 'direct'

¹⁰ The interest rate differential is computed as the weighted 12 month swap interest rates among Norway's seven main trading partners (see Norges Bank memo) subtracted from Norwegian 12 month swap interest rates.

effect on the I44, but also an ‘indirect’ effect through the interest rate channel. As noted above, we are interested in distinguishing the effect of an oil price shock on domestic and foreign interest rates separately. Hence, our baseline reduced form VAR-model comprises four variables, see Equation (1).

$$\begin{pmatrix} \Delta p_t \\ \Delta i_t^{12Mtp} \\ \dots \\ \Delta i_t^{12Mn} \\ \Delta s_t \end{pmatrix} = \underbrace{\begin{pmatrix} c^p \\ c^{i12Mtp} \\ \dots \\ c^{i12Mn} \\ c^s \end{pmatrix}}_C + \underbrace{\begin{pmatrix} b_{11} & b_{12} & b_{13} & b_{14} \\ b_{21} & b_{22} & b_{23} & b_{24} \\ \dots & \dots & \dots & \dots \\ b_{31} & b_{32} & b_{33} & b_{34} \\ b_{41} & b_{42} & b_{43} & b_{44} \end{pmatrix}}_B \begin{pmatrix} \Delta p_{t-1} \\ \Delta i_{t-1}^{12Mtp} \\ \dots \\ \Delta i_{t-1}^{12Mn} \\ \Delta s_{t-1} \end{pmatrix} + \underbrace{\begin{pmatrix} u_t^p \\ u_t^{i12Mtp} \\ \dots \\ u_t^{i12Mn} \\ u_t^s \end{pmatrix}}_U \quad (1)$$

In the equation, p is the log oil price, i^{12Mtp} is the level of trading partners’ 12 month swap interest rates, i^{12Mn} is the level of Norwegian 12 month swap interest rates and s is the log I44. The Δ -sign indicates that the variables are differenced, hence Δp_t is the change in oil price in percent between time $t-1$ and t . C is a 4-by-1 vector of constants c , B is a 4-by-4 matrix of coefficients of the lag endogenous variables. Lastly, U is a 4-by-1 vector of error terms. In our estimations, we have chosen a model with two lags, i.e. a VAR(2), meaning two lags of each endogenous variables. The two lags have been chosen using a BIC test. As a matter of notation, we write $B(2)$ hereafter, with (2) indicating the two lags. The dotted lines in the equation are included to visually distinguish between foreign (above the dotted line) and domestic variables (below).

4.2 Identification

Although a reduced form VAR is helpful in describing our variables of interest, its error terms are correlated with each other and hence we cannot use it to draw any conclusions about the interaction of the variables, nor can we distinguish and interpret structural shocks to the system. To distinguish the effect of one shock under the assumptions that all other shocks are held constant, we need to apply a structure to the VAR that makes its shocks orthogonal and economically meaningful. In order to identify the structural shocks in a SVAR model, we need to have an idea about the underlying relation between the endogenous variables in our model. There are by now various ways in which to do this. The methodology chosen depends on one’s assumed structure of the economy, as well as the research topics in question.

One of the most frequently used and computational friendly ways of identifying the system is to apply recursive identification – or Cholesky identification¹¹. In this setup, the most important is ordering the variables in accordance with their level of exogeneity to the system. The variable that is ordered as the most exogenous is not contemporaneously affected by any of the other variables in the model. The variable that is ordered as the most endogenous is contemporaneously affected by all other variables in the model. However, a shock to this variable can only have a delayed effect on the other variables in the system.

Cholesky identification implies that one uses zero restrictions, i.e. one assumes that a certain variable has zero (contemporaneous) impact on another variable. Assumptions made to apply Cholesky identification may therefore be very strong, especially as compared to sign restrictions, where one only restricts the direction of the relation between different variables. Especially when working with financial variables, which adjust on a very high frequency, it may be hard to convincingly exclude a

¹¹ For an introduction to (structural) VARs, see for instance Lutkepohl (2005).

contemporaneous relation between two variables, unless the data is used on a very high frequency. Since we have financial variables in our setup on a weekly frequency, this could be a reason to choose a different type of identification.

However, as Norway is a small open economy, we can safely assume that shocks to Norwegian variables do not affect the oil price or interest rates of its largest trading partners, such as the U.S. and Europe. This allows us to create two ‘blocks’ in our model: the exogenous block, which comprises of foreign variables such as the oil price and weighted foreign interest rates, and the endogenous variables related to the Norwegian economy. Even within these blocks, the ordering of variables matter. We argue that in the exogenous block, the oil price should be ordered as *most* exogenous. After all, the foreign interest rate used in our model is a weighted average of the interest rates of Norway’s main trading partners. This implies that a small country such as Sweden has a substantial weight in this variable. We would therefore argue that it is more likely that an oil price shock contemporaneously affects interest rates of Norway’s trading partners than, for example, that a monetary policy shock in Sweden would have an impact on the oil price.¹²

Ordering the domestic variables is a bit less straightforward. One could say that information transmission in the foreign exchange market is faster than in the money market, but this only holds on a very high frequency. Since we work with weekly data, it is likely that within one period, both the exchange rate and the interest rate affect each other. However, ordering of the domestic variables is not that important, considering we are interested in identifying the effect of an oil price shock on the I44. In this setup it does not matter whether the domestic variables have a contemporaneous impact on each other.

$$\begin{pmatrix} \Delta p_t \\ \Delta i_t^{12Mtp} \\ \dots \\ \Delta i_t^{12Mn} \\ \Delta s_t \end{pmatrix} = C + B(2) \begin{pmatrix} \Delta p_{t-1} \\ \Delta i_{t-1}^{12Mtp} \\ \dots \\ \Delta i_{t-1}^{12Mn} \\ \Delta s_{t-1} \end{pmatrix} + \underbrace{\begin{pmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ \dots & \dots & \dots & \dots \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{pmatrix}}_A \underbrace{\begin{pmatrix} e_t^p \\ e_t^{i12Mtp} \\ \dots \\ e_t^{i12Mn} \\ e_t^s \end{pmatrix}}_E \quad (2)$$

Variables and symbols are as described in Equation (1). The structural errors $A \times E$ is equal to the error term vector U in Equation (1), however $A \times E$ have been restricted to achieve identification of the system. The four zeros on the upper right-hand side (marked red) in Equation (2) are restricted by identification of the assumption of block exogeneity, where domestic shocks do not affect foreign variables. Moreover, the fact that $a_{12} = 0$ is the Cholesky restriction that foreign interest rates do not affect the oil price contemporaneously¹³. Likewise, $a_{34} = 0$ imply that a shock to the I44 does not contemporaneously affect domestic interest rates, which is a reasonable assumption under an inflation targeting regime.

Note that, due to the fact that we estimate the structural VAR in differences rather than in log levels, the oil price shocks in our model are persistent: there will be a one-period change in the oil price, after which the oil price stays at its new level.

¹² The foreign interest rate also consists of US and UK interest rates, which may be contemporaneously affecting the oil price (as is shown in Arora and Tanner, 2013). As we are interested in the effect of an oil price shock on the I44 rather than on the foreign interest rate, this should not be affecting our main results though. However, to be completely sure, the analysis has also been conducted with ordering the foreign interest rates as most exogenous. Results are robust to this ordering and are available upon request.

¹³ Although this may seem a controversial assumption, our results are robust to the ordering of the foreign variables.

Extending the baseline model

After the financial crisis, some of Norway's trading partners started conducting unconventional monetary policy with the aim of lowering longer term rates. These unconventional monetary policy measures have most often been implemented when key interest rates have been at (what has been considered as) a lower bound. As an extension of our baseline model, and to encompass the effect longer term interest rates may have had on the Norwegian effective exchange rate, we thus add both the Norwegian and the trading partners' 10 year swap interest rates to our SVAR-equation (2).

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$$\begin{pmatrix} \Delta p_t \\ \Delta i_t^{10Ytp} \\ \Delta i_t^{12Mtp} \\ \dots \\ \Delta i_t^{10Yn} \\ \Delta i_t^{12Mn} \\ \Delta S_t \end{pmatrix} = C + B(2) \begin{pmatrix} \Delta p_{t-1} \\ \Delta i_{t-1}^{10Ytp} \\ \Delta i_t^{12Mtp} \\ \dots \\ \Delta i_{t-1}^{10Yn} \\ \Delta i_t^{12Mtp} \\ \Delta S_{t-1} \end{pmatrix} + \begin{pmatrix} a_{11} & 0 & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & 0 \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} \end{pmatrix} \begin{pmatrix} e_t^p \\ e_t^{i10Ytp} \\ e_t^{i12Mtp} \\ \dots \\ e_t^{i10Yn} \\ e_t^{i12Mn} \\ e_t^s \end{pmatrix} \quad (3)$$

Equation (3) displays the *medium-sized model*, where the baseline model has been extended to also include Norwegian and Norway's trading partners' 10 year swap interest rates. Following the reasoning behind the block exogeneity assumption, foreign 10 year swap interest rates are expected not to be affected by shocks to Norwegian variables. Hence, this variable is included together with the other foreign variables, while, for the same reason, the Norwegian 10 year swap interest rate is included in the domestic block. In terms of ordering the variables within the foreign block, we follow the same convention as discussed above. Hence, the foreign 10 year swap interest rate is ordered as more endogenous than the oil price. Whether to order the longer interest rates before or after the shorter interest rates remains an open question. Therefore, we have done robustness checks with the results that our model specifications are robust to whether we order 10 year or 12 month swap interest rates as more endogenous of the two. This result holds for both Norwegian and foreign interest rates.

Uncertainty concerning the Norwegian economy and the future path of Norges Bank's monetary policy increased following the distinct drop in oil prices since second half of 2014. Such uncertainty may give rise to a risk premium, and could as such affect the I44. To capture this uncertainty, we constructed a Norwegian volatility measure labelled 'NOKVOL' from FX option implied volatilities.¹⁴ In the third panel of Figure 2 one can see that there is indeed a sharp rise in 'NOKVOL' in late 2014 and it has remained elevated as compared to historical levels since.

¹⁴ For a more detailed description of this measure, refer to Section 2.

In Equation (4) below, we have extended the *medium-sized model* with the measure of *NOKVOL*, Δnv_t . The variable is included in the domestic block, as it is regarded to be - by construction - mostly related to shocks concerning the Norwegian economy. In terms of ordering of variables within the domestic block, we continue to model I44 as the most endogenous variable in our setup. However, our results are robust to this ordering.

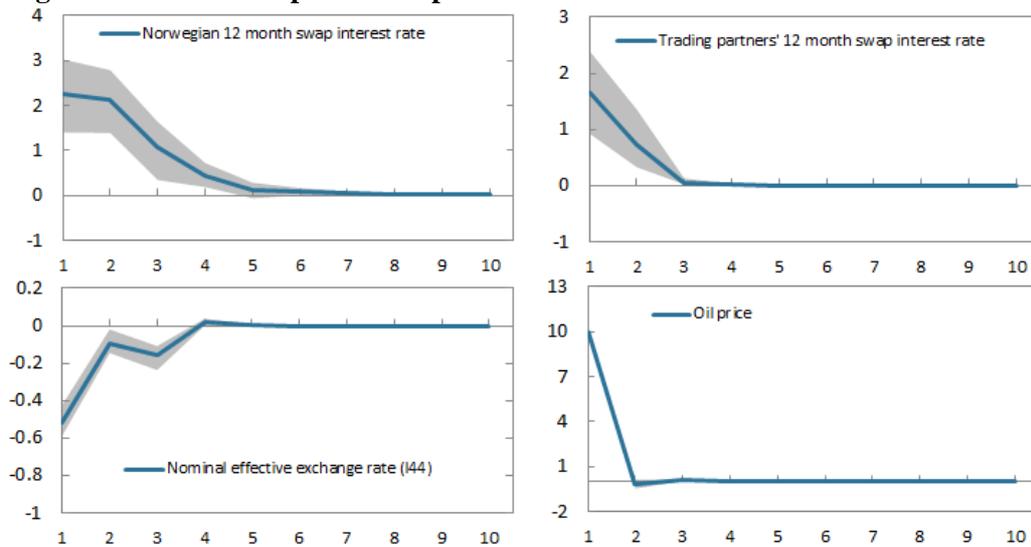
$$\begin{pmatrix} \Delta p_t \\ \Delta i_t^{10Ytp} \\ \Delta i_t^{12Mtp} \\ \dots \\ \Delta i_t^{10Yn} \\ \Delta i_t^{12Mn} \\ \Delta nv_t \\ \Delta s_t \end{pmatrix} = C + B(2) \begin{pmatrix} \Delta p_{t-1} \\ \Delta i_{t-1}^{10Ytp} \\ \Delta i_{t-1}^{12Mtp} \\ \dots \\ \Delta i_{t-1}^{10Yn} \\ \Delta i_{t-1}^{12Mtp} \\ \Delta nv_{t-1} \\ \Delta s_{t-1} \end{pmatrix} + \begin{pmatrix} a_{11} & 0 & 0 & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 & 0 & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 & 0 & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & 0 & 0 \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} & 0 \\ a_{71} & a_{72} & a_{73} & a_{74} & a_{75} & a_{76} & a_{77} \end{pmatrix} \begin{pmatrix} e_t^p \\ e_t^{i10Ytp} \\ e_t^{i12Mtp} \\ \dots \\ e_t^{i10Yn} \\ e_t^{i12Mn} \\ e_t^{nv} \\ e_t^s \end{pmatrix} \quad (4)$$

5. Results

5.1 The baseline model

Chart 5 shows the impulse responses from a positive 10 percent shock in the oil price for the baseline model of Equation (2) for the full sample. In the graph, period 1 refers to a contemporaneous effect, so an effect in the same week as the oil price shock. The grey area represents 68 percent confidence intervals. As expected, an increase in the oil price leads to an appreciation of Norwegian kroner. A one-period shock to the oil price of 10 percent leads to a 0.5 percent appreciation of I44. The impact is persistent and statistically significant based on 68 percent confidence interval bands. Moreover, both Norwegian and trading partners' 12 month swap interest rates increase. However, the point estimates suggest that Norwegian interest rates increase slightly more than those of the trading partners', and the interest rate differential thus increases. In a UIP-framework, the positive change in the interest rate differential makes I44 further appreciate in the following periods until it reaches its aggregate effect after 5 weeks' time of 0,75 percent, see Figure 6.

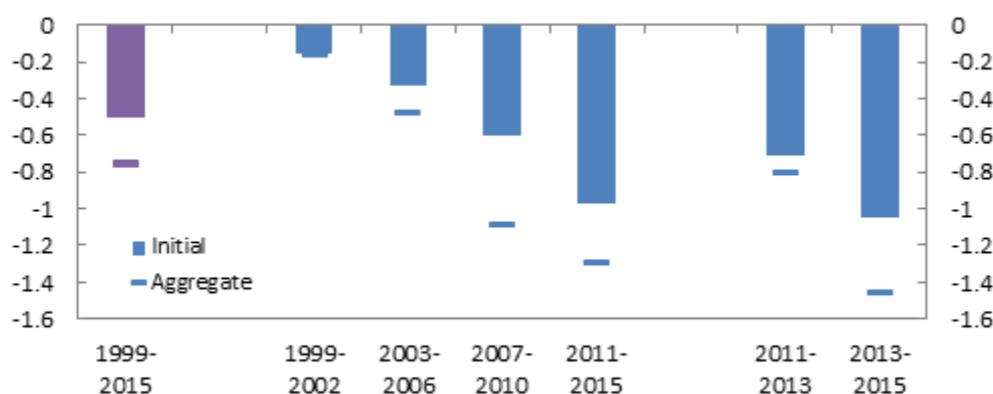
Figure 5. IRFs of a 10 percent oil price shock – small model



Notes: Impulse responses over 10 weeks from a 10 percent shock to oil prices in the baseline model. Sample period is 1999 – 2015, using weekly data. Oil prices and I44 reported in percent, interest rates in basis points. Uncertainty fans for the 68 percent confidence intervals (based on bootstrapping methods).

The impulse responses on the I44 from a shock to the oil price are consistent across subsamples, meaning that an increase in oil price leads to an appreciation of the Norwegian krone. However, the magnitude of the impact has increased monotonically over time. This can be seen in Figure 6. In the first subsample period, from 1999 to 2002, the impact on I44 from a 10 percent increase in oil prices was 0.16 percent, with an accumulated effect of about the same level after 10 weeks. For the next subsample period, from 2003 to 2006, the impact on I44 was 0.33 percent, more than twice the size of the previous subsample period. After 10 weeks, the accumulated effect on I44 from an oil price shock is 0.61 percent. Later subsamples show an impact of up to 1 percent, with the latest subsample from 2013 to 2015 showing an impact of 1.1 percent and an accumulated effect of 1.5 percent after 10 weeks¹⁵. In other words, the I44 has become more sensitive to oil price changes over the years, amid the impact effect being 7 times larger for the last subsample period compared to the first period. Also the accumulated effect after 10 weeks has been increasing over the subsamples covered in this analysis. This stems from both an increasing effect on the I44 from changes in the interest rate differential between Norwegian and trading partners' 12 month swap interest rates, and from an increasing impact of oil shocks on interest rates.

Figure 6. Impact of a 10 percent oil price shock on the I44 – subsample analysis



Notes: Impact and accumulated aggregate effects after 10 weeks on I44 in percent from an oil price shock using the baseline model. Full sample (1999-2015) and different subsamples.

5.2 The medium-sized model

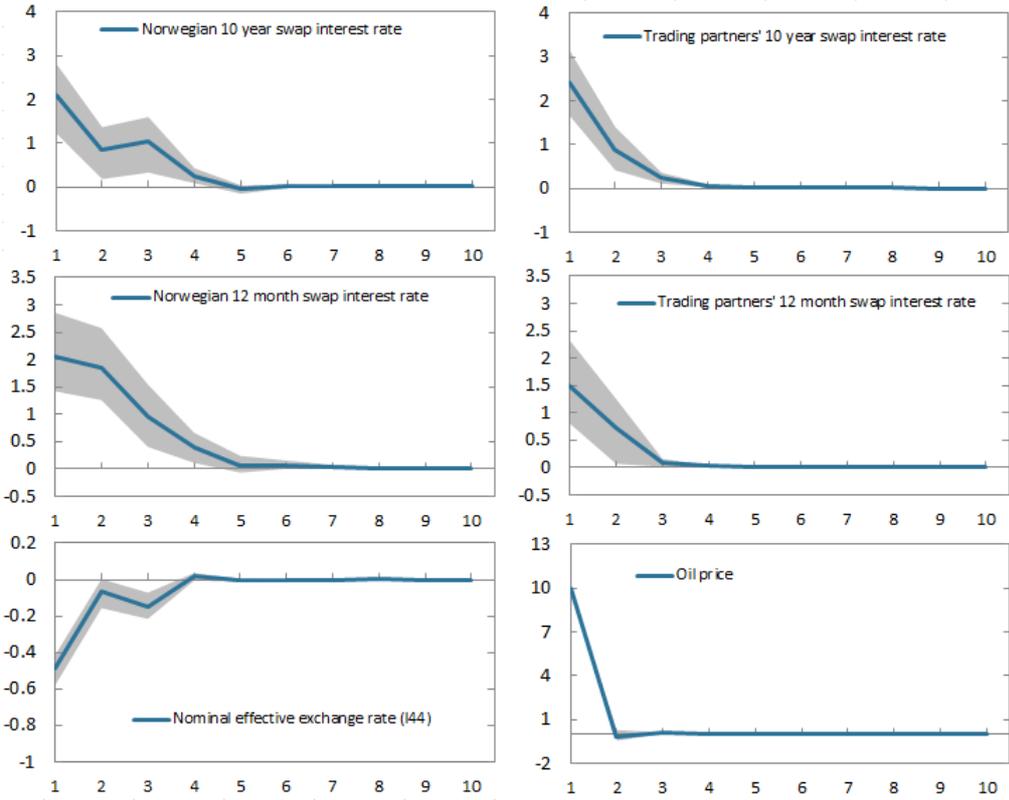
Figure 7 shows the impulse responses of a 10 percent shock to oil prices in the *medium-sized model* using the full sample length from 1999 to 2015. As can be seen, including 10 year swap interest rates yields very little difference as to how an oil price shock impacts I44 or 12 month interest rates.

Although the inclusion of 10 year swap interest rates proves to have very little effect on the impulse responses of I44 from an oil price shock compared to the *baseline model*, the inclusion gives us the opportunity to judge the relative importance of short and long interest rates effects on I44 over time. One way of examining the relative importance between longer term and shorter term swap interest rates with respect to the I44 is by calculating the forecast error variance decomposition (FEVD) with respect to I44. Figure 8 depicts the results from the FEVD and shows that the overall

¹⁵ It should be noted that all effects die out after 3-5 weeks though.

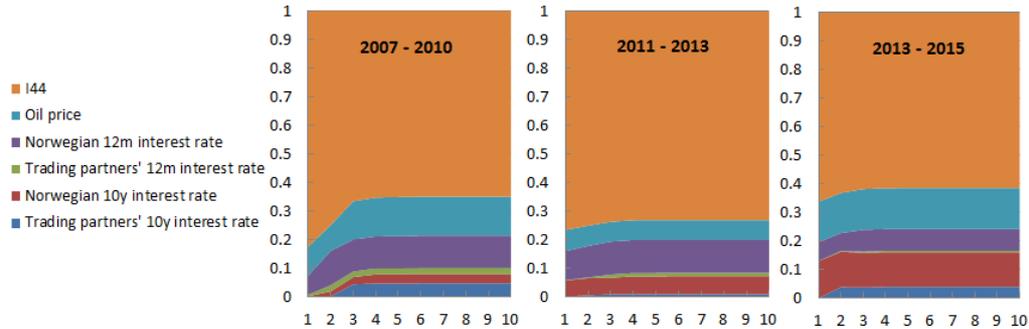
importance of Norwegian (red area) and trading partners' (blue area) 10 year swap interest rates in explaining the variance in I44 has increased over the three latest subsamples, while the overall importance of Norwegian (purple area) and trading partners' (green area) 12 month swap interest rates has decreased. Moreover, in the latest subsample Norwegian and trading partners' 10 year swap interest rates together explain more of the variance in I44 than 12 month swap interest rates. This could indicate that the foreign exchange market has become sensitive to changes to longer term interest rates following unconventional monetary policy measures in the years after the financial crisis.

Figure 7. IRFs of a 10 percent oil price shock – medium-sized model.



Notes: Impulse responses over 10 weeks from a 10 percent shock to oil prices in the medium model. Sample period is 1999 – 2015, using weekly data. Oil prices and I44 reported in percent, interest rates in basis points. Uncertainty fans for the 68 percent confidence intervals (based on bootstrapping methods).

Figure 8. Forecast error variance decomposition of I44 – medium-sized model.



Notes: Forecast error variance decomposition of I44 over the subsamples 2007-2010, 2011-2013 and 2013-2015. Coloured areas show how much shocks to each of the variables contribute to explaining variation in the model's forecast errors of the I44.

5.3 The large-sized model

Finally, we include NOKVOL in our medium-sized SVAR-model, to capture uncertainty in the Norwegian FX market, possibly stemming from large oil price movements and uncertainty about the Norwegian economy. Both the impact on I44 and the accumulated effect after ten weeks in the *large model* are in line with results from the *baseline* and *medium models*, see Figure 9. Moreover, across subsample periods, the results from the *large model* are in line with the results from the previous models, with the effect on I44 increasing over the subsample periods.¹⁶

Figure 10 shows the effects on NOKVOL following a shock to the oil price of 10 percent for various subsamples. Since NOKVOL is a volatility measure, one would expect that the effects on NOKVOL from an oil price shock are larger during periods of high uncertainty. When the oil price is low, or when volatility in the oil price is high, uncertainty about the Norwegian economy increases, which could lead to an increased risk premium in I44. We can see from Figure 10 that there are two subsample periods which stand out as periods in which the impact of oil on NOKVOL has increased. These are also periods in which uncertainties regarding the Norwegian economy and the future path of monetary policy have been higher. From end of August until the end of December 2008, I44 depreciated by almost 20 percent following the outbreak of the financial crisis. Although the uncertainty in the financial markets were not directly related to uncertainties surrounding the Norwegian economy, deterioration of the global growth outlook and lower oil prices may have led to higher risk premiums in Norwegian kroner compared to some of Norway's trading partners. More evident is the effect on NOKVOL from an oil price shock in the latest subsample period, 2013-2015, where NOKVOL decreases by close to 1 percentage point after ten weeks, about twice the size from the financial crisis period and almost six times as large as the period of stable oil prices in 2011-2013.

6. Conclusion

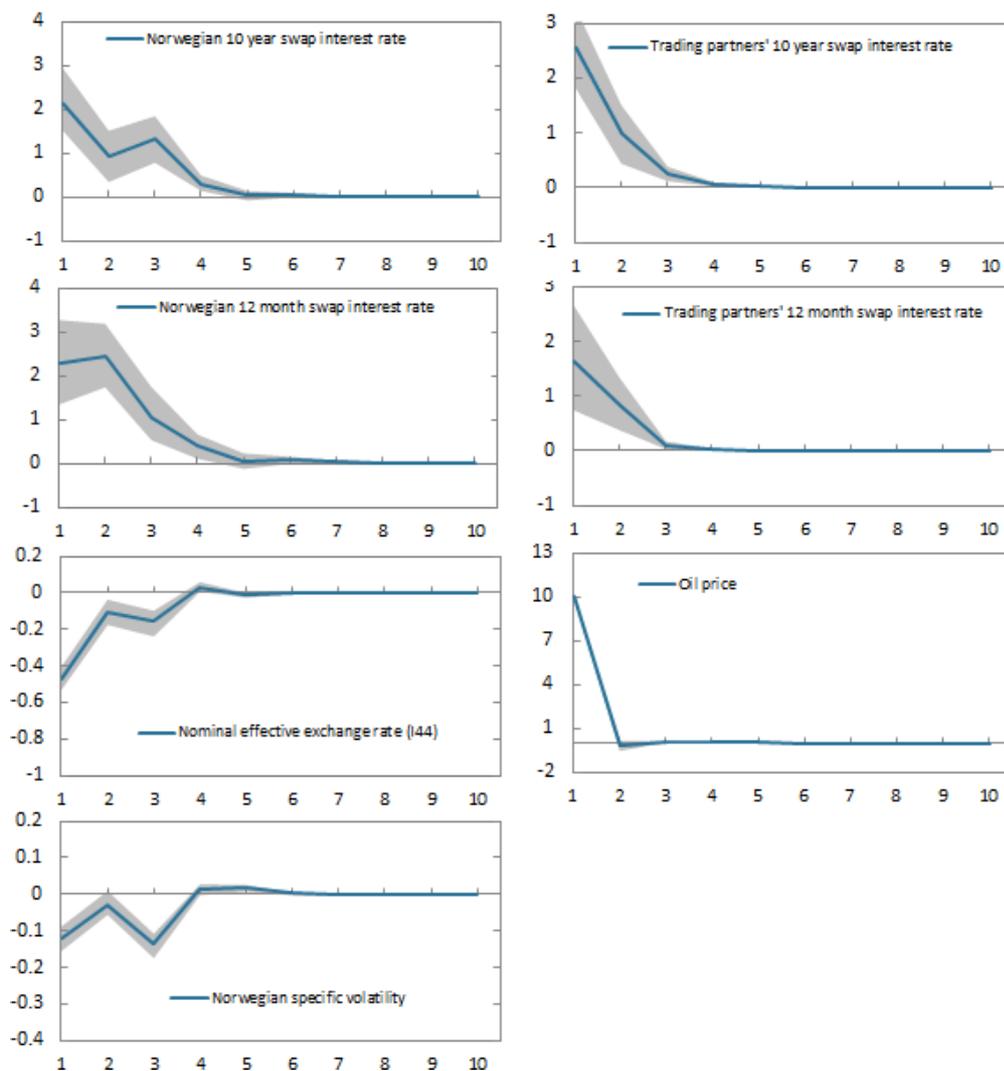
In this paper, we estimate a Structural Vector Autoregressive (SVAR) model to investigate the direct and indirect effects of oil price changes on the Norwegian nominal effective exchange rate (I44). This SVAR is estimated on different subsamples and with different model specifications. Our main finding is that both direct and indirect effects of oil price shocks on the I44 have increased over time, independent of the model specification we choose. The effect on I44 from a ten percent increase in the oil price is about 0.2 percent on impact over the first subsample period, 1999-2002. In the last subsample period, from 2013-2015, the impact effect is more than five times larger. Moreover, the accumulated effect on I44 after ten weeks is close to 1.5 percent. This effect could be due to a stronger relationship between interest rates and I44 and a larger impact of oil price shocks on interest rates in the later subsamples.

Although extending the model with 10 year swap interest rates and a measure of Norwegian volatility does not change the impulse responses on I44 from a shock to the oil price, we are able to offer a greater understanding of the increased importance of long term interest rates. In fact, we find that long term interest differentials have become relatively more important for explaining movements in the I44 during recent subsample periods. This could possibly be explained by the (zero) lower bound and

¹⁶ Since the NOKVOL measure only have available data from 2000, the first subsample period is 2000-2002, and the results are thus not directly comparable with the results of the other models.

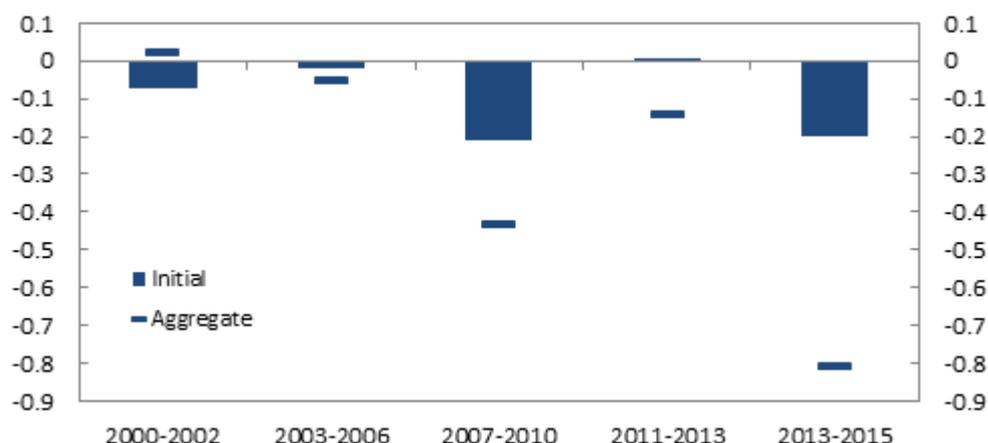
unconventional monetary policy conducted by Norway's trading partners, Lastly, we show that in times of low oil price and high uncertainty regarding the Norwegian economy and the future path of monetary policy, oil price shocks have an increased impact on the risk premium in Norwegian kroner.

Figure 9. IRFs of a 10 percent oil price shock – large model



Notes: Impulse responses over 10 weeks from a 10 percent shock to oil prices in the large model. Sample period is 2000 – 2015, using weekly data. Oil prices and I44 reported in percent, interest rates in basis points. NOKVOL is reported in percentage points. Uncertainty fans for the 68 percent confidence intervals (based on bootstrapping methods).

Figure 10. Impact of a 10 percent oil price shock on NOKVOL – subsample analysis



Notes: Effects on the measure of Norwegian specific volatility (NOKVOL) from a 10 percent shock to oil prices in the large model. Results show the initial response (bars) and accumulated effect (lines) after 10 weeks.

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